Challenges for Updating 3D Cadastral Objects using LiDAR and Image-based Point Clouds

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SUMMARY

Nowadays due to the increasing complex and multifunctional building environment in the urban areas it is required an accurate geometry and proper legal registration of the cadastral objects including third dimension and time aspect. 2D land-parcel data seems insufficient to address the variety of problems in high density residential areas. This fact motivates scientists worldwide to work on 3D Cadastral Data models for representation of 3D legal and physical information. Third dimension is important in cases of space subdivision with different owners and used for various purposes which requires its accurate registration. However, it is of great importance to maintain the 3D information up to date. With the rapid development in the fields of photogrammetry, laser scanning and computer vision high accurate 3D data can be obtained. However, numerous challenges appear while processing, storing, transferring and visualizing. Currently, efficient management of "big data" is widely discussed. In this respect developed algorithms in support of automatization of data processing, segmentation and visualization can be very helpful. Current paper focuses on usage of photogrammetric data for updating 3D information. More specifically, we investigate the opportunities for updating 3D cadastral objects using precise multi epoch airborne laser scanning 3D data, point clouds derived from high resolution imagery from dense matching algorithms and maps used to provide semantic information about the land cover class and 2D special information of the boundary of the cadastral objects. In the paper we describe the type and size of uncertainties when updating 3D cadastral models. This includes the uncertainty of the initial model, caused by inaccuracies in the measurements when building the initial models. Next, a careful registration with the newly acquired dataset is necessary in order to better describe changes of objects, instead of changes in datasets. The benefits of the fourth dimension in cadastral information systems are also discussed in the paper. Different methods for detecting changes in time using airborne laser scanning (ALS) data have been used for various application such as map updating (Vosselman, et al, 2004), evaluation of damages as a result from a physical disasters (Murakami et al, 1999) etc. Usually change detection is done by segmentation, classification or implementation of specific mapping rules. In our paper we focus on detecting changes while comparing ALS dataset from different epochs and between point clouds obtained from ALS and high resolution images for same territory. We also discuss the difficulties in detecting changes for different types of 3D cadastral objects. The analysis is done for a common dataset located in Netherlands. In conclusion the opportunities of using high accurate point cloud data for keeping up to date 3D cadastral systems are presented and the challenges and problems are shown.

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1. INTRODUCTION

Over the past few years due to the increasing complexity in the urban areas nowadays, with constructions on top of each other or under the ground, it is required an accurate geometry and proper land registration (Aien, A., 2013). Current cadastral systems are still two-dimensional with some exceptions where hybrid solution for inserting in the 2D cadaster a single 3D situation has been adopted. The mostly used concept of 2D land parcel data is limited in this respect and is insufficient to address the variety of problems in the high residential areas. Therefore third and even fourth dimension was considered from researches as needed to be included for accurate and effective registration of 3D land volumetric parcels, above and below the ground considering their rights, restrictions and responsibilities (RRR) for land valuation, representation and documentation.

Parcels in cadastre can be described by 2D, 3D geometrical information but also even textual. The objects can be legal and virtual (not visible in reality). However, sometimes boundary of the parcels coincide with the real physical objects. In 3D situation the complexity is even more, because each individual geometric physical object such as building, construction, tunnel and in more details apartments even rooms have attached unique RRR.

The physical 3D objects in a complex urban environment are hardly to be represented as a cadastral objects on the current maps. Therefore as 3D cadastral objects are considered situations like (1) apartments (with mixes usage such as residential, trade, administrative), (2) physical objects and subterranean constructions such as underground parking spaces, tunnels, pipes and cables, and (3) constructions on top of each other. Third dimension in a complex urban situation for the 3D cadastral objects should be maintained and developed into 3D spaces (LADM, 2012). For this reason the accurate geometric construction and maintenance in DBMS environment is needed. This will provide an opportunity for special analysis and can be accepted by legal authorities. There are countries that aligned their databases with LADM such as Croatia an Czech Republic but still additional work is needed for a complete registration.

The concept of 3D cadaster emerged from 2000 and a lot of efforts and developments have been done recently, however there is no fully functioning 3D cadaster implemented in the world (Stoter et al, 2002; van Oosterom et al, 2011). The main reason for that is the need of efficient integration between legal, institutional and institutional organizations. However, still efforts are spent for clarification of the real scope and structure that 3D cadastres should have. In many countries infrastructure and utility network are not considered as part of the land administration and as cadastral objects with an unique identifier (van Oosterom et al, 2014).

With the nowadays 3D data acquisition methods and developments in technology, accurate representation of land use and cadastral objects (physical and legal) with defined geometrical and topological rules can be a reality for the purposes of 3D cadastres. However, the relationship between people and land is very complex and dynamic process which motivated us to think of the importance of fourth dimension-time (Jing, Bennett and Zevenbergen, 2013). Currently time component is considered in many cadastral registrations assigning it to the 2D data for keeping the registration of rights, restrictions and responsibilities. Therefore 3D cadastre should contain all temporal information of any changes in space (physical and legal) and transactions. In order to have up-to-date information the time component should be considered as beneficial not only for processing the data but also for its usage, for monitoring the development of the cities and villages over time, statistic of the changes of the land use and land cover, planning purposes and historical archiving. Challenge in this case is that in most countries the registration of 3D boundaries and the responsibly of its correctness is done by the local land registries.

Cadastres should be able to reflect the current status of land tenure with an up to date information because as mentioned people and land management are dynamic. Usually conventional methods are time consuming and labor intensive (Zevenbergen et al, 2011). Maintaining up-to-date information is one of the most challenging tasks for the current cadastres and will remain such in 3D cadastres. Therefore automatic processes for regular update of the cadastral information are in high demand which motivated the current research.

As a main form of obtaining 3D data for 3D cadastres is considered an accurate coordinated ground survey. However with the rapid development in the fields of photogrammetry, laser scanning and computer vision, accurate, fast and up-to-date 3D data can be obtained and used for various applications. LiDAR technology and the very high resolution digital aerial images are considered recently as reliable source for obtaining precise 3D information. However, numerous challenges appear while processing, storing, transferring and visualizing the data obtained from such technologies. Currently there is huge research on discussing efficient management of "big data". Obtaining millions and billions of points as a result from laser scanning technology is provoking the question for efficient processing, presenting and management of such a big amount of data (Martinez-Rubi et al, 2015).

Using airborne laser scanning (ALS) data different methods for detecting changes in time have been tested for various application such as map updating (Vosselman et al, 2004), evaluation of damages as a result from a physical disasters (Murakami et al, 1999) etc. Usually change detection is done by segmentation, classification or implementation of specific mapping rules. In our paper we focus on challenges that we encountered while comparing ALS dataset from different epochs and between point clouds obtained from ALS and high resolution images for the same territory. It is important to have an overview of the problems and issues that can be faced before using such data for updating procedures.

The remainder of the current paper is organized as follows. Section 2 describes the relevant work in the field. In section 3 the used data is described and in section 4 we analyze the challenges of using point cloud data obtained from different sources. Finally the paper is concluded in Section 5 with the main findings as a result of the research.

2. RELATED WORK

Change detection can be achieved by applying various techniques, often depending on the availability of useful datasets. A dataset is useful if it fulfills requirements such as appropriate dates of acquisition and levels of detail. Nowadays many organizations have access to a second or third generation of detailed height models captured by laser scanning and/or image based matching techniques. Researchers using multi-epoch point clouds emphasize the advantage of being able to compare 3D geometry differences (changes) without the need to deal with differences in brightness and shadows. Xu et al (2015) first classified the point clouds to better interpret the 3D differences, resulting in a change detection procedure for objects such as dormers and roof extensions. Choi et al (2009) not only output the changed areas but also the category of transition from class A to class B, by looking at the changes of properties of surface patches. Learning these transitions is helpful to get probabilities of a certain object change from one class to another.

The quality of point clouds from image matching has been improved over the past years, driven by the push forward from dense image matching, first published by Hirschmuller (2008). Since then, these kind of point clouds are used more and more as an alternative to laser scanning points (White et al, 2015), although many still consider them as complementary (Gerke, 2009, Remondino et al, 2014).

3. USED DATA

Current paper focuses on usage of photogrammetric data for updating 3D information. More specifically, we investigate the opportunities for updating 3D cadastral objects using precise multi epoch airborne laser scanning 3D data, point clouds derived from high resolution imagery from dense matching algorithms and maps used to provide semantic information about the land cover class and 2D special information of the boundary of the cadastral objects.

For the purpose of the research, two epochs of data of Rotterdam, The Netherlands, were provided from the Municipality of Rotterdam. They were obtained in 2008 and 2010 and the coverage is 120 km^2. The average point densities are 20-30 points/m^2 for 2008 and 30-40 points/m^2 for 2010. The study area is relatively flat with slight variation in relief (see Figure1).

Data was pre-processed which included organization and filtering (separation between terrain points and non-terrain ones). The datasets were registered to meet the requirements for change detection.

Figure 1. Study area – Rotterdam. Source: (Xu, 2015)

4. CHALLENGES WHILE COMPARING POINT CLOUD DATA

Changes in urban areas can be due to different reasons. Sometimes they are caused by natural disasters, but more often they are as a result of various human activities which can be permanent or temporary as explained by Xiao et al (2013). For keeping up to date information for 3D cadastres it is important to detect the structural geometric changes of urban objects such as buildings and it is preferable if possible to use automatic methods. For this reason analysis of the geometric differences between point cloud data from different epochs can provide us useful information. The methods used for change detection using point clouds are based in searching the missing points in between the epochs. When comparing datasets sometimes differences can be observed due to occlusions on specific parts, absorption of the ALS pulses, outliers etc. The difficulties are connected with clarification if the changes are real ones or due to reasons such as differences in scanning geometry, lack of data, surface characteristics etc. Considering buildings as cadastral objects, changes can be caused also from sun shades, flags, stairs or vegetation. A challenge is to detect which are the real changed connected with building constructions. Usually detection of the changes is done only visually which requires experience and is quite time consuming. For our study we used the algorithm for automatic change detection described in Xu et al (2015). The output is a difference map which contains the geometric indication of an existing change.

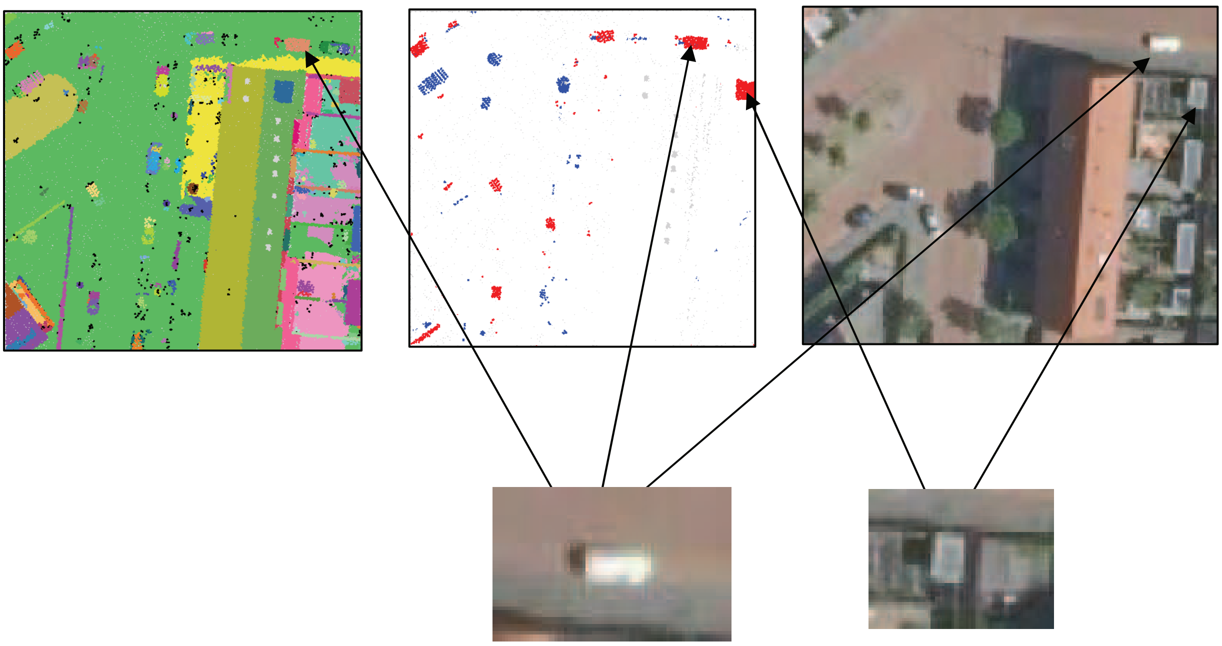
In the following sub-sections some of the observed challenges are described to emphasize the need for further research on detecting changes on cadastral objects if using such methods. The first group of challenges relates to situations where there is a difference between point clouds from two epochs, but not necessarily caused by a change of interest.

4.1 3D geometric differences vs changes

While investigating differences dynamic objects such as traffic, trees, flags, sun screens, trash bins, garden furniture, scaffoldings, open doors and windows, water level changes etc. where detected. The main problem with these objects is that these are at edge of being detectable or not. Many researchers (Choi et al, 2009; Xu et al 2013) use a minimum size of object to be of interest to stay away from details like garden furniture, but it is clear that objects trucks and scaffoldings are in the same range as the changes of interest to buildings.

4.1.1 Dynamic objects and real changes

On Figure 1 (a) the green color represents points that appear after the segmentation between the two epochs of the ALS data from 2008 and 2010. The white color on Figure 1 (b) indicates that there are no differences between the epochs. The red color on the same figure show the points from epoch 2 where there are no points in epoch 1. On Figure 1 (c) for comparison and clarification it is shown the same location from the national open data PDOK[1].



(a) (b) (c)

Figure 2. Detected changes while overlaying ALS point clouds from epoch1 and epoch 2

From Figure 2 it is clear that different changes were detected. However, the car is a dynamic object and the new construction-shed is the one that is of interest. The challenge is to distinguish between the detected changes and to find the objects that are relevant.

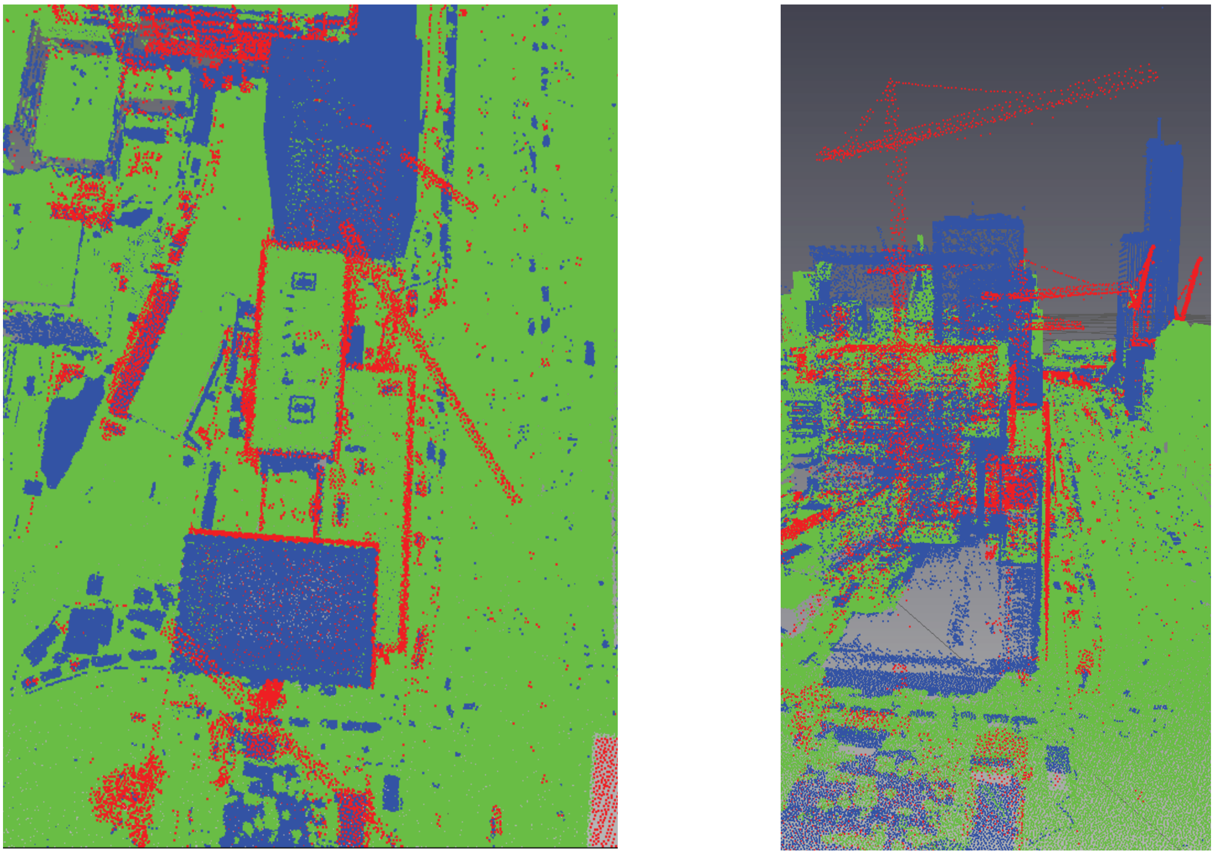
[1] https://www.pdok.nl/

4.1.2 Transition period between old and new situation

Many cadastral databases have a certain fixed update rate, e.g. 1, 2 or 5 years. As a consequence data acquisition projects are also conducted with the same or at a higher frequency. Especially for the larger projects, it is likely that the transition period is more than 1 or 2 years, meaning that a detected change is not a permanent one.

Using the same ALS dataset the detected changes are viewed on Figure 3 from different perspectives - (a) orthogonal and (b) frontal. The green color in this case represents the areas without change. Red and blue colors are respectively the differences between the two epochs.

The blue points are the new buildings. As seen on the figure, a scaffolding and cranes are clues that the objects are changing, but the definitive shape and boundary of the object cannot be determined yet. This information can be considered as a sign for an expected future change.



(a) (b)

Figure 3. Detected temporal constructions

4.1.3 Vegetation influences

The influence of vegetation on change detection is shown on Figure 4. We checked weather there are nearby points detected in the second epoch which were not there in the first one. The blue color represents the changes and if there is no change the points are colored in white. Since the vegetation is growing it is visible that the blue colored changes were detected in the second epoch. Such differences disturb the automatic change detection procedure because they don't represent real change in the cadastral objects. Similar result, because of the growing vegetation, can be expected in situations where we have green hedges, which are very regularly structured, as the example shown in Figure 5 which sometimes coincide with the real cadastral boundaries.

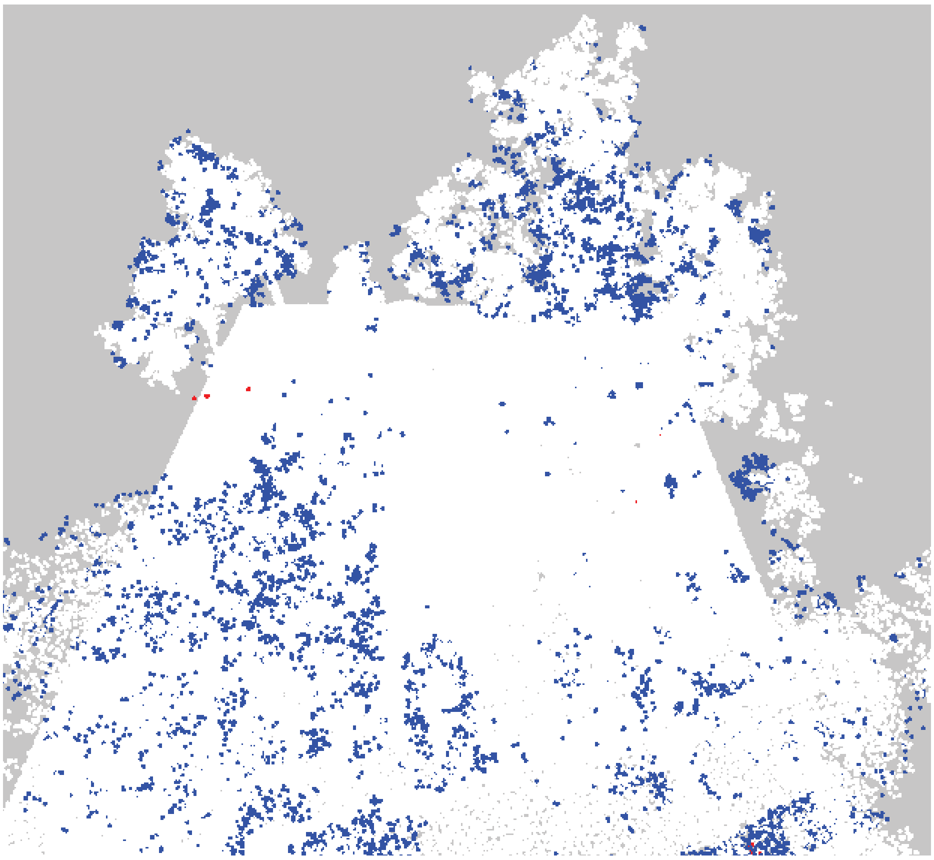


Figure 4. Effect of vegetation growth on change detection

Figure 5. Green hedges

4.1.4 Different viewing angle

Due to the different viewing angles we observed detected changes in both epochs colored respectively in red and blue colors as shown on Figure 6. The geometry of the building obviously has no change but because of the angle the change detection algorithm is highlighting these points. From a non-experiences observer this detected changes could be confusing.

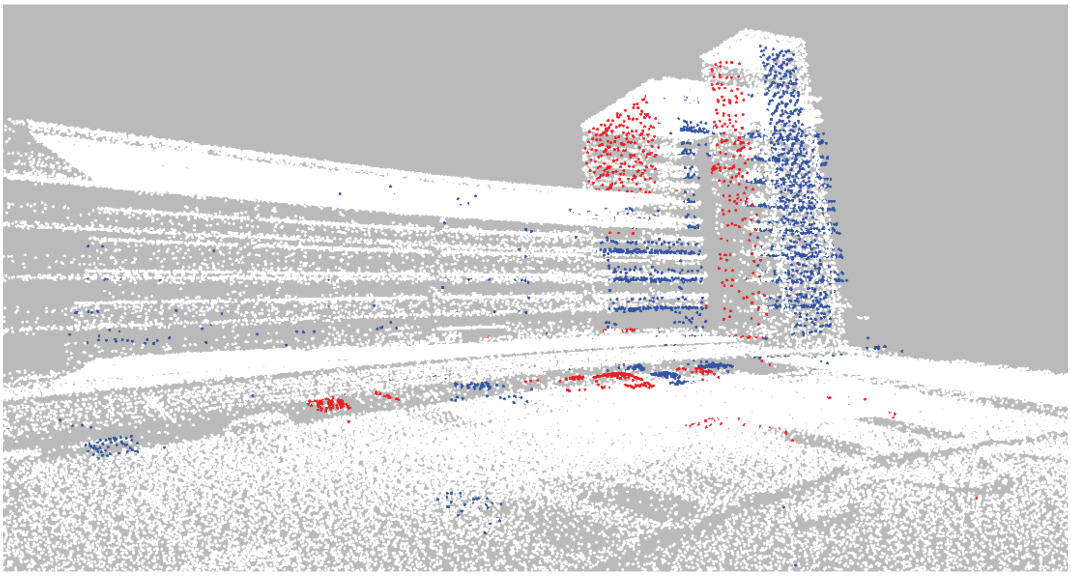
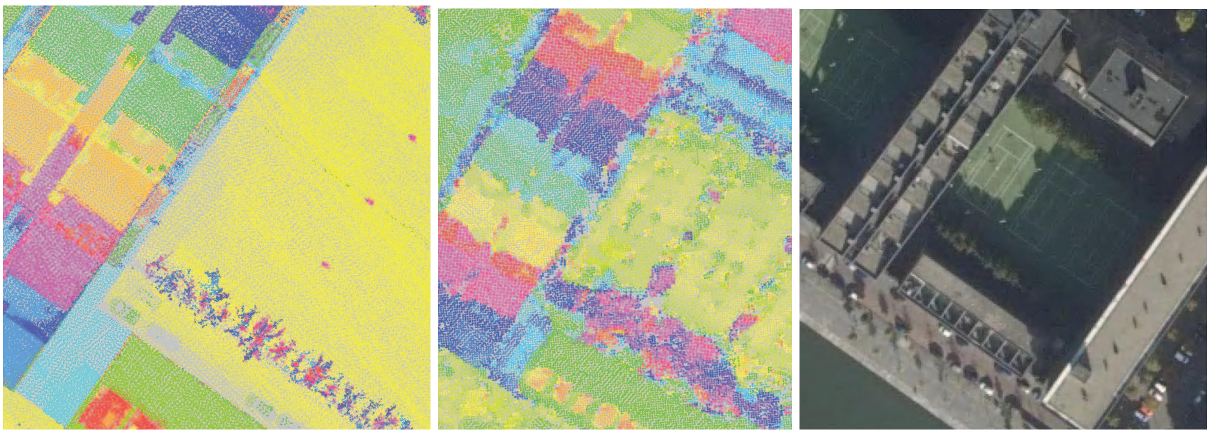


Figure 6. Detected changes due to differences in the viewing angle

4.1.5 Different acquisition techniques

Looking at advantages and disadvantages while combining data acquired differently, we observed that many challenges may occur but also some problems can be solved. For example, conflicts may occur when applying different thresholds for different datasets or due to differences in techniques and point density. Such an example is shown on Figure 7 where (a) shows ALS point clouds, (b) generated point clouds from image matching technique and (c) aerial image taken with digital Ultracam camera with 10 cm. resolution.



(a) (b) (c)

Figure 7. Point clouds from different acquisition technique and a digital aerial image

After the comparison the highlighted changes were not due to a geometric modification of the cadastral objects but from the differences between the acquisition techniques. There are several benefits of the image based point clouds such as: (1) the technology is cheaper, (2) covered area can be bigger, and (3) the acquisition can be done more frequently, However the edges of the objects, as shown on the figure above, are more rough which affects the change detection and clear visibility of the outlines of the buildings.

4.1.6. Map based segmentation of ALS data

Maps are valuable source of semantic information for the land cover class and 2D special information of the boundaries of the cadastral objects. Applying segmentation models based on combination of maps and ALS data the urban scenes from the test data were divided into 4 land cover classes (buildings, plants, roads and water) and according to the characteristics of each class different segmentation strategies were tested. As an example map based segmentation for multi-land-cover landscape is shown on Figure 8.

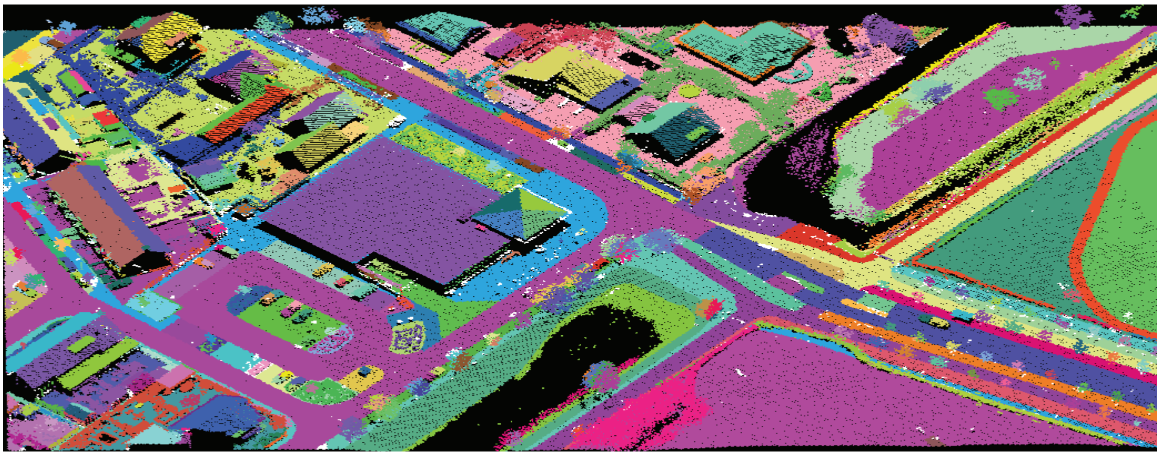


Figure 8. Result of map based segmentation for multi-land-cover landscape. Source: (Wang, 2016)

The challenging aspect in this example is to correctly assign the ALS data with the map data as there might be differences between objects in laser scanning data and objects in the map.

4.2 Changes that do not cause geometric differences.

Cadastres play important roles in different land registration systems around the world, for juridical or fiscal purposes (Zevenbergen, 2002). As defined by Dale & McLaughlin (2000) cadastre is an official record of a real property's ownership, value, location and dimensions. Considering this, changes from point clouds can be detected only for the visible part of the objects or boundaries. For example the change in the legal and administrative status of a property is invisible. Therefore, in this study we focused only on detecting visual geometric changes of cadastral objects.

5. CONCLUSIONS

Detection of changes of the physical cadastral objects over time is essential step for any cadastre. Moreover automatization of this process can be undoubtedly beneficial. Although some of the discussed challenges in the paper might be exceptions, we think that showing examples that can provoke confusion can prevent from mistakes concerning wrong change detection for updating processes. From the research it can be concluded that full automatization is still challenging and for some cases semi-automatic methods from an experiences operator might be recommendable. In the paper we have addressed some challenges that we observed, however there are a lot of other possible cadastral situations using point cloud data comparison that can be topics for further research. For future investigation we think that comparison and combinations with other point cloud data obtained from terrestrial laser scanning technology or Building Information Models (BIM), construction plans, CAD, and GIS data as additional information ca be beneficial for automatic detection of changes for updating purposes. Next to that images acquired from different platforms such as UAVs could be helpful to regularly update the local situation. The more precise data is available the better is the possibility of distinguishing between real changes and wrongly detected ones.

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BIOGRAPHICAL NOTES

Mila Koeva works as an Assistant Professor working in 3D Land Information. She holds a PhD in 3D modelling in architectural photogrammetry from the University of University of Architecture, Civil engineering and Geodesy in Sofia. She also holds a MSc. degrees in Engineering (Geodesy) from the same institution obtained in 2001. After her work in Municipality company GIS-Sofia Ltd. and later on in the private company Mapex JSC., combining multidisciplinary approach for cadastre needs, she moved to University of Twente at the faculty of Geo-Information Science and Earth Observation (ITC) where she was teaching topics of Photogrammetry and Remote sensing. From the University of Twente she holds a university teaching qualification. Her main areas of expertise include 3D modelling and visualization, 3D Cadastre, 3D Land Information, UAV, digital photogrammetry, image processing, producing large scale topographic and cadastral maps, GIS, application of satellite imagery for updating cadastral information among others.

Sander Oude Elberink graduated as Geodetic Engineer from Delft University of Technology in 2000, and finished his PhD on the Acquisition of 3D Topography in March 2010. In September 2005 Oude Elberink started his PhD research on "Acquisition of 3D topography" at the International Institute for Geo-Information Science and Earth observation (ITC) Enschede. His research was part of the project '3D Topography' which received the RGI Innovation Award in the category science in 2007. He received a young author's award for best papers at the ISPRS congress in Beijing, China in 2008. In 2009 Sander received the ITC research award for a journal paper on 3D road reconstruction, which was co-authored by George Vosselman and published in the Photogrammetric Record. From September 2009 Sander holds a position of assistant professor at the department of Earth Observation Science at ITC. In 2016 Sander received the ISPRS Guiseppi Inghilleri award for his high quality and innovative research in 3D landscape modelling that has successfully been transferred to practice to serve the society.

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