

COMPARISON OF AERIAL IMAGES, SATELLITE IMAGES AND LASER SCANNING DSM IN A 3D CITY MODELS PRODUCTION FRAMEWORK

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ABSTRACT

During the past decade, the automatic generation of 3D city models has been a constant topic of research for several universities and cartographic or photogrammetric institutes. These 3D city models have a great potential for many applications, there is a real demand for. The costs of data acquisition are still high. The choice of the input data for a framework is one of the most important key to the production line. The object of this paper is to study the potential and impact of different input data contexts. Therefore, we use an operational building extraction framework able to reconstruct buildings from aerial images and cadastral maps. Concerning the reconstruction modules the buildings can be extracted with fully automatic methods as a prismatic extraction or a model driven algorithm. Although this framework has been initially developed for an aerial image context, laser Digital Surface Model (DSM) and satellite images context has been studied. So, on several datasets, 3D city models are produced through this approach with aerial or satellite images with different resolutions (from 80 cm to 20 cm) or laser scanning DSM. An external 3D reference allows to evaluate from qualitative and quantitative points of view. The results obtained from each input data context are compared. Finally, for each input data context, we discuss the different possibilities of 3D city models specifications, especially for the level of details, geometric accuracy and exhaustiveness.

1 INTRODUCTION

Concerning 3D city models production, reconstruction paper are as easy to find as there still is very few papers on evaluation topic. ISPRS WGIII/8 and EuroSDR Commission 3 aim at increasing the number of publications on assessment theme. The difficulty to provide on a same area different sources of data and a reference explains why there is a lack of papers. Consequently the premium very practical issue of the ISPRS WGIII/8 is to provide within a website (<http://isprs.ign.fr>) a set of free and available source data. In this paper, some of these data have been exploited in addition to other complementary data sources to produce, compare and evaluate 3D buildings reconstructions.

In terms of input data there are different alternatives to produce 3D city models. In the optic field, the sensor is loaded on an aircraft or on a satellite. On the one hand, the two main technologies for digital aerial images acquisition are frame camera systems and the line scanner systems. In (Loedeman, 2000), digital camera experts present their views to elucidate the pros and cons of these two concepts. On the other hand, year after year radiometric quality and geometric accuracy of new high resolution satellites keep on improving and become a potential solution for building reconstruction applications. For instance, Pleiades-HR, a CNES (Centre National d'Etudes Spatiales) system ready for launch in 2008 will acquire stereoscopic image pairs or triplets simultaneously (Figure 7). The Pleiades-HR ground sampling distance is 70 cm on the nadir (full specifications on Figure 6). Secondly, instead of optical sensors, Airborne Laser Scanning become more and more widespread in 3D reconstruction (Maas, 1999), (Haala and Brenner, 1999), (Vosselman and Suveg, 2001). Finally, in addition to these optic and laser sensors, large scale 2D cadastral maps are now available for many countries, and can help building reconstruction (Pasko and M., 1996), (Roux and Maître, 1997), (Jibrini et al., 2000).

The operational building extraction framework used in this paper, has been published in (Flamanc et al., 2003). Although this framework has been initially developed to deal with aerial images

and cadastral maps, laser DSM and satellite images can be managed as well. The focus of this paper is to reconstruct buildings on same areas, with different input data contexts, thanks to this operational framework. For each data context we have tried to produce a model as detailed as possible with the same production line. After describing reconstruction tools, datasets and quality evaluation protocol, we will discuss the results.

2 DATASETS

We have worked on two different areas. First on Toulouse, which is a town of the south of France, and the other one on Amiens in the north. Architectural characteristics are different between them in terms of density, regularity and roof slopes. Figure 1 is an example of buildings on Toulouse test area.

2.1 Toulouse area

The three datasets on Toulouse are called T1, T2, and T3 in all the paper. Cadastral maps are not available on this area.

2.1.1 T1 - IGN Camera Images with known calibration which come from a digital frame color camera produced by the National Geographic Institute of France (IGN) (Thom and Souchon, 2001) compose T1. The ground resolution is about 20 cm. The overlap along track is approximately 60% and 20% across track.

2.1.2 T2 - Pleiades-HR It is a very fine simulation, provided by the CNES, of a stereoscopic triplet (backward, nadir, forward) which could be acquired simultaneously by Pleiades-HR system (Figure 6). During the design phase of the Pleiades-HR system in years 1999-2001, CNES involved the users community into series of feasibility studies so as to make the technical capacity of the system fit at best to the end-user requirements: in particular, many stereo and tri-stereo simulations acquired under various B/H, ground resolution, spectral ranges, were produced. Images are in panchromatic mode and the ground resolution is about 80 cm.

2.1.3 T3 - Istar DSM-TO The last one on Toulouse T3 is made up of one raster DSM (Digital Surface Model) at the resolution of 1m and a panchromatic true orthophoto at 25 cm (DSM-TO). These data come from ISTAR©company. ISTAR has developed a processing chain for calculating DSM and true orthophoto for several years. The sensor is a digital aerial scanner (0.25 meter HRSC Imagery - Copyright DLR/ISTAR - more precisions on the website www.istar.com).

2.2 Amiens area

The two datasets on Amiens are A1 and A2. For each of them, large scale cadastral maps are available (XY RMS < 70 cm).

2.2.1 A1 - IGN Camera The first one (A1) is composed of digital color IGN camera images in a multiview context (60% overlap intra and inter strip). The ground resolution is around 25 cm.

2.2.2 A2 - Laser DSM For the second one A2, a laser dataset has been acquired by TopoSys©. This firm owns a self-made lidar acquisition system, which is composed of two rigid blocks of optical fibers (emission and reception of laser pulses). Figure 8 gathers the main technical information about the system. In this data set, the density is 7.5 points/km², with one point every 10 cm along the flying direction and every 1.2m in the cross direction.

2.3 Reference models

In addition, 3D models which come from fully manual stereo plotting cover Toulouse and Amiens areas. Quality evaluation in relation to reference 3D model can be efficient only if reference is better than other reconstructions. Concerning AR, planimetric and altimetric RMS is 0.2m. Though we do not know exactly numeric specifications and accuracy on TR, these 3D model is most accurate and detailed than T1, T2 and T3. We call them TR (Toulouse) and AR (Amiens) with R for reference.

At last, the reconstruction framework handles images with known calibration. For all the datasets (T1 T2 T3 TR A1 A2 AR) the bundle adjustment is different. This paper do not talk about this step.

Figure 10 sums up main data characteristics.

3 THE RECONSTRUCTION FRAMEWORK

The reconstruction framework used in all datasets, has been presented in (Flamanc et al., 2003). This flexible framework includes lots of reconstruction tools. The operator has used different modules in order to make the most in terms of model details and time consuming. In the following list, main modules are briefly described. There is not chronological order in the list, and some modules are not available with all input data context.

- Production of DSM and Ortho-images from images
- 2D plotting to produce or complete building footprints on Ortho and/or DSM (using cadastral maps if available)
- Automatic, or user-assisted 3D reconstruction using 2D ground maps
- 2D Control and correction using DSM and Ortho-images
- 3D Control and correction (require stereo images)

- 3D User-assisted or manual reconstruction (require stereo images)

The framework takes advantages of multi-view or triplets of images context, especially in the generation of DSM.



Figure 1: Dense area on Toulouse dataset.

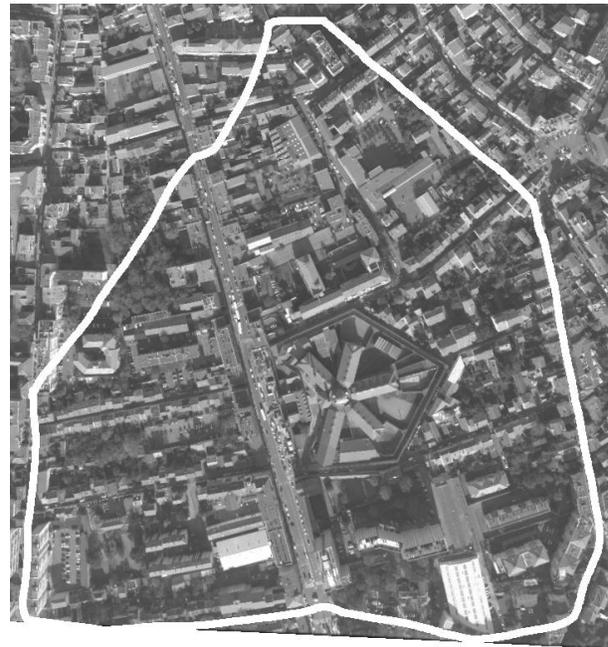


Figure 2: Toulouse reconstruction area.

4 INTER COMPARISON PROTOCOL

The goal of this part is to explain how the reconstruction results have been crossed. First thanks to visualization tools we estimate possible local XY shift between two reconstructions. Especially for laser data the GPS/INS measurements cause systematic deformations of laser-scanner data strips (Bretar, 2003).

Secondly, four indicators have been used:

- Accuracy: RMS of the punctual height difference
- Time cost: the time to produce one km²

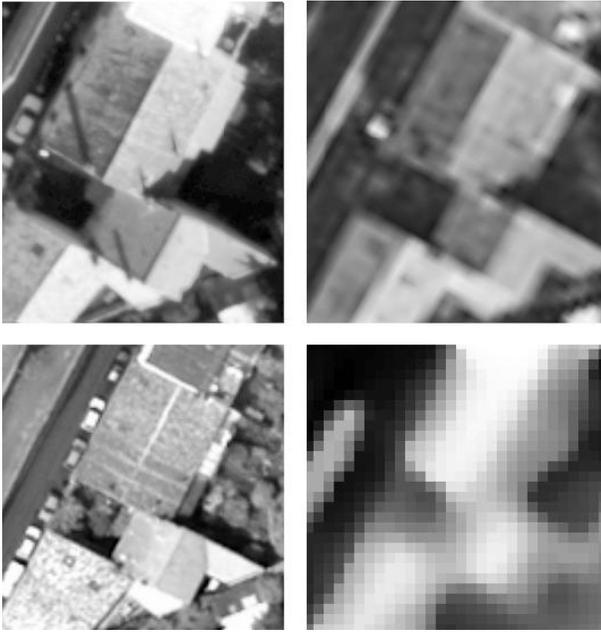


Figure 3: IGN camera image (top left), Pleiades-HR image (top right), Istar TO (bottom left), Istar DSM (bottom right), on Toulouse.

| Image characteristics | |
|---|---|
| Panchromatic resolution | 0.7m at nadir [PAN : 480-830 nm] |
| Swath | 20km at nadir |
| Spectral bandwidths Resolution : 4 times the resolution of the panchromatic mode | blue : 430-550 nm green : 490-610 nm red : 600-720 nm PIR : 750-950 nm |
| Agility | |
| Roll 60 deg | 25 seconds |
| Pitch 60 deg | 25 seconds |
| Location Accuracy | |
| with a ground control point | 1m |
| with no ground control point | better than 15m RMS |
| Acquisition capability | |
| Up to 450 images per day and per satellite | |
| Acquisition Examples | |
| stereo over 60 km with B/H ratio 0.2 | |
| stereo over 120 km with B/H ratio 0.3 | |
| tri-stereo over 20 km with B/H ratios 0.15 - 0.15 | |
| tri-stereo over 60 km with B/H ratios 0.2 - 0.2 | |

Figure 6: Pleiades-HR satellite characteristics.



Figure 4: Amiens reconstruction area.

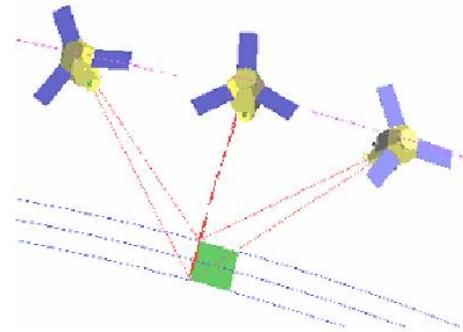


Figure 7: Simultaneous stereoscopic or tri-stereoscopic acquisitions mode with Pleiades-HR.

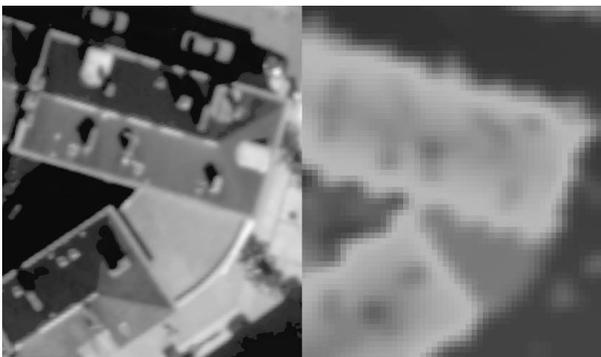


Figure 5: IGN camera image and Laser DSM crops on Amiens.

| | |
|------------------------|--------|
| Intra-strip resolution | 0.1m |
| Inter-strip resolution | 1.2m |
| Height flight | 1005m |
| Strip width | 230m |
| Scanning frequency | 650 Hz |
| Pulse length | 5 ns |
| Acquisition frequency | 83 kHz |
| Laser wave length | 1.55m |
| FOV | 14 deg |

Figure 8: Technical characteristics of the TopoSys©lidar system.

- Level of details: roughly estimated with the number of facets per km²
- Exhaustiveness: estimated with the ratio of reference buildings surface covered in the reconstructed model

The punctual height difference is a very basic method for accuracy estimation. (Abbas, 1994) describes the method and his inherent problems. Through a regular grid on the overlap area of two datasets we collect height differences. The ground resolution of the grid is 25 cm. All these height differences constitute the statistical population we use for our statistic evaluations. We estimate our height difference median and RMS with two iterations. After rejecting outliers over 3m in absolute value we calculate first height median and RMS. Then after re-centering on the height median and rejecting with 3xRMS threshold we calculate the second estimation.

| RMS (m) | A1 IGN Camera | A2 Laser DSM | AR Ref |
|-----------------|------------------|-----------------|-----------|
| A1 (IGN Camera) | 0 | 0.50 | 0.61 |
| A2 (Laser DSM) | 0.50 | 0 | 0.67 |
| AR (Ref) | 0.61 | 0.67 | 0 |

Figure 9: RMS between the datasets on Amiens.

5 RESULTS AND DISCUSSION

All the results are summarized in 10. The RMS do not estimate the plotting accuracy but the modeling accuracy: it mixes measurements accuracy and generalization precision. Concerning the RMS value, the generalization is more influent than plotting accuracy. On the Figure 9, T2 is closer to T1 and T3 than TR, probably because the level of generalization is close between the models T1, T2 and T3. The Figure 11 shows the same phenomenon: the levels of details of A1 and A2 are closer than the one of the reference (see Figure 13).

5.1 Interest of using stereo images

On the Toulouse dataset, it appears clearly that using aerial digital frame images make the production of a more exhaustive 3D model possible (87% for T1, versus 79% for T3). Even without a stereoscopic visualization, the possibility to see the scene from different points of view helps the operator to better understand the scene. Moreover, the number of facets/km² shows that the reconstruction is also more detailed (4133 for T1 versus 3163 for T3). This is due to the fact that very complexed buildings can always be reconstructed through 3D measurements contrary to the T3 context where the operator can only make 2D ground measurements. Finally, we notice that the direct re-projection of the reconstructed models in conic views is very convenient for the quality control step.

5.2 Quickness with Istar DSM-TO

The T3 production context offers a good quality reconstructed model with an good time ratio (5.6 for T3 versus 8.3 for T1). First because of the fact this true orthophoto is very easy to read. And secondly the lack of huge errors in the DSM ensures robustness of automatic reconstruction tools.

5.3 Usefulness of satellite images for 3D reconstruction

Even if small details can hardly be reconstructed with 80 cm satellite images, the T2 results show that it is possible to produce 3D city models with an acceptable precision (1.07 m) and a good time cost (6.5h/km²). Of course there are more omissions than for the two other contexts (T1 and T3).

5.4 Aerial images and laser DSM nearly equivalent if using cadastral maps

On Amiens area cadastral maps are available. That is one of the reasons for not making any comparisons with Toulouse. Numerically speaking the results are very close between A1 (IGN camera) and A2 (Laser DSM). But the A2 data set does not include a pushbroom scanner (even if these images are now available in commercial laser scanning offers), and it is important to notice that it is quite difficult to precisely measure bounds of buildings on the laser DSM because of the important interpolation artefacts along the facades. And of course, without images, photo realistic models cannot be produced. Finally, even if we do not take in account economic aspects in this paper, it is important to notice that the flight cost, related to the number of strips, can be very different between a laser and an optic acquisition.

6 CONCLUSION

We have presented some comparisons between 3D buildings reconstruction in different data context. Of course, high resolution stereo aerial images guarantee the best quality and precision, but the goal of this paper is chiefly to estimate the difference in terms of accuracy and reconstruction time-cost between these different data context. It appears that each type of data offer a different compromise between precision, exhaustiveness and cost and operational facilities. We are convinced that all these data could be suitable for specific applications. In particular, new and future high resolution satellites seems to become a real alternative for 3D city model production.

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| Area (surface) | Toulouse (0.24 km ²) | | | | Amiens (0.42 km ²) | | |
|--------------------------------------|----------------------------------|-------------------|--------------------|-------------|--------------------------------|-----------------|-------------|
| | T1 IGN Camera | T2 Pleiades-HR | T3 Istar DSM-TO | TR Ref | A1 IGN Camera | A2 Laser DSM | AR Ref |
| Images (m) | 0.20 | 0.80 | | | 0.25 | | |
| Ortho (m) | 0.20 | 0.80 | 0.25 | | 0.25 | | |
| DSM (m) | 0.20 | 0.80 | 1 | | 0.25 | 0.50 | |
| Cadastral maps | | | | | X | X | |
| WGIII/8 website | | | | | X | X | X |
| Nb Images | 2 | 3 | | | multiview | | |
| Base/height | 0.4 | 0.09/0.30 | | | 0.19→0.76 | | |
| Height (m) | 830 | | | | 1440 | 1005 | |
| Focal distance (mm) | 51 | | | | 28 | | |
| Rejection | 7.16% | 7.11% | 6.74% | | 4.15% | 4.98% | |
| DZ median (m) | 0 | -0.6 | -0.1 | | -0.2 | 0 | |
| RMS (m) | 0.52 | 1.07 | 0.62 | | 0.61 | 0.67 | |
| Time ratio (h/km²) | 8.33 | 6.25 | 5.6 | | 11.9 | 11.9 | |
| Nb facets/km² | 4133 | 2438 | 3163 | 7925 | 5988 | 5692 | 6310 |
| Exhaustiveness | 87% | 70% | 79% | | 91% | 92% | |

Figure 10: Technical characteristics and results of datasets.

| RMS (m) | T1 IGN Camera | T2 Pleiades-HR | T3 Istar DSM-TO | TR Ref |
|------------|------------------|-------------------|--------------------|-----------|
| T1 | 0 | 0.94 | 0.54 | 0.52 |
| T2 | 0.94 | 0 | 0.90 | 1.07 |
| T3 | 0.54 | 0.90 | 0 | 0.62 |
| TR | 0.52 | 1.07 | 0.62 | 0 |

Figure 11: RMS between the datasets on Toulouse.

Roux, M. and Maître, H., 1997. Three-dimensional description of dense urban areas using maps and aerial images. In: B. B. Verlag (ed.), Automatic Extraction of Man-Made objects from aerial and space images II, pp. 311–322.

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Vosselman, G. and Suveg, I., 2001. Map based building reconstruction from laser data and images. In: B. B. Verlag (ed.), Automatic Extraction of Man-Made objects from aerial and space images, Ascona, pp. 231–239.

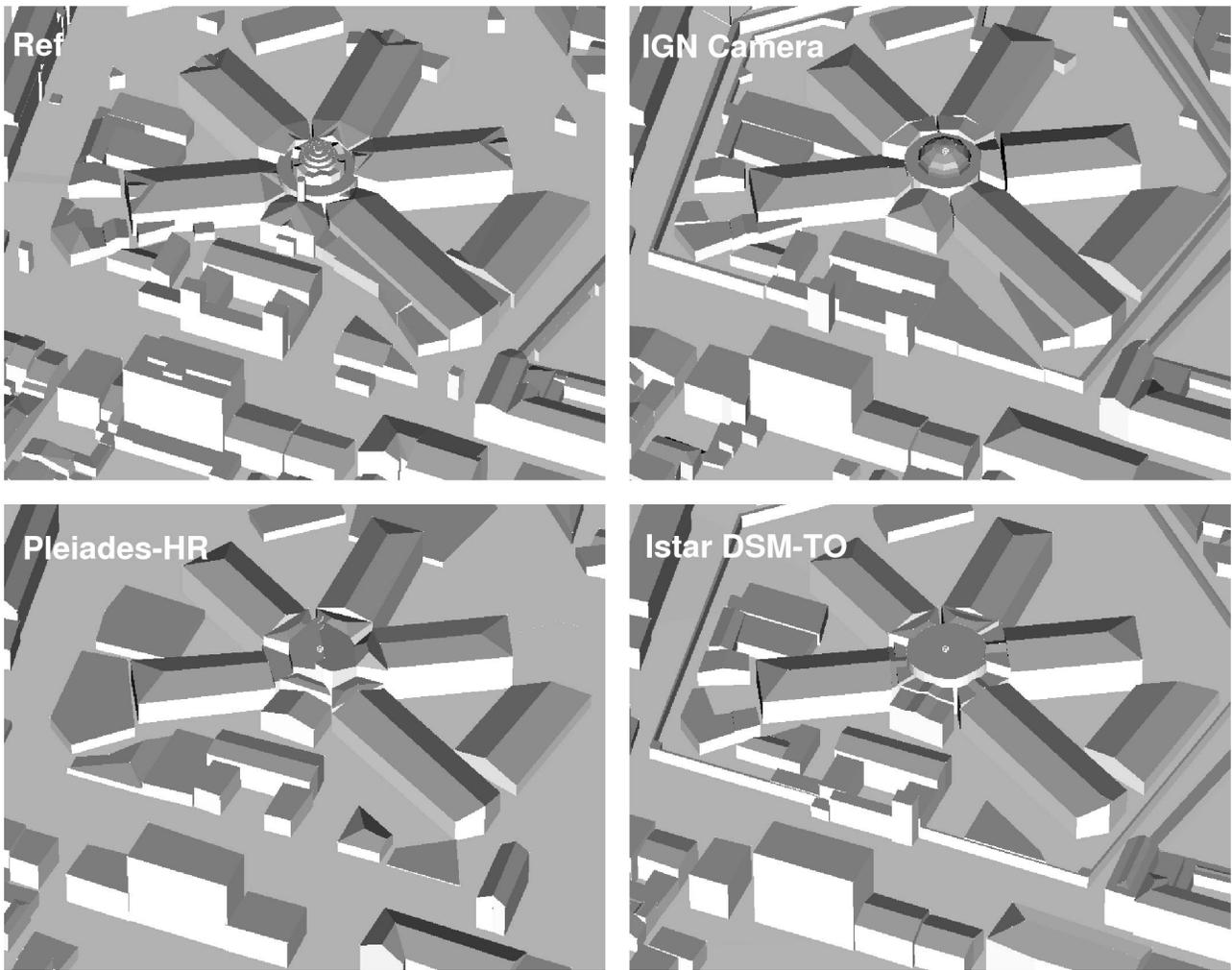


Figure 12: Crops on Toulouse TR (up left), T1 IGN Camera (up right), T2-Pleiades-HR (down left) and T3 Istar DSM-TO (down right)

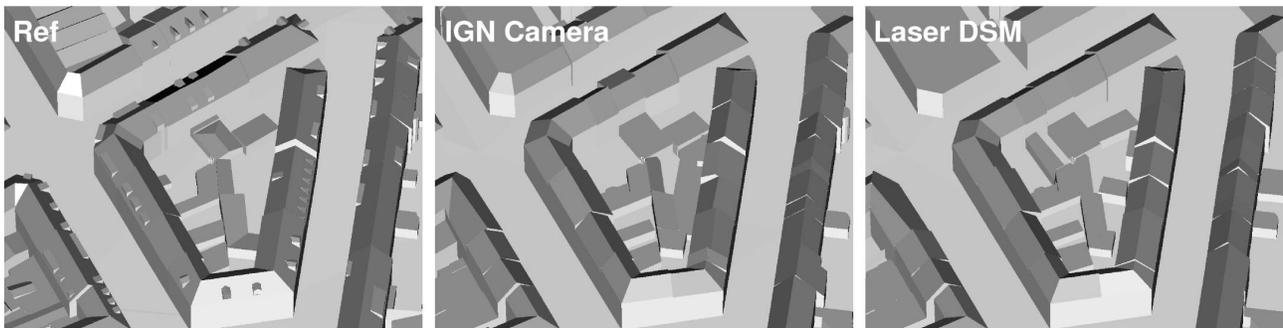


Figure 13: Crops on Amiens AR, A1 IGN Camera, A2 Laser DSM