

## ANALYSIS OF BUILDINGS HEIGHT COMPUTED ON A DSM GENERATED FROM A VHR SATELLITE STEREOPAIR

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### ABSTRACT

At the final meeting of the SPIDER project, the users wanted to know if it was possible to evaluate the building height or the number of floors, from the DSM obtained from a VHR satellite stereopair. Combined with the 2D delineation of the buildings – for example coming from the cadastre register - this information could be useful in urban studies – e.g. population density assessment - or to generate quasi realistic 3D views.

In this example, the DSM is extracted from an IKONOS stereopair ( $DSM_{sat}$ ) on the hilly area of Liège in Belgium. It is used in combination with a 3D vector file. On the one hand, this file is used for the 2D delineation of the buildings. On the other hand, the third dimension provided by this file is also exploited for the assessment of the extracted building height. Moreover LIDAR data are also available over the test area, permitting the creation of a reference DSM ( $DSM_{ref}$ ).

\* The first step of the process consists in the determination of the ground altitude around the buildings. A procedure was setup in order to compute it and to generate the DTM for the reference and satellite data ( $DTM_{ref}$  and  $DTM_{sat}$ ).

\* The second step consists in the extraction of statistics, for every building (min, max, mean, etc.) as well from the  $DSM_{sat}$  and  $DSM_{ref}$ , as from the  $DTM_{sat}$  and  $DTM_{ref}$ .

The analysis shows that the satellite approach globally underestimates the building height of about 4 m. These results are discussed regarding building height versus the area and the heterogeneity of the roof height.

### INTRODUCTION

This paper presents some results of the SPIDER project (*Improving **S**Patial Information extraction for local and regional **D**Ecision makers using very high resolution **R**emotely sensed data*) carried out in the vicinity of the city of Liège (Belgium). The SPIDER project itself fits in the STEREO (*Support to The **E**xploitation and **R**esearch of **E**arth **O**bservation data*) programme of the Belgian Science Policy Office. At the final meeting of the SPIDER research project, some users asked for the computation - and quality assessment - of the building height from a DSM (Digital Surface Model or envelop DTM) obtained from a VHR satellite stereopair. Until now, the validation of our DSM was mainly achieved at the ground level. Three kinds of analyses can be expected from this information related to the building height: (a) the evaluation of the number of floors can improve several urban planning studies such as the computation of the population densities and, in turn, the calibration of accessibility and potential analyses (i); (b) the characteristics of the building roofs (ii) together with the building height extrusion can be used to model vertical façades in order to provide quasi realistic 3D views; (c) 3D information can also improve satellite image classifications by solving e.g. the confusion in the use of asphalt (land cover) on the roads or on a building roofs (land use) (iii).

## METHODS

### Study material

The IKONOS stereopair was acquired on the Liège test-site on the 3rd September 2004. A satellite DSM at 10 m resolution achieved by the Ghent SPIDER team is available on the whole test-site (142 km<sup>2</sup>) (iv) and recently a DSM (noted DSM<sub>sat</sub>) at 1 m resolution (v) is available on four test-zones (3.7 km<sup>2</sup>) (Figure 1). This paper deals with this high resolution DSM<sub>sat</sub>. A reference DSM (noted DSM<sub>ref</sub>) at 1 m resolution produced by our team from various data (vi,vii) is also available on the whole test-site. One can notice that DSM<sub>ref</sub> on TZ1 and TZ5 is entirely generated from LIDAR data (acquired in winter 2001 and 2002 - Figure 1). On TZ6 and TZ7, where LIDAR data are not available and where a hilly morphology is observed, the reference DMS was achieved from the PICC database.

The PICC database of the Walloon region (3D vector data at 1:1 000 scale) covers the whole test-site. These data are mainly used for the 2D building delineation (1712 buildings - see Table 1 for their distribution into the 4 test-zones). Nevertheless, 3D vector data are also useful to control the building heights. Unfortunately, in the PICC data, the elevation of the buildings is only available at the level of the building cornice.

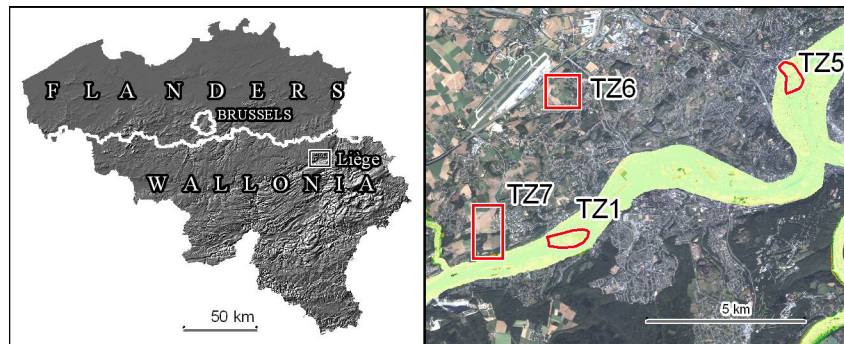


Figure 1: Location of the Liège test-site in Belgium (left) and the four test-zones in the Liège area (right). LIDAR data are available along the main river valleys (pale yellow and green colours)



Figure 2: Classification of the building heights computed in the different test-zones from reference data

TZ1 is an industrial area. The size and the height of the buildings are very heterogeneous (see Figure 2 and Table 1). New buildings are clearly seen on the eastern part of TZ1 but they are not included in the present study (PICC data are not updated). TZ1 and TZ5 are located in a flat area corresponding to the alluvial plain of the Meuse river. TZ5 covers the city centre, with very high and big buildings but also with old town houses. TZ6 and TZ7 are located in the suburban area where meadow and crop land uses are predominant. The buildings cover less than one quarter of these two test-zones located in a hilly landscape. The minimum and maximum altitudes are 104 m and 194 m respectively in TZ6, and 66 m and 205 m in TZ7.

## Procedures and methods

The buildings delineated in the PICC are used to compute statistics (1712 buildings). Alternatively, corrected cadastre data or delineation performed by visual interpretation of an orthorectified satellite image could also be used. Four parameters are extracted with the standard procedure of the ArcGIS 9.1 software: minimum, maximum, mean and standard deviation.

The DSM is used to extract the altitude of the top of the buildings. The mean value has been selected because this parameter is less sensitive to abnormal values or to a small shift in image registration. Unfortunately, the median parameter, that should likely be more efficient, is not available.

The altitude of building footprint is also needed to determine the buildings height. As no actual DTM is available, a similar procedure is used to generate satellite (<sub>sat</sub>) and reference (<sub>ref</sub>) DTM from the couple of DSM. The procedure is based on the postulate that the altitude of the building footprint corresponds to the minimum ground value observed in their close neighbourhood. Then a morphological erosion (minimum) is performed on the two DSM within a (7 x 7) pixels moving window (noted DSM\_m7\*7), in order to select the minimum altitude value located in the 3 m buffer around every building. This process leads to the generation of two images: respectively the altitude of the buildings foot <sub>ref</sub> and <sub>sat</sub>. Finally, the building height <sub>ref</sub> and <sub>sat</sub> for every polygonal feature are simply computed by the following formula:

$$\text{Building\_height\_ref} = \text{Mean\_DSM\_ref} - \text{Min\_DSM\_m7*7\_ref} \quad (1)$$

$$\text{Building\_height\_sat} = \text{Mean\_DSM\_sat} - \text{Min\_DSM\_m7*7\_sat} \quad (2)$$

The difference between these two height values can be considered as an indication of the error of the satellite extraction process:

$$\text{Error} = \text{Building\_height\_sat} - \text{Building\_height\_ref} \quad (3) = (2) - (1)$$

## RESULTS

The table 1 shows a root mean square error of 6.37m (accuracy). The building height extracted from the satellite source has a mean underestimation of 4.07m while the standard deviation of the error is 4.90 m (precision). It must be quoted that the underestimation is also observed for every test-zone taken individually. The industrial zone TZ1 presents a low RMSE of 3.54 m and nearly no systematic underestimation of the buildings height (0.15m). This is certainly due to the large average footprint of the buildings in this area (more than 9 426 m<sup>2</sup>) and also maybe to the "box" shape of this kind of buildings. The old centre of the city, TZ5, is also validated by LIDAR and presents quite poor values: a RMSE of 8.15 m and a mean underestimation of 5.36 m. A more accurate analysis shows that the worst values are observed close to the areas where occlusion is observed for the stereopair (viii). This is particularly the case in the neighbourhood of the "Kennedy" building (highest building of Liège). Finally, the two suburban test-zones validated by the PICC data present very similar results. The RMSE value varies from 3.28 to 3.50m, while the heights are underestimated of 2.75 m in average, and the low standard deviation of the error varies from 1.74 to 2.02m. The small houses constitute the main type of buildings in these test-zones.

Table 1: Statistics calculated in the different test-zones

Test-Zone	All	TZ1 & TZ5	TZ1	TZ5	TZ6 & TZ7	TZ6	TZ7
Reference	LIDAR & PICC(*)	LIDAR	LIDAR	LIDAR	PICC(*)	PICC(*)	PICC(*)
Total Buildings Area (ha)	37.86	30.81	14.53	16.28	7.06	3.93	3.13
Mean Building Area (m <sup>2</sup> )	221	82	3 632	180	92	84	105
St. Dev. Building Area (m <sup>2</sup> )	1 570	2 104	9 426	437	124	132	110
Number of Buildings	1712	945	40	905	767	469	298
Standard Deviation of the Error (m)	4.90	6.14	3.58	6.14	2.02	2.02	1.74
Mean Error (m)	-4.07	-5.14	-0.15	-5.36	-2.76	-2.74	-2.79
RMSE (m)	6.37	8.01	3.54	8.15	3.41	3.50	3.28

(\*) 3D vector database - Building height taken at the cornice level

The figure 3 shows the spatial distribution of the errors (unsigned or absolute values of the errors are used). Few buildings have an error greater than 9 m in TZ 6 & 7. This is also the case inside TZ1 (industrial) with the exception of two buildings. The old city centre presents another situation, as errors greater than 15 m are quite numerous. But the figure 1 shows also that most of these buildings are higher than 30 m. It appears that the error increases slightly with the height of the buildings. The figure 4 takes this fact into account by using relative units: the errors are given in percentage of the reference building height. Two buildings located in the south-eastern part of TZ5 are affected by a relative error of more than 150 % due to various artefacts: error in the LIDAR reference data, occlusion area and amalgamation in one polygon of buildings of very different heights (from 77 to 151 m).

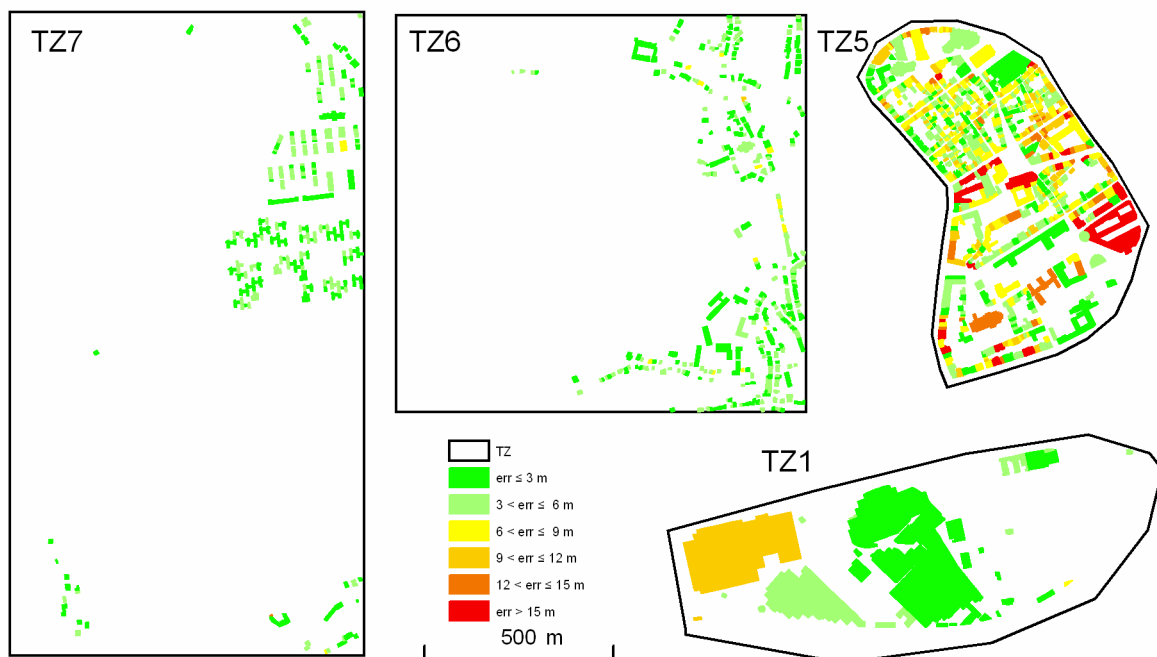


Figure 3: Spatial distribution of the unsigned error for the 4 test-zones

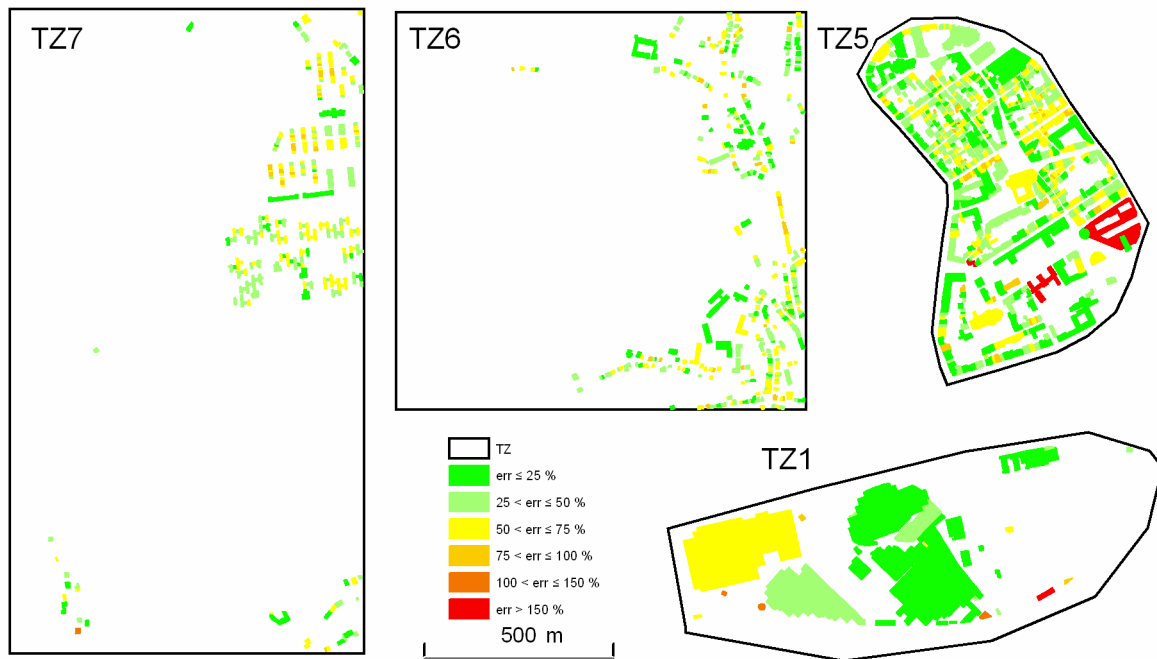


Figure 4: Spatial distribution of the unsigned error given in relative number (% of height<sub>ref</sub>)

It can be seen in Table 2 that more than 50 % of the building areas present a relative error lower than 50 %.

Table 2: Proportion of the building areas in the different test-zones vs. the relative error (between brackets: the number of buildings)

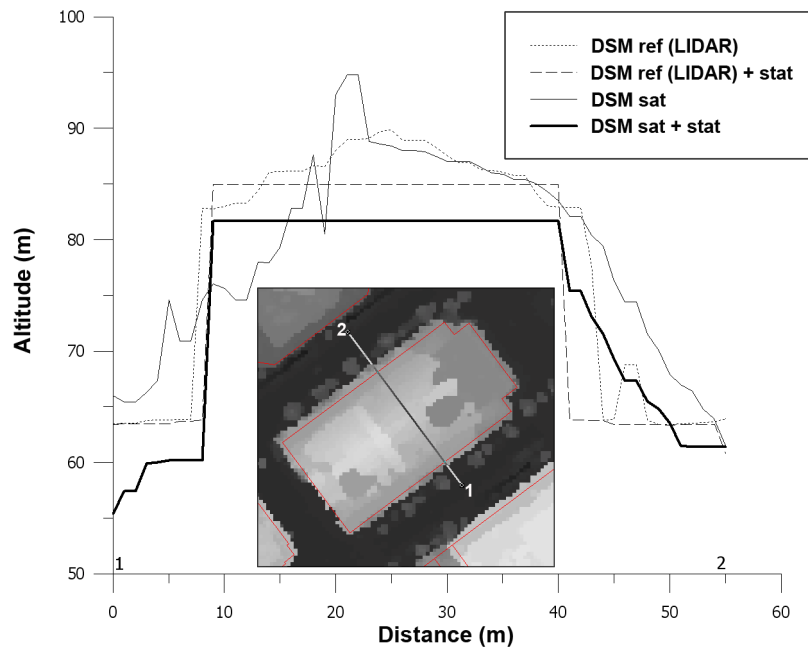
Relative error	Test-zone			
	TZ1	TZ5	TZ6	TZ7
≤ 25 %	51 % (22)	38 % (240)	36 % (111)	23 % (41)
25 < err. ≤ 50 %	19 % (7)	32 % (334)	32 % (167)	37 % (101)
50 < err. ≤ 75 %	29 % (4)	21 % (278)	27 % (149)	34 % (128)
75 < err. ≤ 100 %	0 % (2)	3 % (47)	5 % (42)	5 % (26)
100 < err. ≤ 150 %	0 % (3)	0 (1)	-	0 % (1)
Err > 150 %	1 % (2)	6 % (5)	-	0 % (1)

The usefulness of such figures can only be assessed by professional users involved in city planning. In this connexion, a comparison between the population densities based on these figures, and the figures provided by census data, is expected in the next future.

Besides four kinds of 3D views have been generated: from LIDAR and from satellite images, and with and without the extrusion technique (application of the computed mean height to the building footprint). The comparison of the results is illustrated on a profile realized across the “Opera” building (Figure 5) located in the northern part of TZ5 and appearing in the centre of the four 3D views (Figure 6). The profile based on the LIDAR data (dot line) keeps the verticality of the side walls of the building and shows its double and symmetric sloping roof. When the extrusion technique is applied on the LIDAR data (dashed line), the sloping roof is replaced by a flat roof at the average height of the building. The profile based on the satellite DSM (DSM<sub>sat</sub>) is very chaotic (thin line): the



side walls are not vertical and only one slope of the roof is obvious. The extrusion method applied to the satellite DSM provides a slightly improved profile (thick line): the verticality of the side walls is partially rectified but a flat roof is superimposed. It is clear that the extrusion process generalises the building shapes but this rough estimate of the building gauges is generally accepted by the users. However the roof shape is lost in this process and, from this point of view, the satellite source cannot compete with the LIDAR data, but for flat roof buildings (most part of modern skyscrapers).



*Figure 5: Profile across the “Opera” building on LIDAR and satellite DSM, with and without the “extrusion” process of the building height*

The orthorectified QuickBird image of Liège (acquired on the 26th September 2003) is draped on the four DSMs. The “Opera” building used for the profile analysis in the figure 5, is located in the first plane of the figure 6 (whitish building). The 3D view based on  $DSM_{sat}$  is really poor (upper right image) compared to the 3D view generated from the LIDAR data ( $DSM_{ref}$  – upper left). When the extrusion process is applied, the 3D views based on LIDAR and satellite data are more similar (bottom left and right). It is worth noting that, despite the levelling of the roofs, the generalisation resulting from the extrusion process enhances the plausibility of the 3D views thanks to the preserved verticality of the walls and the widening of the road footprints.



Figure 6: 3D views based on various DSM (LIDAR on the left and Satellite on the right) and on the extrusion process (below)

## CONCLUSIONS

In the old centre of the town, the building height derived from a satellite DSM can be useful for urban applications that can put up with a weak accuracy (about 2 floors in this experiment). Some improvement can certainly be achieved notably in the occlusion areas. Moreover, in this application, some limitations are caused by the vector file providing the building footprint: the buildings must be located on the street-front (buildings located inside blocks are not identified) and they are assimilated to polygons which can gather several components of various sizes and shapes. The cadastre survey could be an interesting alternative source provided that it is precisely georeferenced (it is presently not the case on the test-site selected for this application).

3D views generated from satellite DSM and generalised by building extrusion seem to be promising but further investigations are required to extract information dealing with the building shape characterisation. In the present state of the art, it can be expected that several applications concerned by the spatial disaggregation of socioeconomic data could already take advantage of the 3D information obtained from VHR satellite imagery.

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