

AUTOMATIC 3D BUILDING RECONSTRUCTION FROM DEMS : AN APPLICATION TO PLEIADES SIMULATIONS

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ABSTRACT:

This paper is about an example of PLEIADES applications, the 3D building reconstruction. The future PLEIADES satellites are especially well adapted to deal with 3D building reconstruction through the sub-metric resolution of images and its stereoscopic characteristics. We propose a fully automatic 3D-city model of dense urban areas using a parametric approach. First, a Digital Elevation Model (DEM) is generated using an algorithm based on a maximum-flow formulation using three views. Then, building footprints are extracted from the DEM through an automatic method based on marked point processes : they are represented by an association of rectangles that we regularize by improving the connection of the neighboring rectangles and the facade discontinuity detection. Finally, a 3D-reconstruction method based on a skeleton process which allows to model the rooftops is proposed from the DEM and the building footprints. The different building heights constitute parameters which are estimated and then regularized by the "K-means" algorithm including an entropy term.

1. INTRODUCTION

Faced with the urbanization development, the automatic 3D-reconstruction of urban areas has become a topic of interest in the last few years. The use of models with connected planar facets has been recently used in various applications such as the computing of electromagnetic wave propagation or the creation of virtual realities. Several automatic methods giving satisfactory results have been developed using aerial images or laser scanning. Aerial images are the most popular data to deal with this type of problems. Different techniques have been proposed such as perceptual organization (Nevatia and Price, 2002), polyhedral approach (Baillard and Zisserman, 2000), parametric models (Weidner and Forstner, 1995) or structural approach (Fuchs and Le Men, 2000). Laser scanning is also very popular since the decrease of the acquisition cost. Although laser measurements are very accurate, laser scanning is known to have a low density of points compared to aerial data. For instance, we can quote the parametric approach of (Maas, 1999).

Nowadays, this problem can be tackled by another kind of data : the sub-metric satellite images. The future PLEIADES satellites are especially well adapted to deal with 3D building reconstruction through the high resolution of images (0.7 meter) and the stereoscopic characteristics (three views - B/H=0.2). The main advantages of satellite data compared to aerial images are a high swath width and ground coverage. However, such data have a "relatively low" resolution and a "low" Signal to Noise Ratio (SNR) to deal with 3D city modelings. For example, PLEIADES simulations have 2 pixels per square meter density contrary to standard aerial images used in 3D-reconstruction problems which have about 25 pixels per square meter. Those drawbacks do not allow to use standard methods developed for the aerial image case and lead us to propose a new method based on an important a priori knowledge concerning urban structures.

Using an automatic parametric approach, we propose a 3D-model with connected planar facets of dense urban areas from PLEIA-

DES simulations. The proposed method is composed of three steps. The first one consists in generating a Digital Elevation Model (DEM) which is an altimetric description of urban areas. It is computed by an algorithm based on a maximum-flow formulation using three views. The second step consists in extracting the building footprints from the DEM. An automatic method based on marked point processes is used to provide rectangular building footprints. We then regularize these footprints by improving the linking up of the neighboring rectangles and detecting the facade discontinuities. The obtained building footprints are more than simple cadastral information : each element represents a specific part of an urban structure. Finally, the third step corresponds to the 3D-reconstruction from the DEM and the extracted building footprints. A skeleton process is used to model the rooftops of buildings. The different heights of buildings constitute parameters which are estimated and then regularized in order to favor the rooftop and getter of roof continuities. Results are obtained from PLEIADES simulations on the city of Amiens (France) which means on a dense urban area. PLEIADES simulations have been computed by the French Space Agency (CNES) from aerial images. They take into account the different characteristics of PLEIADES satellites such as the image resolution and the SNR.

2. DEM GENERATION

The first step consists in generating DEMs from 3-views PLEIADES simulations. A method based on a multi-resolution implementation of a Cox and Roy optimal flow matching image algorithm (Roy and Cox, 1998) is used. This method, detailed in (Pierrot-Deseilligny and Paparoditis, 2006), aims at solving the surface reconstruction problem formalized as a minimization of an energy. This energy is composed of a data attachment term and a regularizing term which depends on the smoothness of the surface. A multi-resolution approach is necessary for achieving

reasonable processing times on extended areas and improving robustness by restraining matching ambiguities. A result obtained from 3-views PLEIADES simulations on a single building is presented on figure 1.

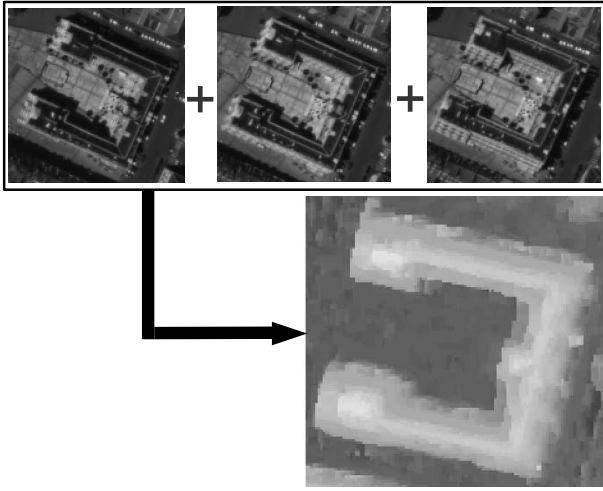


Figure 1. 3-views PLEIADES simulations ©CNES and the associated DEM ©IGN

3. FOOTPRINT EXTRACTION

In order to compensate for the lack of cadastral information, the second step consists in extracting building footprints from the DEM.

3.1 Rectangular building footprints

An object approach is used to provide rectangle layouts which represent the building footprints (Ortner, Descombes, and Zerubia, 2003). A similar method has been developed in (Vinson and Cohen, 2002). Faced with the complexity and the diversity of building forms, this approach based on marked point processes is well adapted since it provides a modeling by simple geometric objects (i.e rectangles) and allows the introduction of a priori knowledge concerning the object layout and doesn't need initialization states (i.e. no building localization maps).

A data term based on a discontinuity detection is introduced. An a priori term incorporating geometrical interactions between rectangles is also developed in order to regularize the rectangle configuration. An energy is associated to each configuration, and the global minimum of this energy is then found by applying a Reversible Jump Monte Carlo Markov Chain sampler embedded in a simulated annealing scheme (Green, 1995).

Figure 2 presents a result from PLEIADES simulations on an Amiens building. The result is satisfactory in an automatic context. However, applying directly a 3D-reconstruction process from these rectangular building footprints engenders the presence of artefacts in the 3D-results (Lafarge, Descombes, Zerubia, and Deseilligny, 2006a). That is why these rectangle layouts need to be regularized, especially the connection between neighboring rectangles.

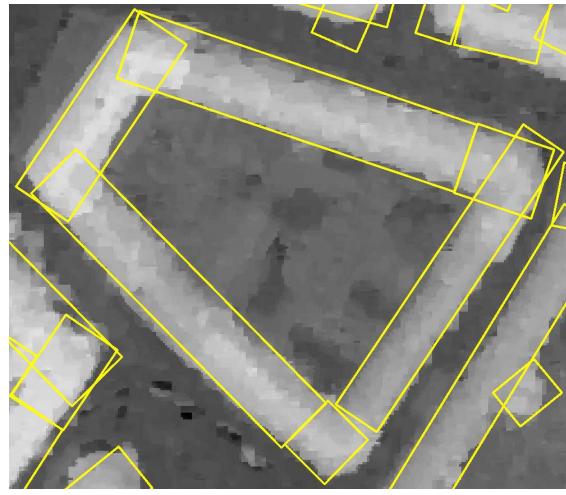


Figure 2. Rectangular footprint result and the Digital Elevation Model ©INRIA

3.2 Structured building footprints

The rectangle layouts are regularized by improving, firstly, the connection between neighboring rectangles (through a local fusion of rectangles) and, secondly, the positioning of facades (through a facade discontinuity detection). More details could be found in (Lafarge, Descombes, Zerubia, and Deseilligny, 2006b).

3.21 Local fusion of rectangles We aim at merging two neighboring rectangles, it means we search for connecting both point A and point B (outside sector), and point C and point D (inside sector) of figure 3.

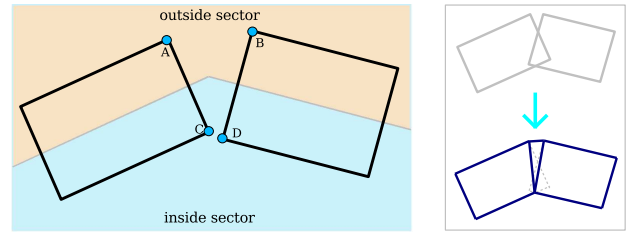


Figure 3. Local fusion of rectangles - two neighboring rectangles (left) and an example of a fusion (right)

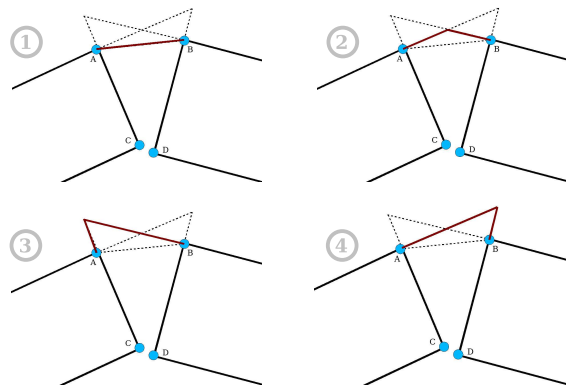


Figure 4. The 4 connection configurations of the outside sector

Figure 4 shows the 4 proposed configurations of the outside sector (it means the connection between point A and point B). Concerning the inside sector (i.e the connection between point C and

point D), the 4 same configurations are allowed. Eventually, 16 configurations of local fusion are proposed. Figure 3 represents an example of a configuration. In order to select the best configuration, we define a cost function which depends on three terms :

$$C = C_{recovering} + \omega_{data}C_{data} + \omega_{complexity}C_{complexity} \quad (1)$$

where ω_{data} and $\omega_{complexity}$ represent weights which are tuned by trial and errors. The first term $C_{recovering}$ corresponds to a recovering piece of information which compares the proposed polygon surface to the rectangle surfaces. Then, a data term C_{data} allows to fit the proposed configuration to the DEM. The last term $C_{complexity}$ estimates the complexity of a configuration which is based on convexity criteria.

Figure 7 shows the result from the rectangular footprints of the figure 2. This result is satisfactory : the artefacts of rectangle connections have disappeared.

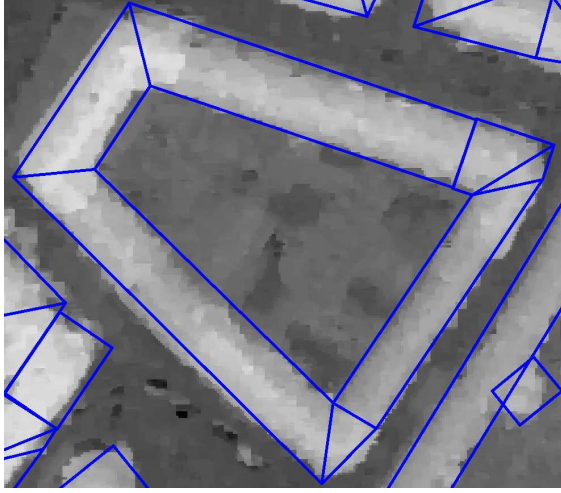


Figure 5. Building footprints with fusion of rectangles
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3.22 Facade discontinuity detection The second improvement consists in detecting the facade discontinuities in the building footprints. In fact, several roof heights can exist inside a footprint as we can see on the figure 6-(a). To do so, a rooftop profile is computed for each footprint (see figure 6-(b)). This profile is obtained by estimating the average roof height (i.e. Z) in a sliding window. Then, the high gradients are detected by applying a thresholding on the profile derivative (see figure 6-(c)). The threshold is a parameter which has been set up to 2 (this value corresponds to the Z -variation to X -variation ratio). Finally, the selected gradients are accumulated (figure 6-(d)) in order to obtain the facade discontinuities presented figure 6-(e).

Figure 6 shows the result from the footprints of the figure 2. This result represents structured building footprints since each element corresponds to a specific part of an urban structure.

4. 3D-RECONSTRUCTION

The last step corresponds to the 3D-reconstruction process from a DEM and structured building footprints. Faced with the quality of the data which are very noisy, a parametric approach has been preferred because of its robustness. However, this approach proposes restricted 3D-modelings.

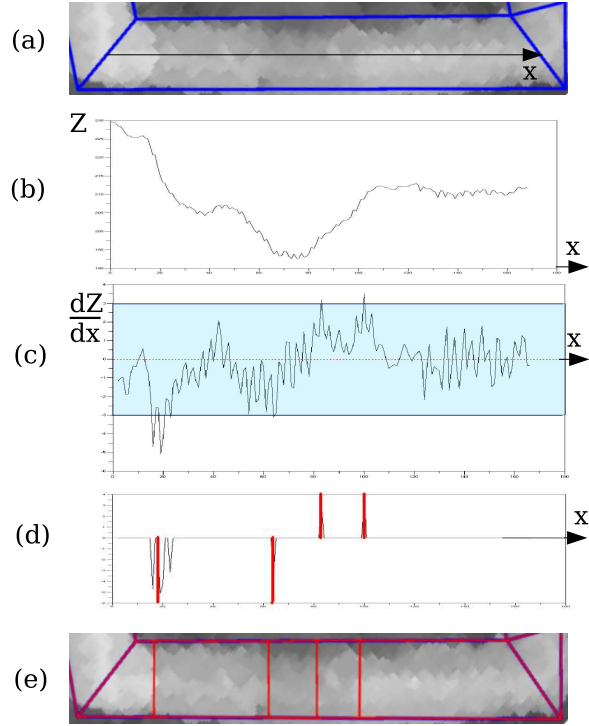


Figure 6. Facade discontinuity detection (a): initial footprint (b): rooftop profile (c): gradient selection (d): gradient accumulation (e): resulted footprint with facade discontinuities (in red)

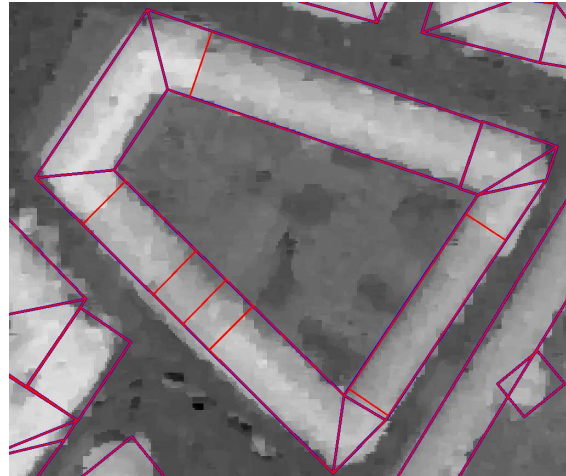


Figure 7. Building footprints with facade discontinuities
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4.1 Skeleton process of the footprints

The proposed parametric method is based on a skeleton process of the footprints which allow to model the rooftops of buildings. It is a very simple process : roofs are constrained to be symmetric two-planes. Such a process has been used in (Flamanc and Maillet, 2005). The roof forms are fully determined by the structured building footprints : it allows to reduce the computing time comparatively to others approaches.

Figure 8 represents the result of the skeleton process.

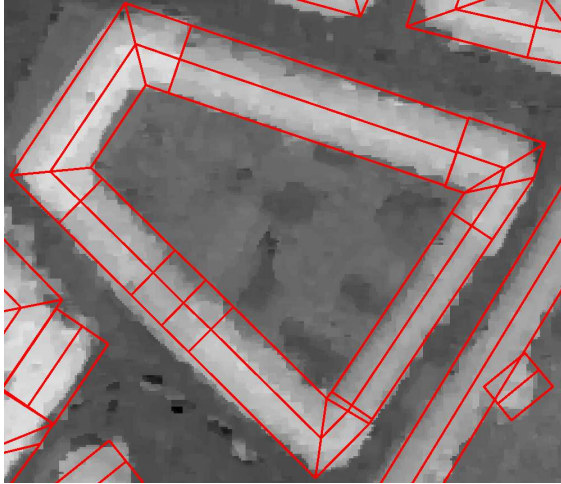


Figure 8. Projected roof form using a skeleton process

4.2 Setting of the building heights

The different heights of buildings constitute the parameters of the model. For each part of the footprints, a getter of roof height and a rooftop height are estimated by a method developed in (Lafarge, Descombes, Zerubia, and Deseilligny, 2006b). These heights are then regularized on all the scene by using the "K-means" algorithm including an entropy term (Palubinskas, Descombes, and Kruggel, 1998). The advantage of such an algorithm is that the number of classes does not need to be known a priori. It allows to favor the rooftop continuity and reduces the presence of artefacts.

Figure 9 represents examples of a reconstructed building. The first one (a) is obtained without regularizing building heights : we can see the presence of artefacts through the bad adjustments of the rooftop heights and getter of roof heights. The second building (b) is regularized.

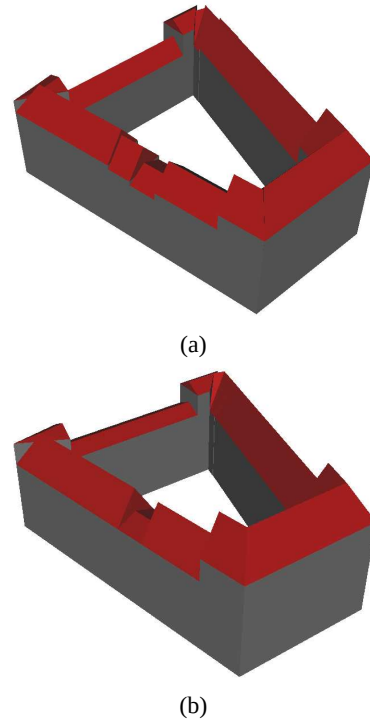


Figure 9. **(a)** : non-regularizing 3D-reconstruction **(b)** : regularizing 3D-reconstruction ©INRIA/IGN/CNES

5. RESULTS

Results have been obtained on Amiens city (France). The associated 3D-ground truths have been semi-automatically established by the French Geographic Institute (IGN) from aerial images (0.2 meter resolution) and ground maps.

Figure 10 presents an example of 3D building reconstruction (b) associated with the structured building footprints (a) and the 3D-ground truth (c). This result is satisfactory compared to the 3D-ground truth. The proposed modeling does not allow to represent some details. However, the global shape is respected and the generalization level is acceptable for satellite data in an automatic context.

Figures 11 and 12 show results on two Amiens areas. Figures 11/12-(a), (b) and (c) respectively represent PLEIADES simulations, rectangular building footprints associated with the DEM

and structured building footprints of the areas. The 3D-results (figures 11/12-(d)) are satisfactory compared to the associated 3D-ground truths (figures 11/12-(e)). Building footprints are correctly detected in general. Even if the 3D-modeling is simple (the roof forms are constrained to be symmetric two-planes), a majority of urban structures is close to reality. Moreover, these results are aesthetically satisfactory compared, for example, to results presented in (Lafarge, Descombes, Zerubia, and Deseilligny, 2006a).

However, we can see two drawbacks. First, some building footprints have not been detected. They correspond to low flat buildings of inner courtyards that the building extraction method (Ortner, Descombes, and Zerubia, 2003) cannot detect. Second, the building extraction method detects some trees (figure 11). However, this default can be corrected by introducing a vegetation mask in the process.

6. CONCLUSION

Results obtained by the new method proposed in this paper show that the use of a parametric approach is well adapted to deal with HR satellite data, especially PLEIADES simulations, in an automatic context. The obtained 3D-reconstructions are satisfactory : a majority of urban structures is close to reality. Moreover, this 3D-modeling is aesthetically correct : there are few artefacts due to the different regularization steps.

However, this model is very simple : the roof forms are constrained to be symmetric two-planes. A solution would consist in extending the roof form possibilities by using a grammar of 3D-models. This grammar would include more complex roof forms such as dissymmetric two-planes or gambrel roofs. In the future, we should work on this problem.

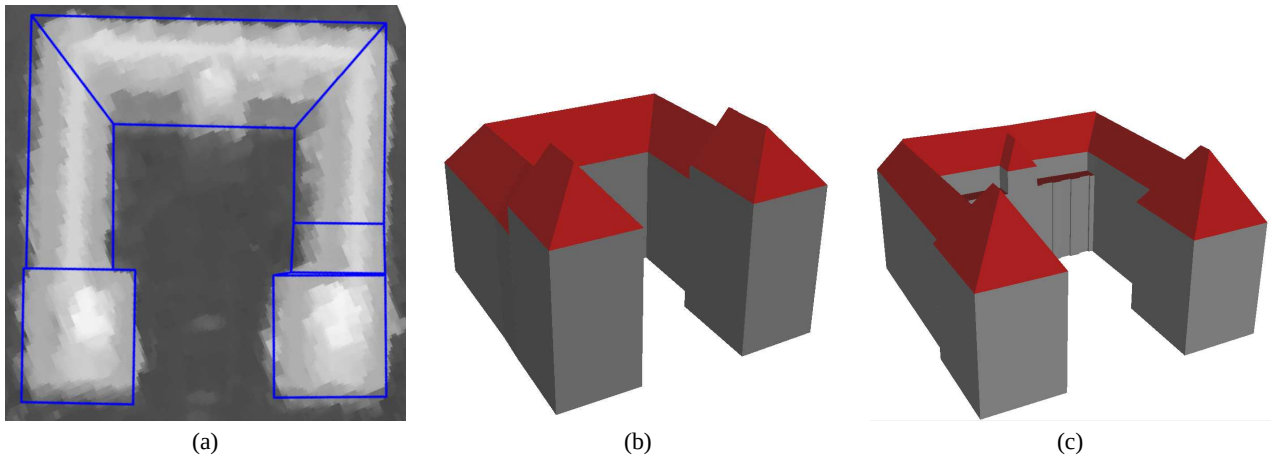


Figure 10. **(a)** : structured building footprints of Amiens city hall **(b)** : 3D-result ©INRIA/IGN/CNES **(c)** : 3D-ground truth ©IGN

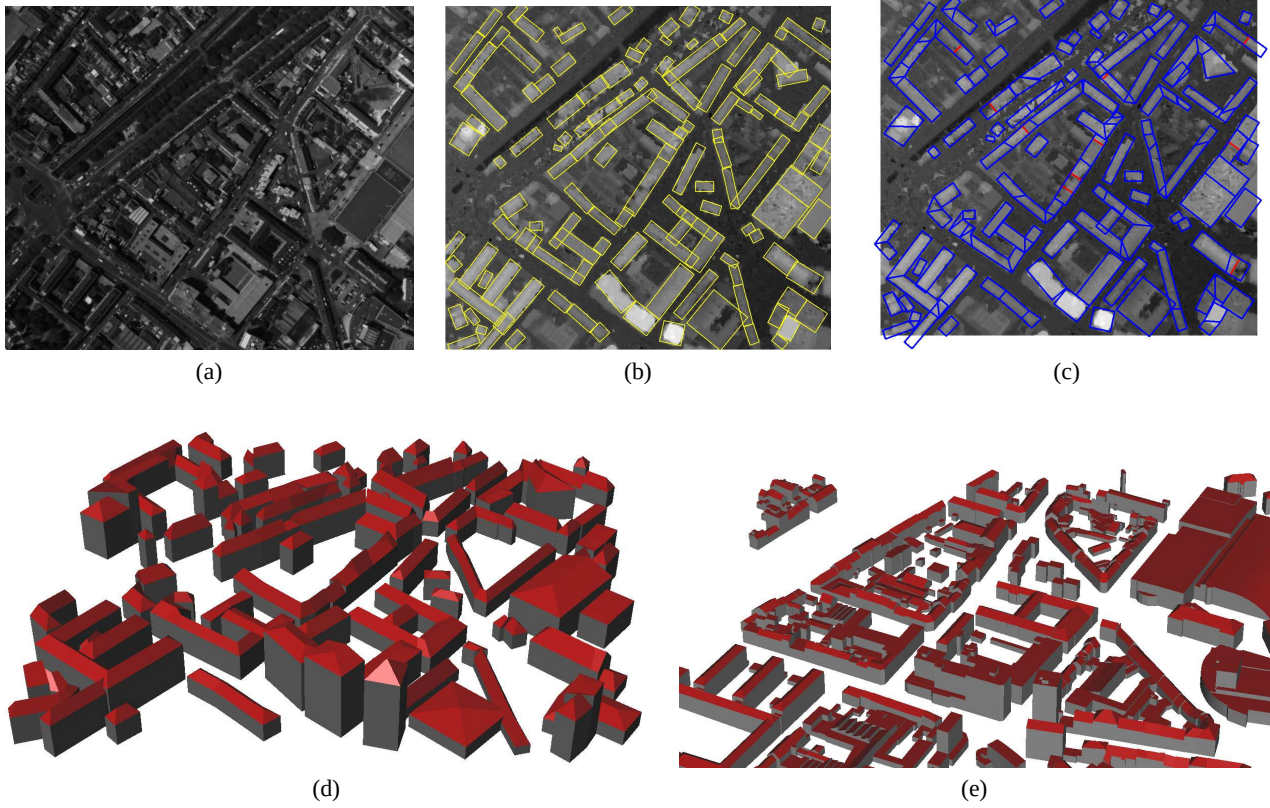


Figure 11. **(a)** : PLEIADES simulation on an Amiens area **(b)** : rectangular building footprints **(c)** : structured building footprints **(d)** : 3D-result ©INRIA/IGN/CNES **(e)** : 3D-ground truth ©IGN

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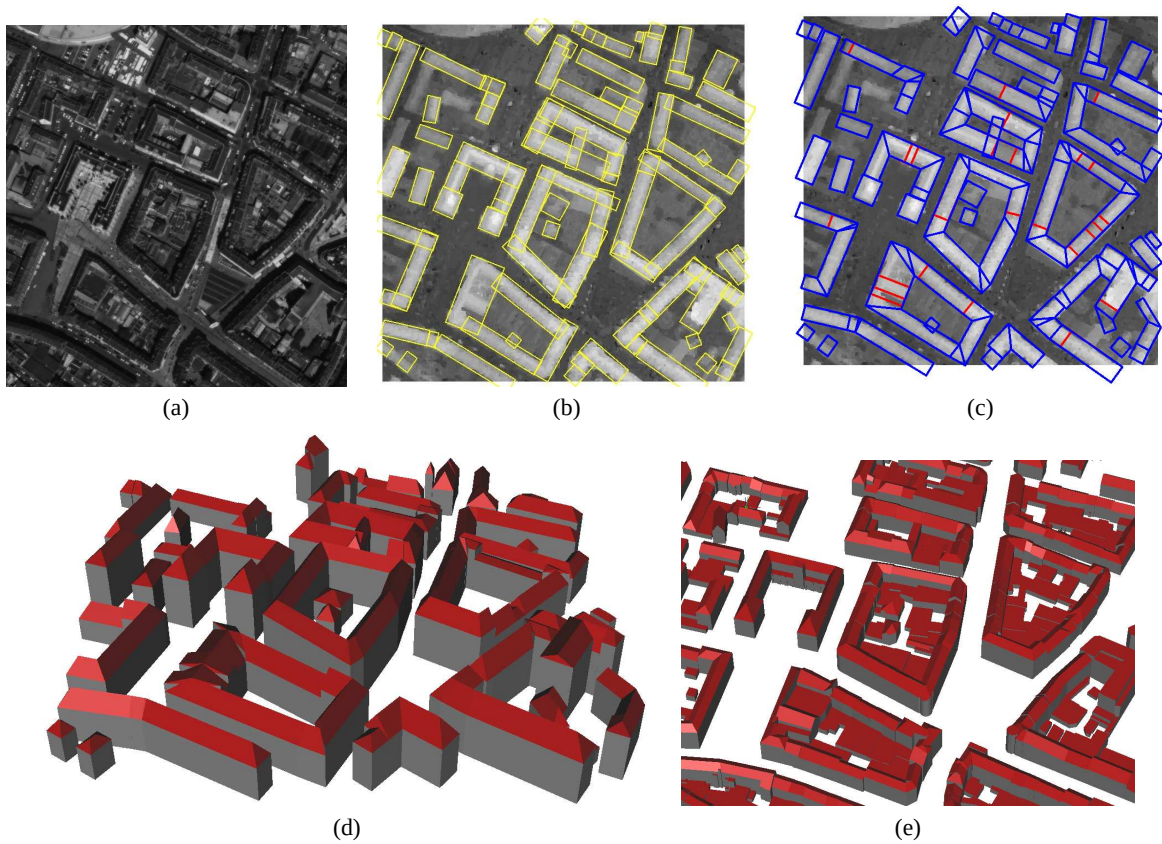


Figure 12. **(a)** : PLEIADES simulation on Amiens downtown **(b)** : rectangular building footprints **(c)** : structured building footprints **(d)** : 3D-result ©INRIA/IGN/CNES **(e)** : 3D-ground truth ©IGN

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