QUANTITATIVE MODELLING OF URBAN CHANGES USING MULTI-TEMPORAL DIGITAL ELEVATION MODELS

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ABSTRACT

The construction of multi-temporal data sets for the modelling and documentation of urban environments has gained a large interest in the last few years. The growing availability of remote sensing data and sophisticated software tools has enabled the construction of Digital Elevation Models (DEMs) with various spatial and temporal resolutions. For this research, multiple scanned airborne images of the inner city of Ghent (Belgium) were processed for the calculation of DEMs using a conventional digital photogrammetric workflow. The aerial images were acquired during four campaigns: 1965, 1977, 1987 and 1990. All resulting image-based DEMs were compared with a DEM acquired with Airborne Laser Scanning (ALS) from 2009. This comparison allowed a model adjustment by minimizing the systematic shift between the data sets. In order to distinct built-up, destroyed or unchanged buildings over time, a threshold of 2.5 m was applied on the resulting vertically shifted points. Finally, a connected component analysis allowed the removal of outliers in the data. The resulting points were evaluated against a 2D digital cadastre map, which enabled a quantitative determination of difference in urban topography. The procedure to detect these changes, as well as the potentials and challenges of this technique, are discussed in this contribution.

INTRODUCTION

Sustainable environmental planning requires monitoring tools to document the dynamics of the environment. These monitoring tools are used for various applications, like the enforcement of building regulations, disaster mapping or research on urban sprawl. In many cases, the algorithms behind these monitoring tools are based on the detection of significant changes of elevations in a DEM (1). Airborne photographs, spaceborne imagery or ALS data are well known data sources for the construction of these DEMs and these techniques are intensively discussed in literature (2). Especially the detection of built, destroyed or unchanged buildings or building blocks is an active research topic. However, for densely built-up urban areas, the construction of DEMs using remote sensing techniques remains a challenging task. This is mainly due to the large diversity and high density of urban features. Therefore, additional spatial data is required. For example, digital topographic charts can be used for the semantic classification of pixels (3) or 2D building maps can be used for improving the geometry of the buildings in the study area (4). In these two cases, high resolution satellite imagery, like IKONOS, QuickBird or GeoEye, are used to construct these DEMs.

For the construction of multi-temporal DEMs, the biggest drawback of using high resolution satellite imagery is the only recent availability of these data sets, starting around 2000. The same issue holds for ALS-based point clouds, which are systematically acquired for about a decade now. However, the biggest advantage of ALS is the high point density and accuracy of these point clouds. Since most monitoring tools require the definition of certain thresholds, these parameters are essential for successful change detection. In this context, thresholds can be related to the minimal elevation or the minimal size of the features to be detected. As a result, ALS-based point clouds are very suitable as a reference for urban change detection, as demonstrated in (2) and (4).

In this contribution, a procedure for the detection of changes in an urban environment is discussed. The workflow is based on the photogrammetric processing of scanned airborne imagery. Airborne

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imagery has been systematically acquired for a century and represents a valuable snapshot of the past. The ability to use old airborne imagery for urban change modelling is demonstrated for the city of Ghent (Belgium). Image-based multi-temporal point clouds are calculated and compared with ALS data. The large availability of historical spatial data creates a unique opportunity to evaluate the change detector for different periods of time. The presented detector operates on a building-level by the evaluation of the point clouds with 2D cadastre data. The results of this study confirm the large potential of airborne imagery for the quantitative modelling of urban dynamics.

AVAILABLE DATA AND STUDY AREA

The proposed change detection methodology is implemented for a test site in the city of Ghent (Belgium). This area still contains a complex mixture of residential, commercial and industrial buildings, notwithstanding important changes of the urban topography in this area over the last 50 years. Different airborne images, a very dense ALS point cloud and 2D cadastre data are available for this area.

A recent ALS data set, which was acquired in July 2009, is used as a reference data set. Some metadata of this point cloud can be found in (5), but it is important to mention that it has an average point density of over 100 points per m^2 and centimetre accuracy. The used 2D cadastre data is a sample of the Flemish reference cartography (GRB, 'Grootschalig ReferentieBestand') from 2011. This data set is acquired by the topographic measurement of all buildings, infrastructure, street furniture, … in the Flemish Region and used as a reference for the indication of buildings. The four stereo couples, dating from 1965, 1977, 1987 and 1990, were scanned using a photogrammetric scanner with a geometrical accuracy of 2 µm or better. Furthermore, camera calibration files were available describing the camera and lens characteristics. Based on the average image scale (1965: 1/28,500; the other sets: 1:21,000), the number of pixels (between 13,000 and 14,000) and the focal length of approximately 153 mm, a resolution of 0.35 m to 0.45 m can be estimated for the scanned images. Besides, 25 Ground Control Points (GCPs) were measured using a Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS). The FLEmish POsitioning System (FLEPOS) was used for these measurements, resulting in typical accuracies of 2 to 3 cm. During the photogrammetric image processing, it was decided to limit human intervention to the selection of fiducial marks and GCPs, but no manual model editing was performed to improve the quality of the model. By this decision, the quality independence between the models was optimized and the required processing time was limited. Conversely, an Iterative Closest Point (ICP) matching between the image-based point clouds and the ALS data was performed to minimize the systematic shift between these data. The remaining deviations between these data sets are used to facilitate the actual change detection.

METHODOLOGY

A workflow of the proposed change detection methodology is presented in Figure 1. The procedure starts with the photogrammetric processing of the different scanned stereo couples [I]. The *Leica Photogrammetric Suite* (*LPS*) and its *enhanced Automatic Terrain Extractor* are used to calculate a point cloud and an ortho-image for each stereo couple. These point clouds are compared with an ALS-based point cloud, which is used as a reference. Points from this ALS-based point cloud need to be classified first [II]. In this case *LASTools* was used to extract ground points and roof points from this point cloud. Points belonging to another class, like vegetation or façades, are not used during the rest of the procedure.

For the following steps, the open-source point processing software *CloudCompare* is used. Since no further manual adjustment of the image based data is performed, these points are adjusted using an ICP matching [III]. The ground points and roof points from the ALS data are used for this adjustment. Furthermore, these reference points are triangulated for the construction of a Triangular Irregular Network (TIN) [IV]. Point-to-mesh distances are calculated for each image-based point in relation with this TIN [V]. These distances are evaluated to determine whether or not a point belongs to a changed feature [VI]. Two thresholds of 2.5 m (point above TIN) and -2.5 m (point below TIN) are used for this evaluation. These thresholds correspond respectively with the destruction or erection of a one-floor construction, regardless the size in planimetry. The resulting image-based points corresponding with significant changes have to be evaluated in terms of outliers or isolated points. Hence, a cluster analysis is performed to eliminate these points and to detect compact groups of points. An octree-based connected component analysis is used to extract these spatially associated points [VII], with a threshold of 25 points per cluster. This value resulted in visually acceptable clusters.

The final step of the procedure is a point in polygon analysis using *ESRI ArcGIS* [VIII]. The 2D cadastre data are used for this step, where the number of points inside a polygon is counted. In order to allow a comparison between different building polygons, the cardinality is normalized by the size of each polygon. In correspondence with (5), a minimal area threshold of 25 m² is considered for detectable built or destroyed features. When taking into account that every built or destroyed building of 25 m² or larger has to contain at least one point, a point density of 0.04 points per m² is needed to visualise all changed features.

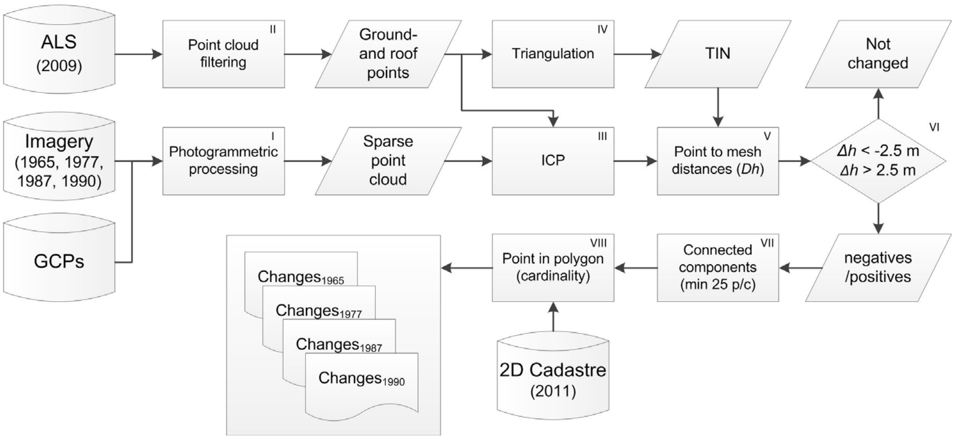

Figure 1: Workflow of the quantitative change detection procedure.

RESULTS

The reduction of the shift between the image-based point clouds and the ALS data after the ICP adjustment is represented by a significant decrease of the mean differences of the elevations. The mean difference before the ICP (ranging from -1.94 m to -0.33 m) can be considered as an indicator of the accuracy of the original image-based models and thus the systematic error of the models. Sub-decimetre differences were gained after the ICP (ranging from -0.04 m to 0.07 m). However, the calculated standard deviations per year (ranging from 4.89 m to 2.79 m before and after ICP) indicate no significant differences. These values incorporate the random errors, errors caused by the different spatial resolution of the data sets and the urban changes in the area.

For each sequence, an ortho-image and the detected changes at building level are presented in Figure 2. In this figure, many changes that visually appear in the different ortho-images are also correctly indicated by blue (destroyed) or red (built) polygons. Notwithstanding the positive results, some profound considerations must be given:

- In order to perform a visual validation of the results, the time difference between the acquisition of the reference data must be limited. The building complex in Figure 3 (A) was measured with ALS during construction. However, it is not yet incorporated in the cadastre data, resulting in a blind period in time. The opposite occurs when buildings are destroyed between incorporation of the feature in the 2D data set and the ALS campaign (Figure 3 (B)). These problems could be solved by using cadastral data from the exactly the same moment as the acquisition of the ALS data;
- A nice example of a recently built large building block which is correctly detected in all four sequences is presented in Figure 3 (C-1). However, an apartment block opposite of this building is also constructed after the ALS campaign and the cadastre measurement (Figure 3 (C-2). Based on Figure 2, this is a situation where most of the previous buildings are rebuild with more or less the same dimensions;

- Figure 3 (D, 1990) illustrates the influence of remaining erroneous points caused by occlusions. This issue can be solved by multiscopic image processing, occlusion filtering or manual model modification. This issue can be solved by using more complex edge detection procedures.

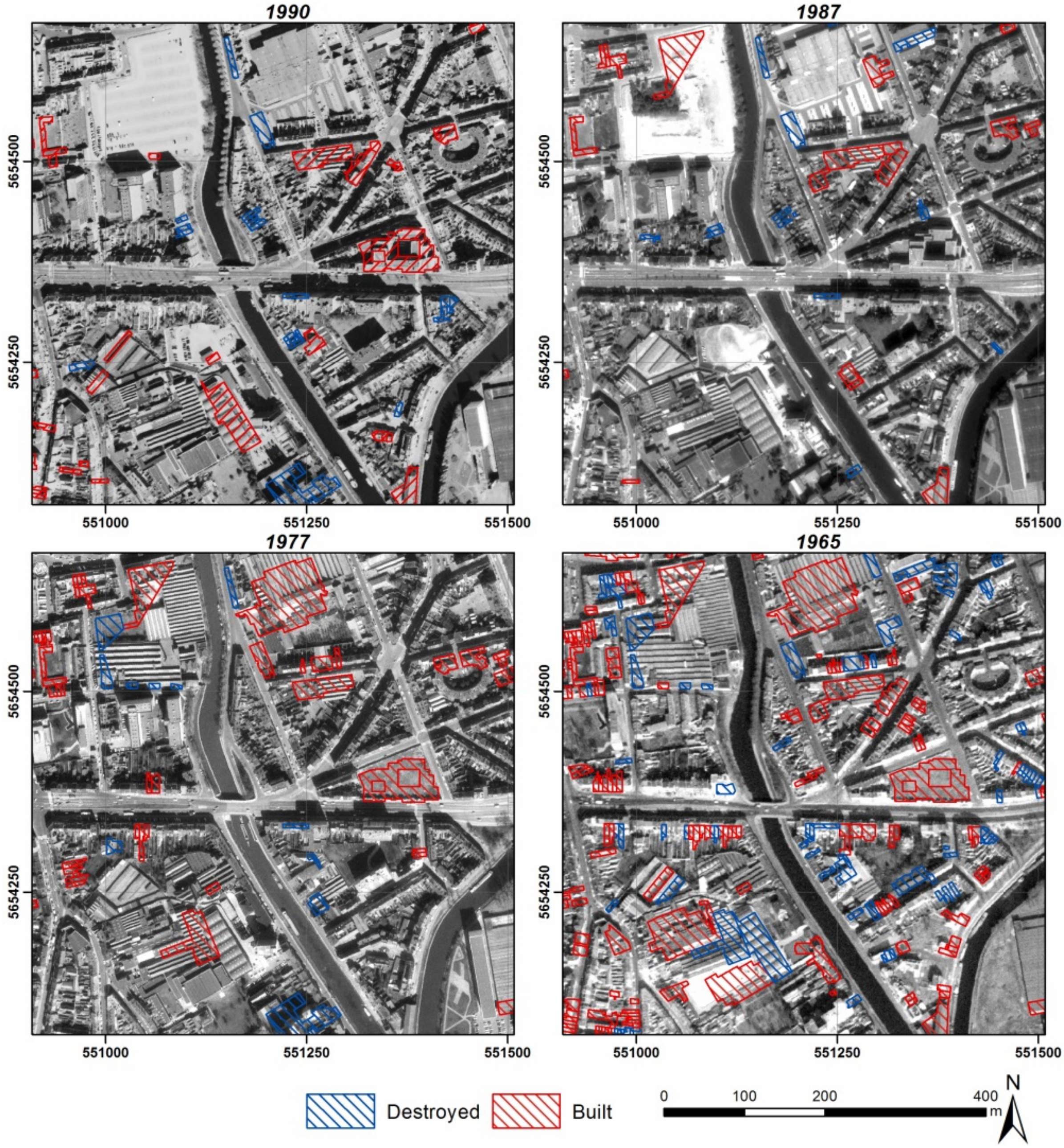

Figure 2: Built and destroyed structures after 1990, 1987, 1977 and 1965, based comparisons with ALS data and 2D cadastre data.

CONCLUSION

In this contribution, the potential of classic airborne imagery for urban change detection was demonstrated. Four stereo couples and an ALS data set, covering a time frame of almost five decennia, are processed and compared. The combination of the resulting point clouds with recent 2D cadastre data enables the quantitative evaluation of urban dynamics at building level. By evaluating the results, the importance of a limited time frame for the acquisition of the reference data must be emphasized, since urban changes occurring between the acquisition of the ALS data and the cadastre data cause blind periods in the comparison. The construction of building polygons from the reference data using some building detection algorithms should overcome this difficulty. In that case, the cadastre data is not required, but the link to a legally acceptable data set would be doubtful and the use of the technique for regulation enforcement limited. Anyhow, the results indicate the large potential of multi-temporal airborne imagery for change detection. Even if the technique is only used for research purposes in areas where the availability of (historical, cadastral) spatial data sets is limited, this approach provides interesting perspective for the documentation of urban sprawl or change detection after disasters, making the technique very useful for urban planners in decision making processes.

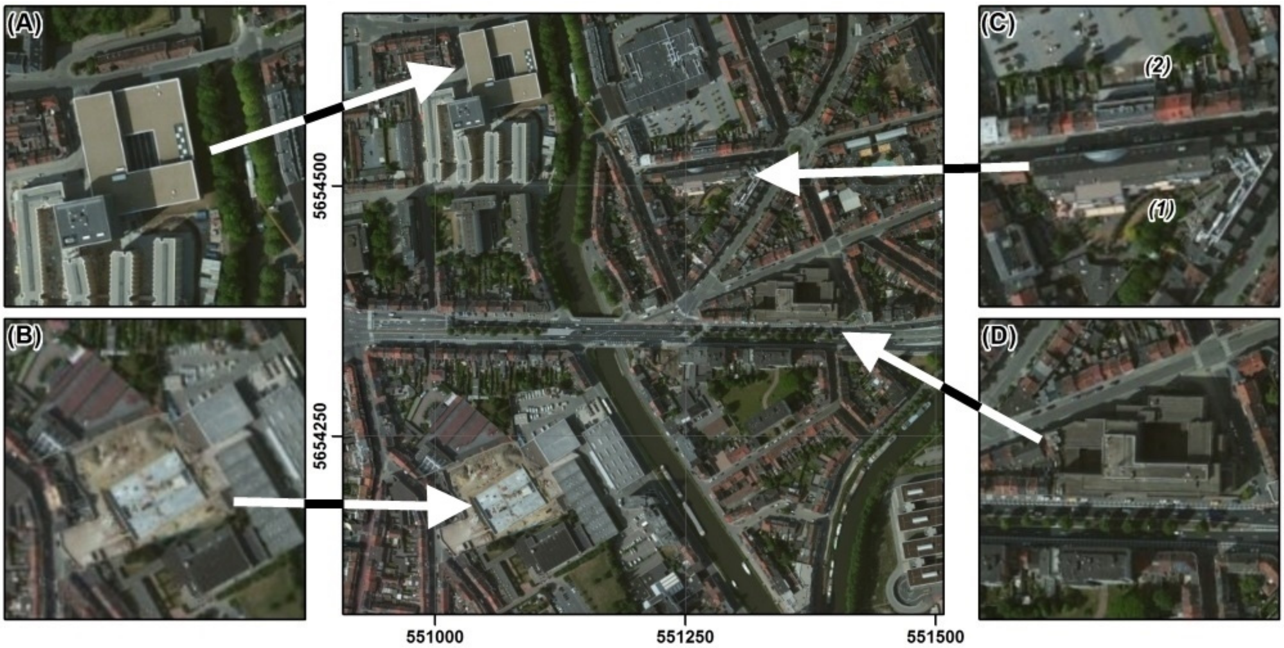

Figure 3: Current situation with features that require special interest (source: AGIV, 2010).

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