CHANGE DETECTION FROM POINT CLOUDS TO SUPPORT INDOOR 3D CADASTRE

S. Nikoohemat*, M. Koeva, S. J. Oude Elberink, C. H. J. Lemmen

Dept. of Earth Observation Science, Faculty ITC, University of Twente, Enschede, The Netherlands –
(s.nikoohemat , m.n.koeva, s.j.oudeelberink, c.h.j.lemmen @utwente.nl)

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ABSTRACT:

Recently in The Netherlands, there are many examples of changes in the functionalities of buildings over time. Tracking these changes could be challenging when the building geometry will change as well; for example a change from administrative to residential use of the space, or merging two spaces in the building without updating the functionality. To record the changes, a common practice is to use 2D plans for subdivisions and to assign new rights, restrictions and responsibilities for the changes in a building. In the meantime, with the advances of 3D data collection techniques, the benefits of 3D models in various forms are increasingly being researched. The current work explores the opportunities of using the point clouds to establish a link between spatial changes and 3D Cadastre in indoor environments. We investigate the changes over time in the geometry of the building that can be automatically detected from point clouds to update the 3D indoor cadastre. The permanent changes (e.g., walls, rooms) are automatically distinguished by dynamic changes (e.g., human, furniture) and will be associated with the space subdivisions. Finally, the results will be linked to the spatial units in a Land Administration Domain Model (LADM).

1. INTRODUCTION

Change detection from point clouds is the common method for detecting the geometry and semantic changes over time in the urban canyons and forests. On the other hand, 3D Cadastre data models are trying to represent the physical objects in connection with the legal objects.

In the recent years, there are many examples of changes in the functionalities of buildings in time. According to the statistics shared by “Rijksolverheid” (Zaken, 2013) in The Netherlands 17% of the office, social and real estate buildings are empty. The Ministry of Interior and Kingdom Relations (BZK) and the Association of Dutch Municipalities (VNG) set up an expert team to support Municipalities in the transformation from office to residential buildings. One of the examples is a nursing home, which was owned 40% by housing associations and 60% by health care organizations, changed into students hotels or private owned apartments with private ownership. For example, the building on Figure 1, located in the City of Hoorn in 2015 was changed into a residential building.

It is challenging to monitor the changes in the physical objects (permanent structure) during the lifetime of a building and accordingly update the 3D Cadastre. In this paper, we study the changes inside the buildings and try to make a bridge between the change detection and the indoor 3D Cadastre. The reason that point clouds are used for change detection and representation of the 3D Cadastre is the originality of the point clouds to the current situation of the cadastre (3D) spatial units. In other words, the point clouds reflect more details of the environment and they are close to the current state of the building. Furthermore, it is easy to convert the point clouds to other data representation forms such as vector and voxel for usage in 3D Cadastre models (Peter van Oosterom, 2018).

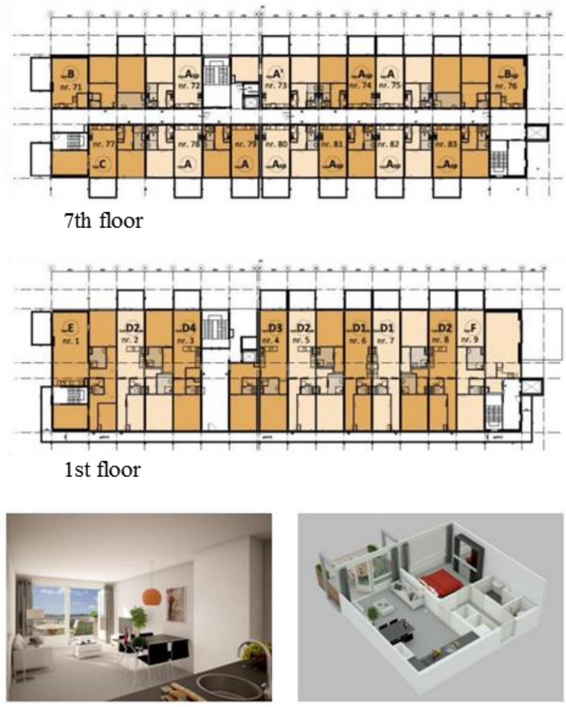


Figure 1. Changing from a nursing house to an apartment (Zaken, 2015).

There is a good potential in using the point clouds during the lifetime of a building. By collecting the point clouds before and after each renovation of the buildings and refurbishments in the structure, it is fast and accurate to find the changes and update the corresponding documents and databases. This fact motivates us to use point clouds and monitor changes in support to updating the 3D Cadastre. Change detection from point clouds can be done

* Corresponding author

merely in a low level of details and just based on the geometry or can be done in a higher level of details by interpretation of the geometry to semantics. For example, the differences in two epochs could be because of changes in the furniture and not the permanent structure which needs a higher level of interpretation from point clouds. Therefore, only comparing the geometry of two point clouds is not sufficient to interpret 3D Cadastre related changes. In our method, we explain how important changes including walls are distinguished from temporary changes such as furniture. Additionally, we need to have an understanding of the spaces inside the buildings to relate them to the 3D spatial units in a 3D cadastre model. The mentioned process can be done using the point clouds and our method.

While it is possible to automatically subdivide the indoor environments to space subdivisions from point clouds, it is not a trivial task to automatically link them to the 3D Cadastre model. Each space subdivision can represent a spatial unit or a group of spatial units in a building. These spatial units to some extent are supported in a Land Administration Domain Model (LADM) through four main classes: LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit (LADM, ISO 19152:2012). Out of them LA_SpatialUnit which represents legal objects and LA_RRR which represents rights, restrictions and responsibilities are interesting for us. The reason that we use the LADM for our experiments is that it is more complete and recent than other cadastral data models such as FGDC (Cadastral Data Content Standard — Federal Geographic Data Committee, 2008), DM01(Steudler, 2006), and The Legal Property Object Model (Kalantari, 2008). Additionally, unlike other cadastral data models that are based on 2D land parcels, LADM suggests modeling classes for 3D objects (Aien et al., 2013). However, there is a lack of support for 3D Cadastre regarding data representation and spatial operations in the current 3D Cadastre models such as LADM. For example, cadastre parcels are mainly represented as a 2D parcel, while in a multi-story building there is a need to show the property as a volumetric object. The only class for supporting 3D spatial units in the LADM is the Class LA_BoundaryFace which uses GM_MultiSurface to model 3D objects. The problem of GM_MultiSurface is that it is not sufficient for 3D spatial analysis and representation (Aien et al., 2013). To compensate for this shortage, in our pipeline, enriched point clouds are used as an external database to store and represent the 3D objects. Using attributed point clouds enables us to calculate necessary spatial attributes for 3D Cadastre.

Currently, there is no framework for connecting point clouds and the LADM, and there is no workflow or standards to connect a building 3D model to the LADM. Therefore, we set an external model between the attributed point clouds and LADM to execute 3D operations (e.g., check the topology, calculate the area) on the point clouds and feed them into the LADM. For understanding the changes, first, we classify the point clouds of each epoch to permanent structures (e.g., walls, floors, ceilings) and temporary (e.g., furniture, outliers) using the methods in (Nikoohemat et al., 2017). Second, space subdivisions such as rooms, corridors, staircases are extracted from the point clouds of each epoch. Then, two epochs are co-registered and the geometry differences are extracted. The changes are classified as important changes such as permanent structure and temporary changes such as changes in the furniture. Finally, the related 3D Cadastre records in the location of changes are queried from the database and a cadastre expert can decide the updating of the cadastre records. An example of a commercial building that the point clouds are acquired using two different MLS systems before and after renovation will be demonstrated. This research invites enthusiastic readers to use point clouds as a primary and finishing data type for data processing and data representation to enrich the 3D Cadastre. Rest of this article explains the related work, the methodology of our work with a use case and the conclusion of the results.

2. RELATED WORK

Point clouds are a valuable source for decision makers in the domain of urban planning and land administration. Laser Scanner data including Aerial Laser Scanner (ALS), Mobile Laser Scanner (MLS) and Terrestrial Laser Scanner (TLS) have been used for reconstruction of 3D cities, building facades and roof reconstruction (Maas and Vosselman, 1999; Oude Elberink, S.J., 2009; Pu and Vosselman, 2009a). Another application of point clouds is for damage assessment of the buildings before and after a disaster (Vetrivel et al., 2015). In the domain of forestry, point clouds are used for monitoring growth of trees and changes in the forest canopy. Xiao et al., (2012) use point clouds to monitor the changes of trees in urban canopies. Regarding building facades, some methods are combining images with laser scanner data to reconstruct the facades of buildings (Müller et al., 2007; Pu and Vosselman, 2009b; Teboul et al., 2010).

In the domain of cadastre, there is a need to subdivide the spatial units vertically and to have a 3D representation in 3D spatial databases. Peter van Oosterom, (2018) in “Best Practices 3D Cadastres” discusses different types of data representation for 3D models storage including voxels, vectors and point clouds. The flexibility of point clouds in conversion to voxel or vector formats makes it easier to use point clouds in cadastre. Additionally, point clouds can represent the 3D details of the buildings from inside and outside.

From the standards and modeling aspects, researchers have developed models to provide a common framework for 3D Cadastre. The main international framework for 3D Cadastre is the Land Administration Domain Model (LADM, ISO 19152, 2012). However, in LADM there is a lack of connection between spatial models such as Building Information Models (BIM) and IndoorGML. Oldfield et al., (2017) tries to fill this gap by facilitating the difficulty of registering the spatial units extracted from BIM into a Land Administration database. Aien et al., (2013) studies the 3D Cadastre in the relation with legal issues and their physical counterparts. The authors introduce a 3D Cadastral Data Model (3DCDM) to support the integration of physical objects linked with the legal objects into a 3D Cadastre. Another application of LADM is for using the access rights for indoor navigation purposes. The access rights of spatial units are defined in the LADM and could be connected to IndoorGML for customized navigation in the spatial units (Alattas et al., 2017).

In the literature, the use of point clouds for indoor cadastre is underestimated. With the recent improvements in automation of 3D modeling from point clouds (Mura et al., 2016; Nikoohemat et al., 2017; Ochmann et al., 2016) using the point clouds for indoor 3D Cadastre is promising. Additionally, there is incredible progress in subdividing the space from point clouds to semantic subdivisions such as offices, corridors, staircases and so forth (Bobkov et al., 2017; Jung et al., 2017). This progress makes it possible to connect the rights, restrictions and responsibilities (LA_RRR) to the spatial units (LA_SpatialUnits) from point clouds or after conversion to a vector model.

Another model build on LADM for supporting the 3D spatial databases in terms of land administration was developed by Rajabifard et al., (2018). The authors propose strategies for the implementation of the (3D) National Digital Cadastral Data Base

(3D-NDCDB) in Malaysia. The proposed database, gives instructions for cadastral data collection, updating the data and storage. Their database is an open-source 3D database which is compliant for the LADM. Other researchers, discuss the need for new spatial representations and spatial profiles (e.g., point clouds profile, for non-topological 3D parcels) (Kalogianni and Dimopoulou, 2018; Thompson, 2018).

Atazadeh et al., (2018) investigate the integration of legal information and physical information based on international standards. The LADM is used as the data model for modelling legal information while Industry Foundation Classes (IFC) standard provides physical data elements for managing the lifecycle of buildings.

3. METHODOLOGY

In this section, the methods for detecting changes from point clouds will be explained. Furthermore, the relevant changes for 3D Cadastre will be distinguished from other changes and will be connected to the space subdivisions. Each space subdivision represents a semantic space that is associated with the 3D Cadastre attributes. An exemplary building shows the link of spatial units extracted from the point clouds to the land administration database in two epochs.

3.1 Indoor Change Detection from Point Clouds

Differences in two epochs of point clouds inside the buildings can be categorized as:

1. Changes in the dynamic objects (e.g., furniture).
2. Changes in the permanent structure (walls, floors, rooms).

There are some other differences between two epochs of point clouds that are interpreted as:

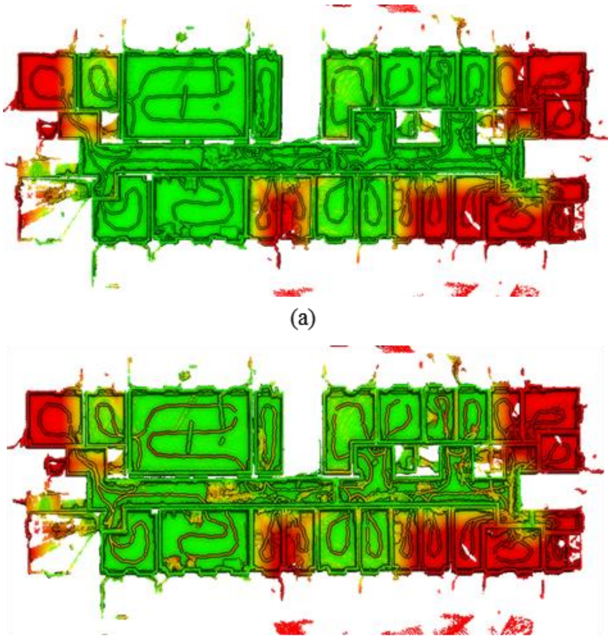
3. Differences because of the acquisition coverage.
4. Differences because of the sensors and registration error.

In our approach, categories number 1 and 2 are dealt with as important changes for 3D Cadastre and categories 3 and 4 are just inevitable differences in two epochs that occurred because of data acquisition systems and are not relevant to the 3D Cadastre.

Assuming to have two point clouds of two time periods that are acquired with two different laser scanners, one a Zeb-Revo handheld MLS and the other with a backpack system. The process of change detection starts with the co-registration of two point clouds. The co-registration of two point clouds datasets is a straightforward approach such as using ICP (Besl and McKay, 1992) and there is a lot of research in this domain (Makadia et al., 2006; Rabbani et al., 2007).

After the registration, two point clouds datasets are compared based on a distance threshold *d* to detect the differences that caused by the registration error and sensors' differences (4th category). The distance threshold can be chosen by summing the *registration error* and *sensor noise*. The registration error and sensor noise already introduce some differences in the two datasets. The registration errors are defined after each co-registration process. The sensor noise is specified in the specification of the systems. This threshold describes that points from two datasets with the distance less than the threshold *d* are not considered as changes and they are in the 4th category because of the differences in the sensors. Points that have distances more than the threshold are in one of the other three categories. In our experiment, we define the distance threshold less than 10 cm. Let the point clouds from epoch one (acquired by a backpack) be PC1 (Figure 3a) and the point clouds from the second epoch (acquired by Zeb-Revo) be PC2 (Figure 3b). The point to point comparison is based on the reconstruction of a Kd-tree (Friedman et al., 1977; Greenspan and Yurick, 2003) and comparing the distance of the points in PC1 from the PC2 and is stored in PC1. Using this method, the differences that caused by an acquisition system and registration error are excluded from the real changes (Figure 3d).

In the next step, the differences are further analyzed to detect and to exclude the acquisition coverage (3rd category). Our change detection method is based on analysing two geometric differences between two point clouds. This is done in a two-step approach: (1) the distinction is made between object changes and coverage differences, and (2) the object changes are separated into changes on permanent structures and dynamic objects such as persons and furniture (section 3.2). The geometric differences are calculated by determining the nearest 2D point, and the nearest 3D point in the other epoch. So, the first nearest point is based on the X, Y coordinates and the second on X, Y, Z coordinates. Figure 2 shows both geometric distances in 2D and 3D, as a point attribute categorized in three colours: green < 20 cm, yellow >20 cm and <50 cm, red > 50cm to the nearest.



(a)

(b)

Figure 2. The distance (green < 20 cm, yellow<50 cm, red > 50cm) to the nearest point in a) 2D and b) 3D.

For both object changes and coverage differences, it is expected that the nearest 3D point is further than a certain threshold. However, the nearest 2D point is close for a changed object but not in case of coverage differences. Points are temporarily labelled as part of changed objects if the distance to the nearest point in 3D is larger than 50cm, but the nearest point in 2D is less than 50 cm. Next, the whole point cloud is segmented into planar segments, and only the vertical segments with a majority of points labelled as potentially changed are considered to be changed. The planar segmentation is performed by the region growing algorithm presented by Vosselman et al., (2004). Note that in this way also the points on a newly built wall near the ground or ceiling are included in the changed objects. The vertical segments labelled as changed objects include permanent structures, such as walls, but also dynamic objects such as persons. In the second step, the aim is to separate permanent from temporary changes, by looking at a method described in (Nikoohemat et al., 2017).

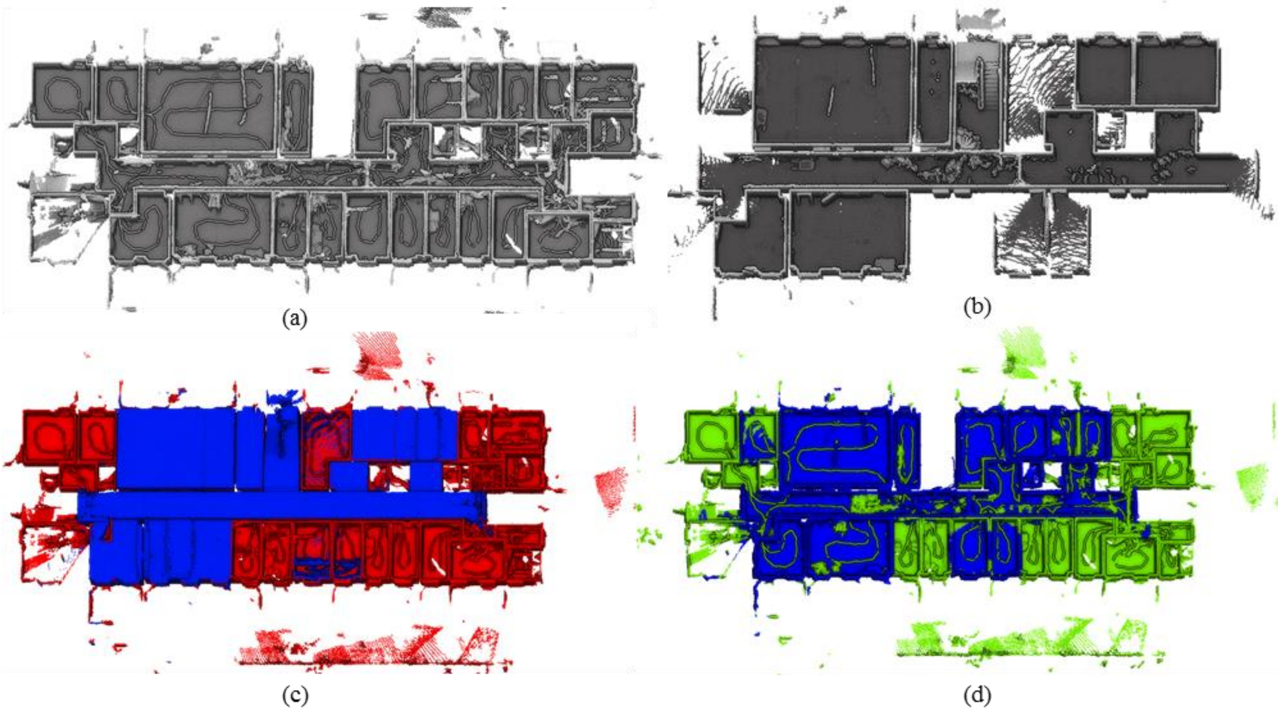


Figure 3. (a) Point clouds from a backpack system from the first epoch. (b) Point clouds from a Zeb-Revo system, from the second epoch. (c) Co-registered point clouds. Blue shows the Zeb-Revo. The red areas indicate the differences in the coverage where PC1 is not covered by PC2. (d) Point clouds of epoch1 after the comparison with the epoch2. The blue points show the points that their distance differences are less than the threshold and are not changed. The green points show the differences because of coverage or furniture or a permanent change. The ceiling is removed for better visualisation.

3.2 Classify Changes to Permanent and Temporary

The next step is to separate the changes that are part of the permanent structure from dynamic objects. This contains classifying the point clouds in each epoch to a permanent structure (e.g., walls, floors, ceilings) and temporary objects (e.g., furniture, clutter and outliers). We apply a method from (Nikoohemat et al., 2017) to semantically label the point clouds in each epoch (see Figure 5). This classification starts with a surface growing segmentation and generating an adjacency graph from the connected segments. By analysing the adjacency graph, it is possible to separate permanent structures such as walls because of their connection to the floor and ceiling. Figure 5c shows the permanent structure (walls and floor) is separated from the temporary objects (clutter, furniture and outliers).

After classification of points in each epoch, by comparing the changes with the semantic labels (walls, floors and ceilings), it possible to distinguish relevant changes for 3D Cadastre. Each point in the set of changes is a possible change for 3D Cadastre if it is labelled as a wall, floor or ceiling otherwise it is a change only because of dynamic objects.

3.3 Changes in the Relation with Indoor Space Subdivisions

The process of detection of permanent changes is continued by linking these changes to the volumetric space or space subdivisions. Space subdivisions represent the semantic space in the indoor environment such as offices, corridors, parking space, staircases and so forth. Each space subdivision is connected to space in a spatial unit in the 3D Cadastre model and all laser points in the space subdivisions carry the attributes of the corresponding cadastre administration. In this step, we explain how these space subdivisions could be extracted from the point clouds and linked to the previously detected changes. Note that an apartment may consist out of one or more spatial units. A spatial unit may consist out of one or more spaces. A spatial unit may have invisible boundaries and needs to be checked by a cadastre expert.

To detect the spatial units from the point clouds, following the method in (Nikoohemat et al., 2017), after the extraction of the permanent structures in each epoch, a voxel grid is reconstructed from the point clouds including walls, floors and ceilings. Then using 3D morphology operation on the voxel grid, the space is subdivided into rooms and corridors. Each space subdivision is represented with the center of voxels as a point cloud segment. To find out in which space subdivisions, the changes occurred, we intersect the space subdivisions of each epoch with the permanent changes detected in the previous step (see Figure 4).

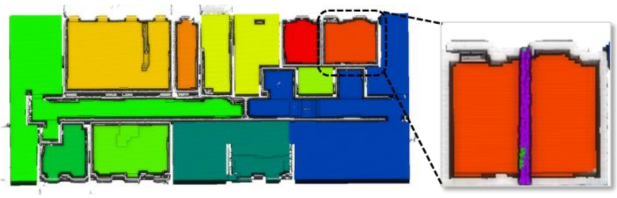


Figure 4. The space subdivisions of PC2 (second epoch), after the change. The purple wall in the right image shows the intersection of a detected change with a space subdivision.

For example, in Figure 5, we can see that in the second epoch (Figure 5b) a wall is removed and two spaces are merged. Since this wall was detected as a change during the previous step (Figure 5c), by the intersection of changed objects with subdivisions, the conflicts in the two epochs are extracted (Figure 4). This conflict is linked to a space subdivision and each space subdivision or a group of them (e.g., a building level) may represent a spatial unit in the 3D Cadastre model.

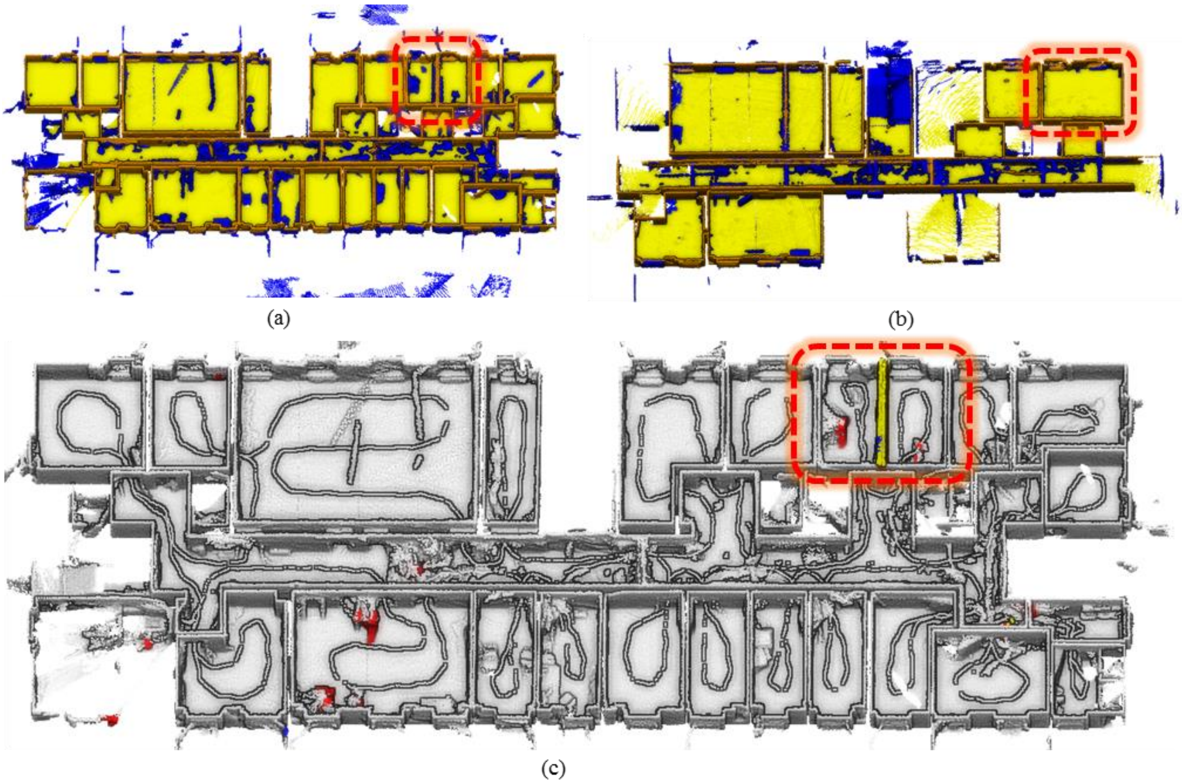


Figure 5. (a) PC1 acquired by a backpack and (b) PC2 is acquired by a Zeb-Revo, walls (orange), floor (yellow), clutter (blue). (c) The changes are detected in PC1 and classified as permanent structure changes (yellow) and temporary changes (red). The red rectangle shows the wall that is showing the permanent change.

3.4 Changes in the Relation with 3D Cadastre Model

To link the cadastre to the detected changes, we assume every space subdivision in the point clouds is represented in the object description of the spatial unit in the LADM. We choose LADM (Figure 6) as our 3D Cadastre model because it is the most recent and the most complete 3D Cadastre data model and it has a class for supporting the 3D objects. Note that an interactive refinement on the space subdivision from the previous step is necessary to group some of the subdivisions according to the 3D Cadastre legal spatial units. For example, a group of offices that belong to the same owner has an invisible boundary that should be interactively corrected.

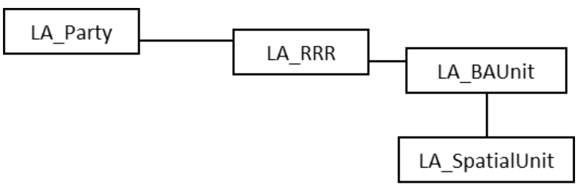


Figure 6. Basic classes of the LADM (ISO 19152:2012)

It is possible to setup the LADM in such a way that each space is represented as a spatial unit and then using the LADM class *LA_BAUnit* to associate those spatial units with a legal unit. Type of building units can be individual or shared. An individual building unit can be an apartment and can represent a legal space. In our example (Figure 5), the wall is removed and two spaces are merged, and their ownership is updated in the LA_BAUnit class.

Every spatial unit in LADM is modelled with *GM_MultiSurface*. 2D parcels are modelled by boundary face string (LA_BoundaryFace). The representation of 3D spatial units is done by boundary face (LA_BoundaryFace) and for the storage, a *GM_Surface* is used (see Figure 7). However, in our approach, we are aiming at keeping the point clouds until the last step for spatial analysis. Therefore, we use the calculated features such as volume, area, neighbour units and so forth for feeding the classes in the LADM.

All spatial attributes and legal issues such as rights, the restriction could be associated with the point clouds and the LADM. The measured spaces are important because apart from the floor space also the volumes are known. This is relevant for evaluation purposes of the individual spaces in apartments. Figure 8 illustrates the LADM representation of an apartment – in this case, owned by a party (right holder) named Frank. This party has an individual space and a share (1/100) in the common or shared space. Individual and shared space (including the ground parcel) compose the building as a whole.

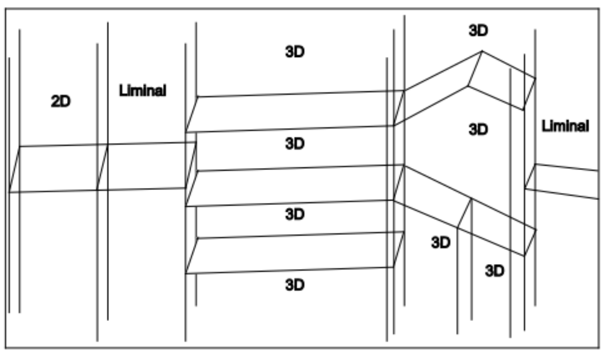


Figure 7. Mixed use of boundary face strings and boundary faces defining both bounded and unbounded 3D volumes (LADM, ISO 19152:2012, Annex B).

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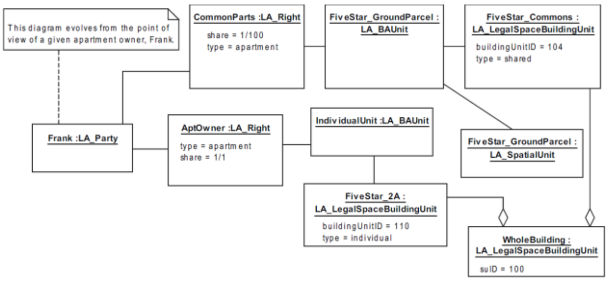

Figure 8. An apartment building in LADM and its legal space (LADM, ISO 19152:2012).

4. DISCUSSION AND FUTURE WORK

We have presented a pipeline to detect geometrical changes in the buildings from two epochs of point clouds captured by mobile laser scanners. In our approach, changes are recognized as dynamic changes (e.g., human, furniture) and permanent changes (e.g., walls, rooms). The permanent changes then are linked to the space subdivisions that are extracted from the point clouds of each epoch (section 3.3). A cadastre expert will interactively group some of the space subdivision according to their legal attributes. Then the spaces that are changed and identified during the process will be further analysed to extract spatial attributes such as boundary, area and volume. This process can be done on point clouds where changes has occurred. Extracted spatial attributes can be exchanged between a cadastre model such as LADM and the point clouds. A cadastre expert should make decisions on updating the cadastre model according to the spatial changes.

Evaluation: In our pipeline, the challenge is detecting the permanent changes from the dynamic changes which are not important for the cadastre. According to (Nikoohemat et al., 2017), the process of permanent structure detection for a point cloud with clutter and noise can have accuracy between 0.88 to 0.93. Furthermore, the extraction of spaces are really crucial in the process, because the volume and area are calculated from the space subdivision result. Therefore, an expert should check the result of space subdivision, and merge or split some of the spaces that are extracted from the point clouds. The interactive corrections are less than 10% of the whole process and for a building of three floors as large as our case study does not take more than 10 minutes.

Limitations: The process of linking the spatial units to the 3D Cadastre model is not automated in our approach. This is because of the lack of spatial support for representation and visualisation of 3D objects in 3D Cadastre models. Therefore, our method is limited when it comes to the storage of 3D spatial objects in the cadastre databases. To link 3D objects and 3D Cadastre models, one solution is using the point clouds as external classes and try to keep the 3D objects as point clouds for all steps. The extraction of vector boundaries for using in the cadastre models can be done with simple functions from the point clouds.

Future work should determine the link between designed space by the architect and the real constructed space as measured with point clouds. This measurement is relevant for the composition of legal space in LADM – but also for building permits and other permits (e.g., for shops and companies). The process of representing and linking 3D objects to the 3D Cadastre especially for indoor is ongoing research.
The authors of this paper hope that this work would introduce a new research avenue regarding the connection between point clouds and indoor cadastral models.

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