The Chillon Project: Aerial/ Terrestrial and Indoor Integration

How can one map a whole castle efficiently in full 3D? Is it possible to have a 3D model containing both the inside and outside? The Chillon project performed by Pix4D in May 2014 is a use case to show the accuracy, feasibility and efficiency of image based 3D modelling for very complex architectural objects.

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1 Introduction

Over the last years, more and more high quality imaging sensors have become available for a very affordable price. At the same time, users have access to software that can handle such sensors efficiently and automatically build 3D models from images only.
For very complex structures and when speaking about "efficient mapping", efficiency relates to the question "how many image locations are needed to model a complex structure (for instance a castle) with all its geometrically complex structures and with all inside rooms".
When considering traditional laser scanning, all points that are not occluded by another object can be reached over a full circle of 360 degrees. One laser scan can thus measure many points from only one position.
Image based 3D reconstructions needs theoretically at least two images. Based on two images, one can compute a 3D point only for the structures visible in both images. The amount of a 3D structure that can be modelled with two images also depends on the lens: a fisheye lens covering 180 degree of the scene can map a much larger area than perspective images that depict only a small area.

2 The test site

The Chillon castle (also known as Chateau de Chillon) is an island castle located on the shore of Lake Geneva, next to city of Montreux. The castle, consisting of over 21 independent buildings that were gradually connected to become the building as it stands now, is Switzerland's most visited historic monument.

The oldest parts of the castle have not been definitively dated, but the first written record of the castle is in 1160 or 1005. The rocky island on which the castle is built was both a natural protection and a strategic location to control the passage between northern and southern Europe. From the mid 12th century, the castle was home to the Counts of Savoy, and it was greatly expanded in the 13th century by Pietro II. The Castle was never taken in a siege, but did change hands through treaties.

It was made popular by Lord Byron, who wrote the poem "The Prisoner Of Chillon" in 1816 and who also carved his name on a pillar of the dungeon. The castle has inspired many artists and writers, from Jean-Jacques Rousseau, Victor Hugo and Henry James to Delacroix and Courbet.

In its current state, the Chillon Castle is the result of several centuries of constant building, adaptations, renovations and restorations.

Figure 1: Chillon Castle

Figure 2: Map of Chillon Castle with modelled inside rooms in green colour

3 The surveying equipments

3.1 GNSS data

A Trimble R 10 GNSS receiver was used in RTK-mode using a virtual reference station for measuring 11 marked points two times in different satellite constellations. The mean differences between the two measurements were 1 cm in x and y and 2 cm in z. Some of the GCPs were visible in the image data (as shown in Figure) and some of them used to define the tachymetric network as described below.

3.2 Tachymeter data

For surveying the control points measurable in the terrestrial and aerial pictures, a tachymetric network was measured with a Trimble 5601 total station from the land side.

Figure 3: Marked control point and laser scan target from oblique aerial view

Being a cultural heritage site, no surveying marks were allowed to be placed on facades. We used distinctive natural points of the buildings for control points instead.

Figure 4: Natural control points

Most of the points were measured from different viewpoints in both instrument faces; some as a spatial intersection without distance measurement (e.g. most of the spheroids on the top of the roofs) and some with reflector-less distance measurement. The least square adjustment took into account the errors of the GNSS-points, also refining them, and led internal to mean standard deviations of 8, 7 and 6 mm in x, y and z.

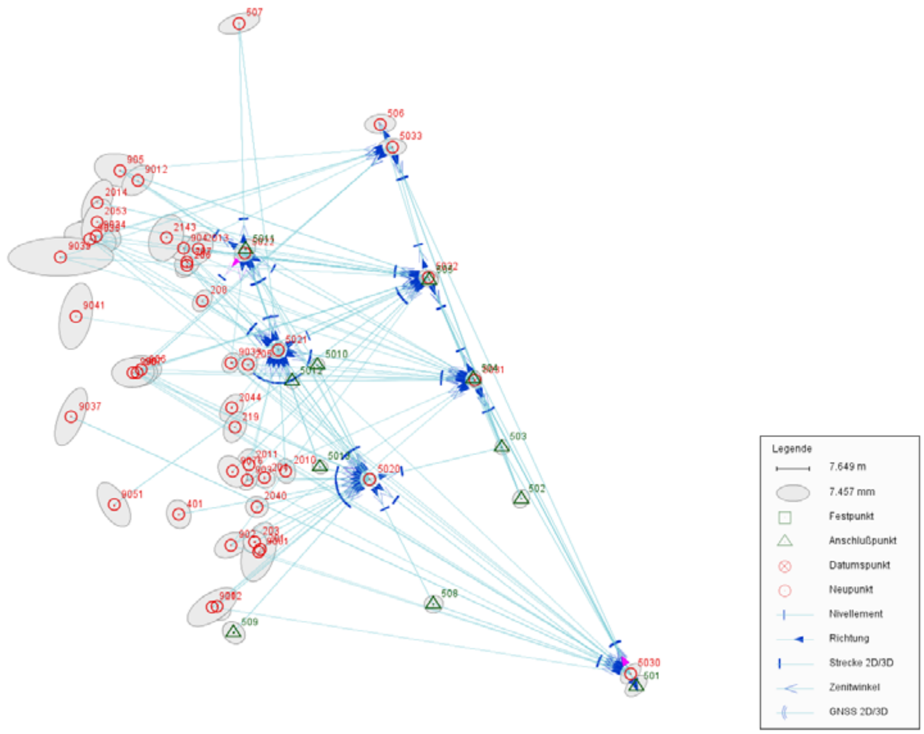

Figure 5: Tachymetric network for surveying the control points

3.3 Canon 6D 8mm Sigma lens

The Canon 6D has a 20.2MP full frame CMOS sensor. The images in this experiment have been capture from various position with the camera mounted on a tripod. The Sigma 8mm lens produces 180 degree imagery.

Figure 4: Canon 6D with Sigma fisheye 8mm

3.4 Sony alpha 7r with 8mm lens

The Sony alpha 7r has a full frame CMOS sensor. In conjunction with the 8mm Rokinon fisheye lens, it captures APS-C size images with 4800x3200 pixels. All images have been captures on a tripod mount.

Figure 6: Sony alpha 7r with 8mm Rikonon fisheye lens

3.5 Gopro Hero3+

Gopro designed this camera as an action camera. It is a wide spread camera which is well suited for use on a UAV due to is light weight of just 100g. The Gopro captures images at a resolution of 4000x3000 pixels and comes with a wide angle fisheye lens. Images can be triggered through a mobile phone connected with WiFi. There is a time laps capturing mode with various time intervals starting from 0.5 sec. The images captured in this paper used tje hand held interval capturing mode of 0.5 sec.

Figure 7: Gopro camera

3.6 Phantom Vision 2

The PhantomVision2 is a remotely controlled quadro-copter. It is fitted with a 4000x3000 pixel camera that can be triggered from a mobile phone or an interval mode starting from 1 image/second. Similar to the Gopro, it has a wide angle fisheye lens. The images in this paper were captures using the PhantomVision2 in remotely controlled flight mode with an image acquisition interval of 1second.

Figure 8: Phantom Vision 2

4 Data Acquisition

The data acquisition was done by several people within one day:

DJI Phantom Vision 2	All five courtyards inside the castle with oblique aerial imagery	1 person 2h
	Outside oblique aerial imagery from street in from of the caste and from a boat to capture the lake side	2 person 2h (1 boat driver)
Custom Quadro-copter with GoPro Hero3+	Nadir and oblique aerial imagery from the castle	1 person ½ h
Canon 6D 8mm fisheye and Sony alpha7R with fisheye	Inside courtyards and all rooms inside the castle from a tripod for the inside caste	2 person 3h
GNNS acquisition	Ground control points from target on the ground.	1 person 2h
Tachymeter	Measurements of the top towers of the castle, these ground control points connect the courtyards of the castle with the street side and the images from the boat on the lake.	2 person 5h

Figure 9: Inside image acquisition with the Canon6D on tripod

Figure 10: the whole team & equipment used

The image data from the various cameras was captured with a very high overlap (80-90%), which is not difficult to achieve considering the use of many wide angle or even fisheye lenses. More care and overlap is needed to connect the outdoor terrestrial images with the indoor images of the same camera. Since we do not have ground control points for the indoor parts, these connections needed to be very strong (high overlap).
The UAV data was captured with a custom made UAV with a GoPro mount that was set to continuous exposure every 1 second. The same setting was used for the Phantom Vision images.

5 Data Processing

Pix4Dmapper software allows to create projects by merging already computed sub projects. This has mainly two advantages:

- Speed: Efficient and fast processing for smaller sized sub projects
- Quality: Separate quality control

In the case of Chillon, the data of the various cameras and sources has been processed first independently. Each sub project has been geo-referenced with the same ground control points (when visible) and the quality/ accuracy had been ensured. After this step we merged the different sub projects into larger projects until – finally- all images have been put together. At each step of the merging process, a separate bundle adjustment was performed ("Re-optimize" option in rayCloud editor). Here after more detail on some of the sub projects.

5.1 Canon 6D 8mm fisheye

1885 images were captured from the castle courtyards and insides rooms. More overlap was needed when moving from the outside courtyards through the open doors towards the inside. Geo-referencing is possible from the tachymetric measurements of the towers that are visible from the individual courtyards.

Figure 11: Example of the Canon 6D Sigma 8mm fisheye imagery from one of the courtyards

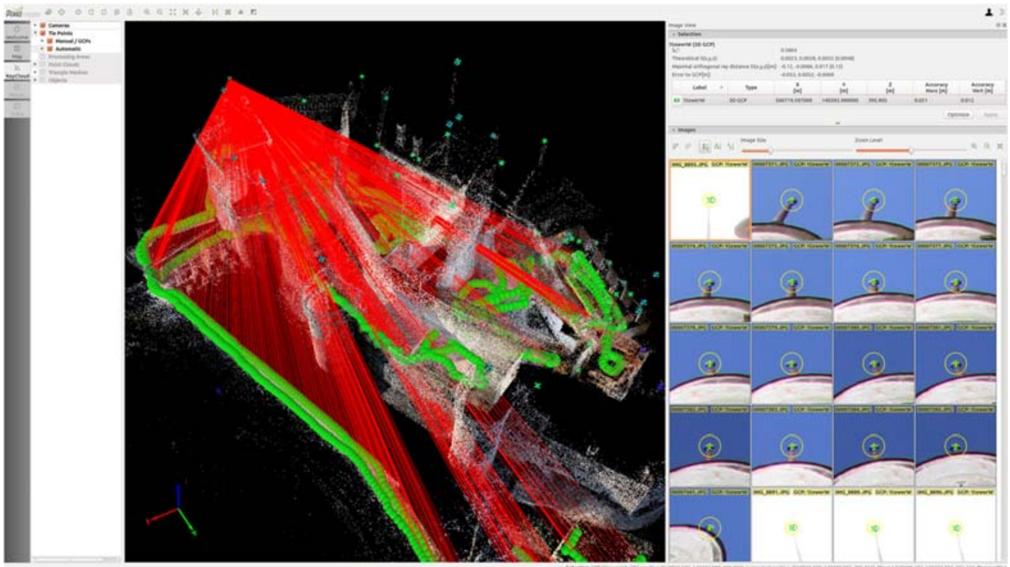

Figure 12: Reconstruction of the 1885 Canon 8mm images of the courtyards and inside rooms

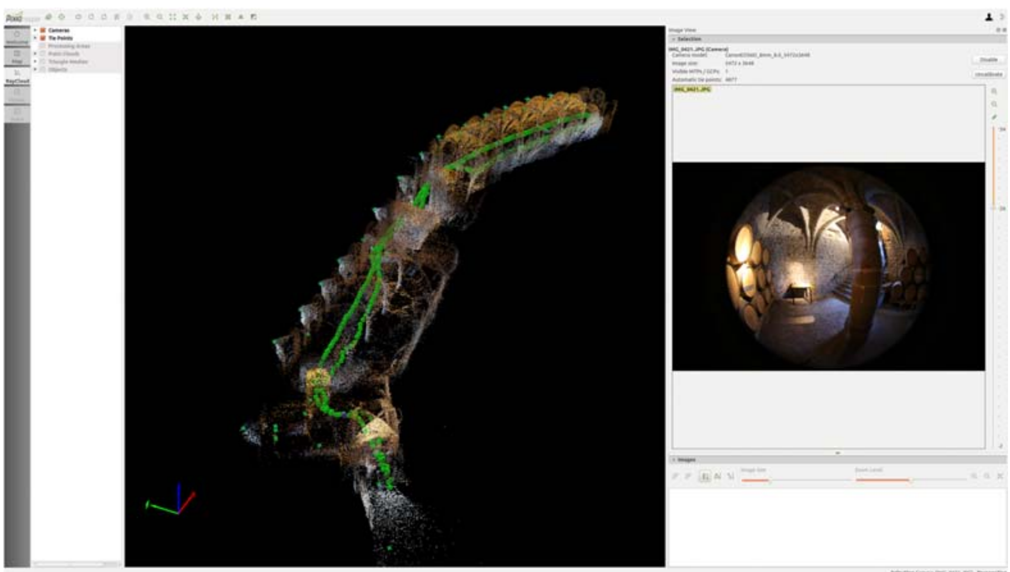

Figure 13: Reconstruction of the 453 Canon 8mm cave images

5.2 Sony alpha 7r with 8mm fisheye lens

The 1933 images taken from a tripod connect the inside rooms with two of the courtyards. The reconstruction is geo-referenced by the GCPs visible in the courtyards.

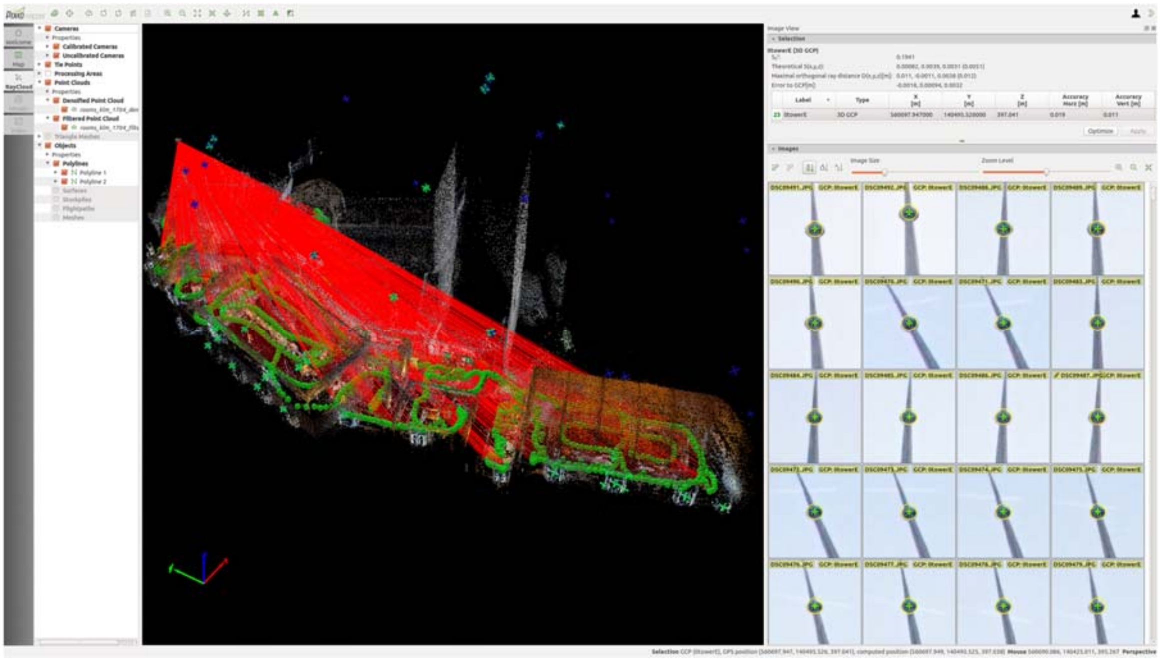

Figure 14: Reconstruction of the 1933 Sony 8mm images connecting the rooms and two of the courtyards

5.3 Gopro Hero3+

725 nadir and oblique images have been captured from a custom made quadro copter with a Gopro gimble mount.

Figure 15: Example of one image from a custom quadro copter UAV with Gopro camera.

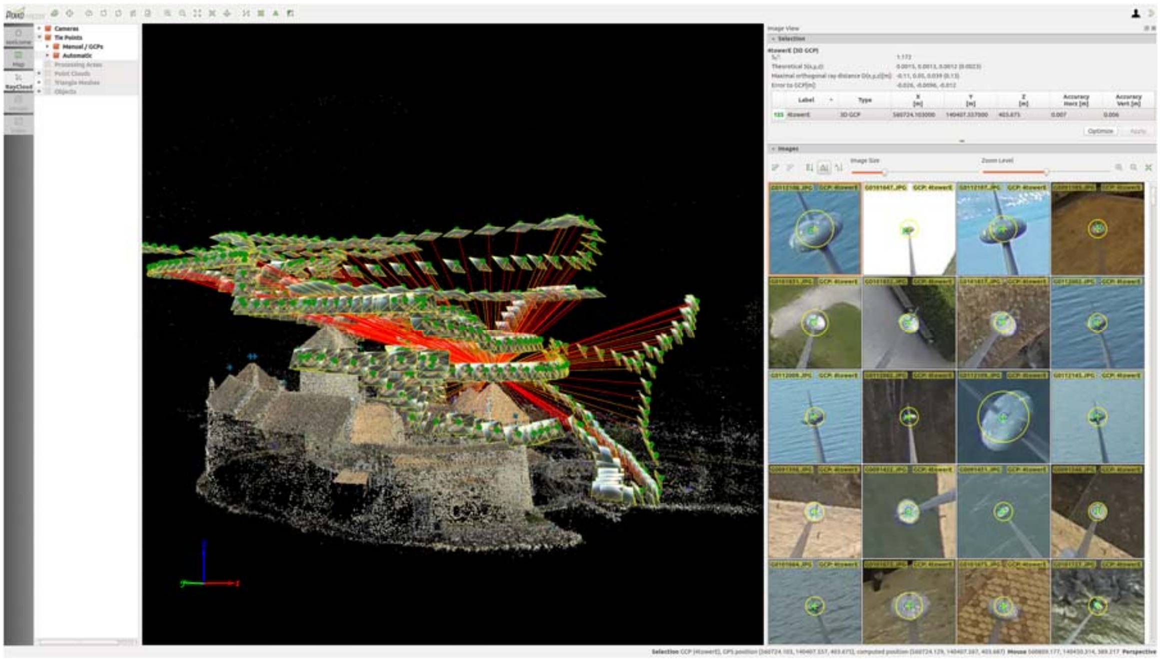

Figure 16: Reconstruction of the Gopro aerial oblique and nadir imagery.

5.4 DJI Phantom Vision 2

712 images have been capture from the courtyards with the DJI Phantom Vision 2. The result is shown in Figure 20.

469 images have been captured from the lake side (with the DJI operated from a boat) and from the front side of the castle and the result of the bundle adjustment is shown in Figure 19.

Figure 17: Example of the Phantom2 Vision imagery from the front side.

Figure 18: Example of one DJI Phantom2 Vision image from the lake side, captured by boat operation

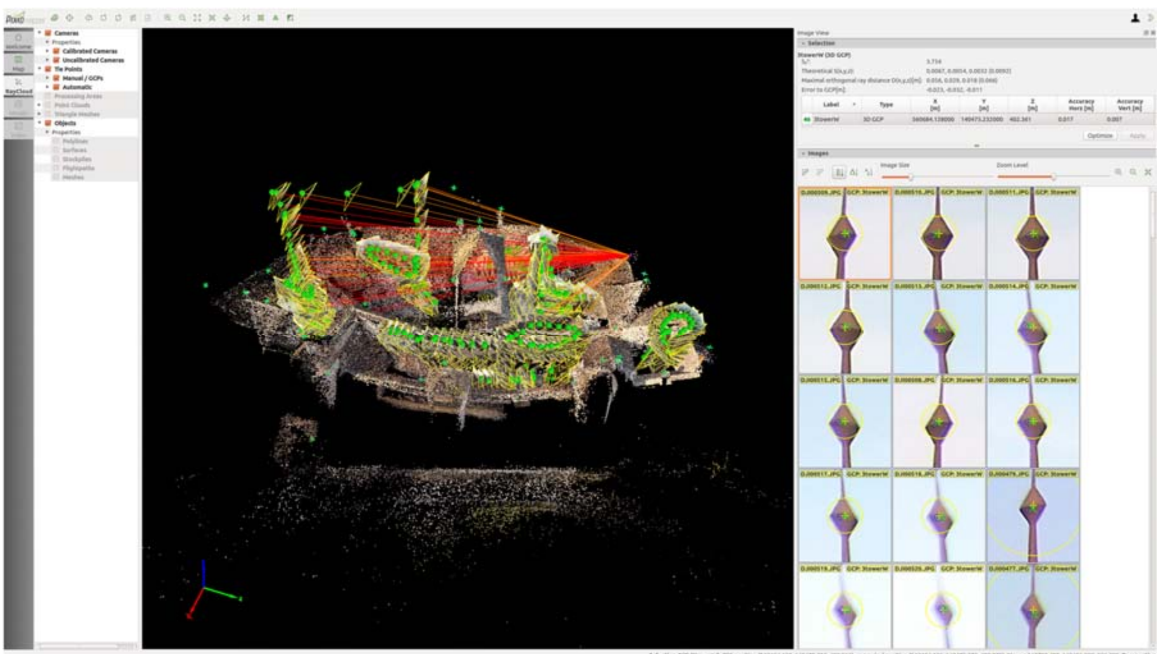

Figure 19: Reconstruction of the DJI Phantom vision images launched from each individual of the five courtyards.

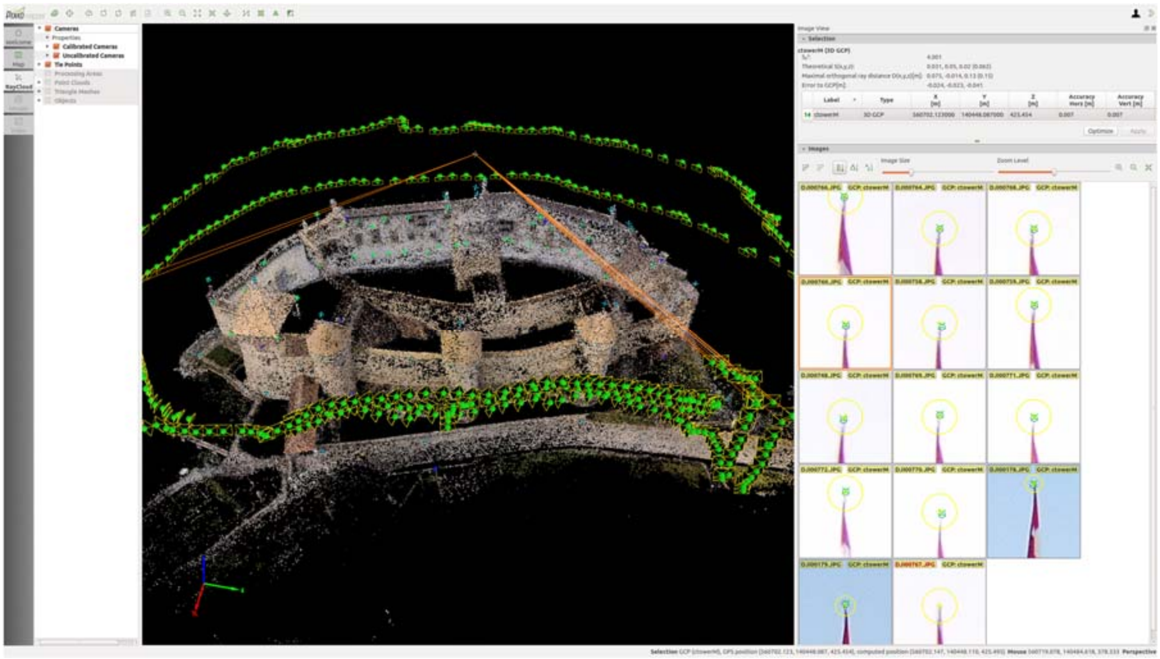

Figure 20: Phantom vision images from the front side of the castle together with the images captured from the lake side.

6 Overall reconstruction

The final reconstruction including all images is obtained by creating a new project and by "merging existing project", i.e. the projects shown above. When merging projects one can use the following cues to bring the individual projects into the same coordinate system by a rigid 7 parameter transformation:

- Overlapping images: if two projects contain at least three of the same images, they will be used to find the rigid transformation that merges both reconstructions together
- Ground control points: if the individual reconstructions are geo-referenced by GCP's there is no need to compute a rigid transformation as the merged project will be the combination of the individual projects.
- Manual tie points: if the individual projects contain manual tie points with the same name, then the corresponding triangulated 3D points are used to compute the rigid transformation that converts the individual reconstructions to the same coordinate system.

When merging projects, image features and matches are not recomputed in order to make the merging process is efficient and fast.

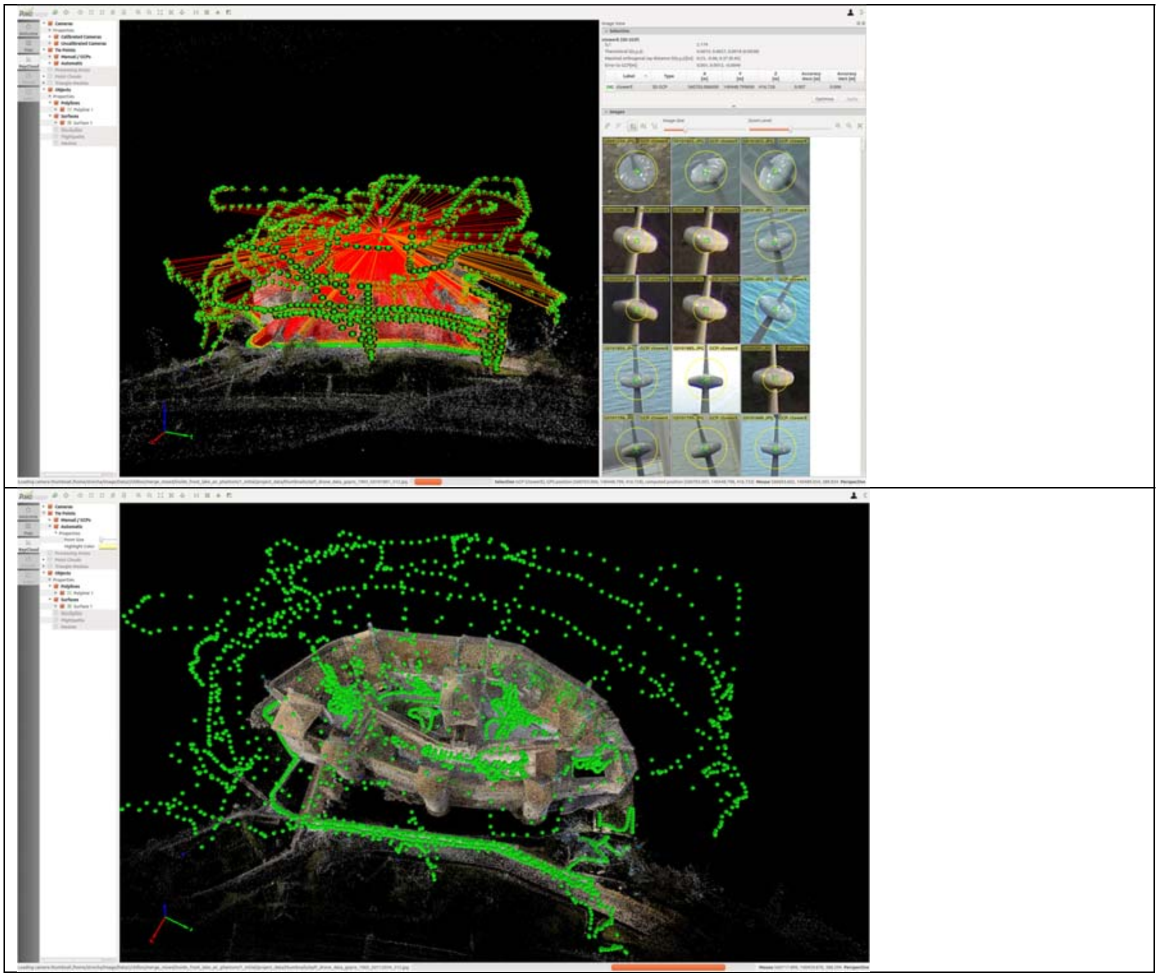

Figure 21: Two different screenshots of the rayCloud from the overall reconstruction after the Bundle block adjustment.

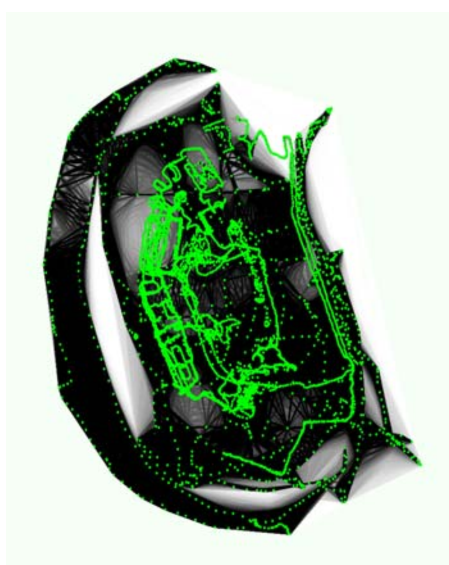

Figure 22: Connectivity graph of the overall reconstruction

Figure 23 shows the final accuracy of all Ground Control Points after bundle block adjustment of the complete project.

GCP name	Error X [m]	Error Y [m]	Error Z [m]	Projection error [pixel]
3D GCP: 1towerW	-0.012	-0.014	0.009	1.604
3D GCP: 4towerE	-0.029	-0.012	-0.006	1.495
3D GCP: 2towerW	-0.001	-0.008	0.010	1.592
3D GCP: ctowerW	-0.010	0.002	-0.002	1.218
3D GCP: 3towerE	-0.005	-0.002	0.008	1.464
3D GCP: 1towerE	-0.011	-0.003	0.004	1.235
3D GCP: 0towerE	-0.003	-0.007	0.001	1.523
3D GCP: ctowerE	0.000	0.000	-0.005	1.479
3D GCP: ctowerM	0.021	0.023	-0.015	1.190
3D GCP: 2towerE	-0.003	0.000	-0.007	1.383
3D GCP: ntowerE	0.007	-0.023	0.011	1.427
3D GCP: ntowerW	0.014	-0.027	0.011	1.306
3D GCP: chimneyM3cornerSE	-0.011	0.020	0.013	2.234
3D GCP: 3towerW	-0.011	-0.026	0.027	1.699
3D GCP: marked_GCP_seaside_south	0.010	-0.010	-0.008	1.293
3D GCP: marked_GCP_wall_N	0.002	-0.001	0.004	1.259
3D GCP: marked_GCP_wall_M	0.003	-0.004	0.009	1.178
3D GCP: marked_GCP_wall_S	0.004	-0.008	0.009	1.050
3D GCP: marked_GCP_courtyard	0.007	-0.003	0.004	0.909
3D GCP: markedGCP_north_just_GPS	-0.019	0.016	0.035	1.179
3D GCP: chimneyM2deepercorner	-0.011	-0.006	-0.036	2.175
3D GCP: chimneyM0deepercorner	0.035	0.012	0.021	1.789
3D GCP: chimney3towerEdeepercorner	-0.022	-0.003	-0.019	2.489
3D GCP: chimney_n_tower_deeper_corner	-0.034	-0.016	-0.066	1.424
3D GCP: ctowerSE	0.002	-0.005	0.001	1.537
3D GCP: ctowerSW	0.003	-0.006	-0.001	1.734
3D GCP: chimneyM2BS	-0.003	-0.039	0.046	1.915
3D GCP: chimneyM2BN	0.014	-0.015	0.023	2.035
3D GCP: top_left_white_stone	0.036	-0.009	-0.015	1.506
3D GCP: circle_down_8	0.010	-0.007	0.011	1.127
3D GCP: top_left_corner_painted_cross	-0.009	0.014	-0.022	1.897
3D GCP: 3towerE_top_left_cross_middle	-0.013	0.019	-0.010	1.296
3D GCP: 1towerE_top_left_cross_left	0.007	-0.000	-0.004	1.446
3D GCP: 1towerE_top_left_cross_middle	0.006	0.015	-0.014	0.567
3D GCP: 2towerE_top_left_cross_middle	0.003	0.012	0.002	0.861
3D GCP: top_left_front_cross_corner	0.033	-0.014	-0.007	1.223
3D GCP: top_left_corner_red_cross_bridge	-0.077	-0.063	-0.002	0.705
Mean	-0.007544	-0.007131	-0.006376	
Sigma	0.039784	0.019542	0.045805	
RMS error	0.040493	0.020803	0.046247	

Figure 23: Ground control point accuracy after final bundle adjustment of the overall project.

After the Initial processing (first step), the external and internal camera parameters of all images are known and will be used for the Point Cloud Densification.

7 Final results

Figures 24 - 30 show the rendering of the dense reconstruction.

The video of the project can be viewed at: http://youtu.be/j7PGgrMSi5o
The 3D model can be viewed both as an inside and outside point cloud as well as a triangulated mesh on www.pix4d.com/chillon

Figure 24: Front side (street side) of outside structure

Figure 25: Back side (lake side) of outside structure

Figure 26: Aerial (oblique) view of outside structure and courtyards

Figure 27: cut of parts of the inside rooms

Figure 28: cut of outside and inside structure

Figure 29: cut of outside and inside structure

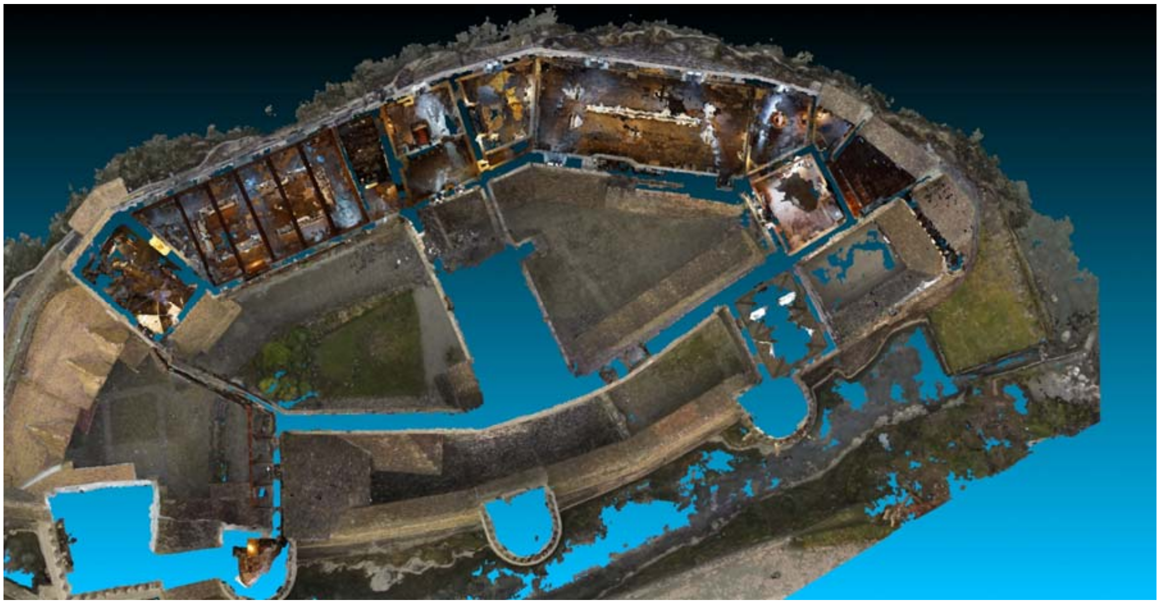

Figure 30: topview of cut