Point Cloud for 3D Land Administration System (LAS)

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Key words: Land Administration System, Point Cloud, Floor Plan, 3D LAS, 3D Web Visualization

SUMMARY

As cities grow denser and more and more in vertical directions, Land Administration Systems (LAS) must evolve to represent complex, multi-level property ownership, particularly in apartment buildings. While Building Information Models (BIM) are commonly used for 3D representation, their availability remains limited for mainly new buildings. This research explores the use of point clouds as an alternative means to represent 3D spatial units in LAS, focusing on the integration of cadastral floor plans and the airborne Lidar point cloud datasets (in our case the national Actual Height Netherlands or AHN data sets). Three apartment cadastral drawings from different years in Rotterdam serve as case studies. The proposed methodology involves five main steps: (1) parsing the scanned image of the floor plans using image processing to extract cadastral room boundary polygons; (2) segmenting AHN point cloud (3); generating synthetic point clouds by extruding floor plan polygons and aligning them with AHN; (4) storing these 3D spatial units in a PostgreSQL-based database following the ISO 19152-1:2024 Land Administration Domain Model (LADM); and (5) developing a web-based 3D LAS portal using Vue.js, CesiumJS, and FastAPI for visualization and interaction. Results show that by combining AHN and cadastral drawings, the cadastral unit boundaries can be extracted and converted into 3D point clouds for integration into a cadastral database. The synthetic point clouds include room-level attributes and spatial identifiers, enabling interactive visualization and data management through a web interface. However, challenges such as misalignment due to occlusion in AHN data and inconsistent quality in older floor plan drawings affect the accuracy and the level of full automation of the process. This research demonstrates that point clouds can effectively serve as final 3D representations in land administration, providing a scalable solution in the absence of BIM models and minimizing the need for additional field surveys.

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1. INTRODUCTION

Rapid urban growth demands a land administration system (LAS) capable of optimally storing and visualizing the legal status of apartment buildings, ideally through 3D representation. As various studies use BIM as a 3D representation (Alonso et al., 2019; Nguyen & Adhikari, 2023), it raises the question of overcoming the limitation that for most (older) buildings there is no BIM data. AHN Point Cloud is a regularly updated Dutch nationwide dataset that can provide a 3D geometric representation of the exterior building envelope for all buildings in the country. Point cloud also can be used to visualize 3D LAS and the topographic context (including, road, vegetation, street furniture, etc.) enabling direct information of LADM with corresponding point cloud data (Beil et al., 2021). On the other hand, providing notarial deeds to the government is obligatory in the Netherlands, including floor plans to register apartment rights. By integrating the interior information from the floor plan and the exterior information from AHN, this research attempts to study to what extent point clouds can represent and visualize 3D spatial units. The benefit of this approach, using point clouds in the context of land administration, lies in the accurate visual representation of real-world feature, such as walls and fences, captured through LiDAR scanning, is particularly valuable, as these features play a critical role in demarcating cadastral boundaries (Luo et al., 2016). Additionally, as AHN offers precise XYZ measurement (vertical accuracy 5-10 cm, horizontal accuracy 10-15 cm[1]), the height of the building and the floor can be simply calculated based on the AHN (Luo et al., 2016). Another advantage is the ability of point clouds to preserve geometric representations that can be directly compared to cadastral reference points measured with GNSS. This comparison is more straightforward than when using a 3D polyhedral mesh, where establishing corresponding points on every face can become complex and error-prone.

This paper is organized into six sections. The first section is the introduction to the research and the objectives of the research, which includes the question and the scope. Chapter 2 describes the relevant theoretical background and other related research about point cloud, floor plan, LADM, and visualization of the 3D land administration system. Section 3 explains the methodology of the research, which is divided into 4 (four) main stages: parsing the floor plan, segmenting point cloud, generating a synthetic point cloud, storing the point cloud in LADM, and visualizing 3D LAS.. Section 4 specifies the required tools to conduct the research, including the software and library. The dataset used as a sample for the study is also explained. Section 5 discusses the results of the experiments from the proposed pipeline. The evaluation and used parameters are also elaborated in this section. Section 6 concludes the study by answering the research question and identifying what improvements can be made for future studies.

[1] https://www.ahn.nl/kwaliteitsbeschrijving

2. RELATED WORK

Various studies have explored the use of point clouds for 3D Land Administration. Koeva et al. (2019) demonstrated the ability to automatically detect changes in building geometry over time by utilizing point clouds linked to the LADM. The study showed promising results, as relevant changes for 3D Land Administration (e.g., walls and rooms) could be differentiated from temporary changes (e.g., people and furniture) and were connected to spatial subdivisions. This approach enables the Land Administration database to be updated based on the detected changes. However, the study was conducted in a university building, which does not fully represent the full range of real-world scenarios involving private units in apartment buildings.

To associate point clouds and LADM, Koeva et al. (2019) stores 3D spatial units in GM - MultiSurface using Class LA BoundaryFace. As GM MultiSurface is not adequate for 3D spatial analysis and representation, enriched point clouds were employed as an external database for storing and representing 3D objects, enabling spatial attributes calculation for 3D Land Administration. The external database is a potential consistency risk, better to manage all the data in the same database.

When registering land, the boundaries of a parcel must be clearly drawn to represent the exact division between it and neighboring properties. In the case of apartment buildings, the boundaries become more complex, as they must be represented not only on horizontal planes but also on vertical planes. Therefore, as stated in Articles 5 and 6 of the Implementation Regulation of the Netherlands Land Registry Act 1994, a detailed drawing must be included when registering an apartment unit in a notarial deed. This drawing should depict the boundaries of the land, as well as a floor plan that clearly illustrates the division of private and common areas on both the ground floor and upper floors of the building (Koninkrijksrelaties, n.d.). Figure 1 illustrates that property boundaries are outlined with thick black lines (Meulmeester, 2019), which are more prominent compared to normal walls. Various studies incorporate floor plans as input to append indoor structures to 3D building models. By integrating 2D floor plans with 3D BAG data, (Kippers et al., 2021) automatically reconstructed 3D building models, including their interiors. However this study focusing on indoor topograghy, not indoor land administration.

Several essential components are identified by Kalogianni et al. (2020) to develop system architecture of a 3D Web-based LAS that integrates both spatial and non-spatial data: (1) datasets and datatypes availability; (2) data processing and validation; (3) data storage and management; (4) data visualization and manipulation. Van Oosterom (2013) specifies four challenge points to visualize 3D Land Administration as follows: (1) visualize dense 3D volumetric divisions where 3D spatial units often obscure each other which can be solved by using selections, wireframes, semi-transparent objects, displaying cross-sectional views (slices), or employing slide-out layers; (2) displaying open or unbounded parcels; (3) integrating the Earth's surface and reference objects like in CityGML for 3D Land Administration parcels; (4) presenting realistic depth perception for subsurface legal spaces associated with utilities by applying techniques such as stereoscopic imaging, perspective shifts, rotational views, or vertical markers connecting subsurface elements to the surface. To ensure the 3D Land Administration visualization is able to address user preference when they are accessing the land administration information using a web client, a set of requirements is collected; see **Table *1***. As both previous studies utilized IFC as their 3D model representation, a new requirement to facilitate the point cloud that will be used in this research, such as a Point cloud-based approach, needs to be considered as well.

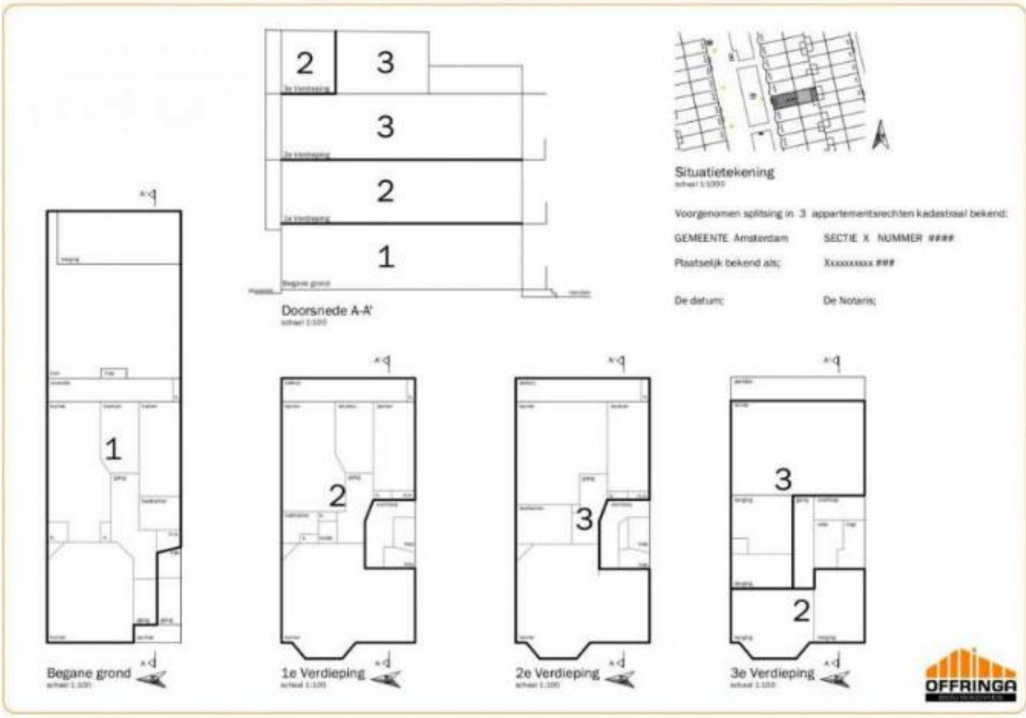

Figure 1. 2D Floor plan example in notarial deed (https://offringa-bm. nl/splitsingstekening)

Table 1. Wish List for 3D Visualization and Web Viewerbased on Cemellini et al.(2020) and Mao et al. (2024)

Wish List	
For 3D Visualization of Land Administration Data	**For 3D Web Viewer**
Navigation tools and view controls	Platform and browser independence
Integrating topography and reference objects	Handling massive data and caching/tiling between server and client
Transparency	Layers control
Object selection	Database support
Object search	Support different models (vector/polyhedral, raster/voxel, point clouds)
Wireframe display	Support of basic 3D topographic visualization
Explode view	Support for georeferencing
Sliding	Ensure spatial validity (3D vector topology)
Cross-section view	Underground view
Visualization cues	Open source platform
3D measurement tools	Possibility for the platform to be extended
3D buffer	2D overview map (orientation)
Display partly unbounded objects and 'complex' geometries	
Party /RRRs visualization and selection	
Point cloud-based	

3. METHODOLOGY

Three cadastral apartment drawings from Kadaster are used as samples for this research, drawn in different years: 1999, 2002, and 2019, located in the Rotterdam municipality. To reconstruct building point clouds from the apartment drawings for 3D LAS web visualization, five main steps are conducted as illustrated in **Figure *2.*** The Overview of Methodology below. The following subsection will address the following challenges: (1) What is the suitable method to parse the cadastral floor plan? (2) How can the AHN data sets (time series, multiple versions) be integrated and pre-processed to best represent building outer envelopes? (3) What approach can be used to represent apartment spatial units and their boundaries using point cloud? (4) How can point clouds be stored in the LADM (Land Administration Domain Model) database? (5) Which web architecture is suitable for representing and visualizing the resulting 3D LAS?

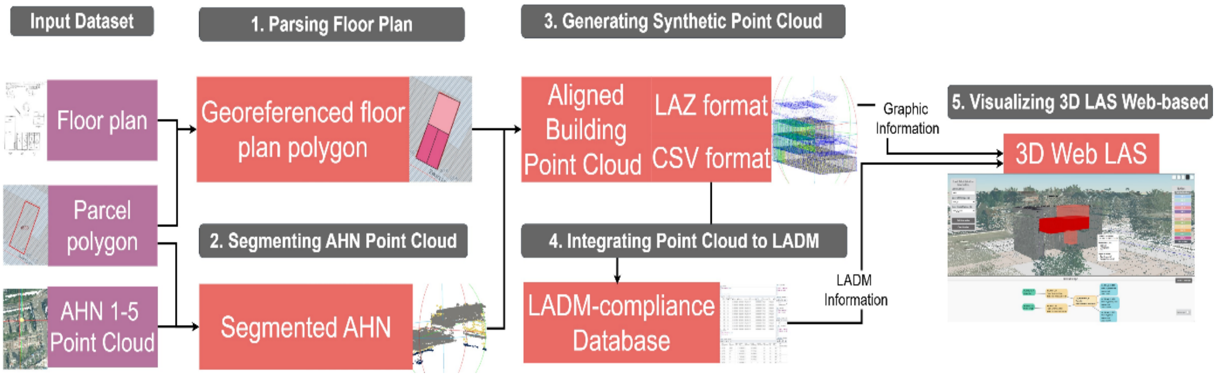

Figure 2. The Overview of Methodology

3.1 Parse Floor Plan

Parsing the floor plan starts by preprocessing a single PDF (scan) of the cadastral apartment that contains multiple floor plans of one building. Please note there are two type of boundaries on the floorplan: the thick boundaries represent property boundaries (with a identifying label) and the thin boundaries represent the spaces inside of them. The Python package easyOCR is used to detect floor keywords and cadastral id. The OpenCV library is then applied to detect contours in the drawing and converted them into polygons. The polygons then are georeferenced based on the cadastral polygon downloaded from PDOK.nl. Coordinate transformation typically involves three fundamental steps: scaling, rotation, and translation (Wolf et al., 2014). It is initialized by matching the Coordinate Reference System (CRS), then computing the orientation of the floor plan and parcel polygon using their respective Minimum Bounding Rectangle (MBR).

3.2 Segmenting AHN Point Cloud

To optimize the coverage of the facades of the building, multiple versions of the AHN dataset are combined and cropped with a 1-meter buffer towards the cadastral polygon to retrieve the building points. A segmentation process should be implemented to distinguish outside walls and roofs of building points.

Ground points are filtered using the CSF through filters.csf feature in PDAL. CSF is based on simulating a simple physical process to extract ground points from LiDAR points. It inverted the original point cloud, and then a rigid grid called cloth was dropped onto the inverted surface from above. The interactions between the nodes of the cloth and the corresponding point clouds can determine the final shape of the cloth to distinguish point clouds into ground and non-ground points (Zhang et al., 2016). The non-ground points are segmented using RANSAC and normal calculation to distinguish the roof and the wall.
Segmentation is grouping several homogeneous points based on their common features. RANdom SAmple Consensus (RANSAC) is a model-fitting method that uses a mathematical representation. It defines a model parameter from a minimum sample of random points. Iteratively checking their neighboring points, then a consensus set is formed if they are a match. The nonground points identified by the CSF filter are iteratively segmented into individual planar patches using RANSAC, implemented via the segment plane function from Open3D, with a distance threshold of 0.3 meters and a minimum of 3 points. Normal for each point in the plane is estimated through Open3D's estimate normal function and converted as a numpy array with Numpy's asarray to compute the angle between the normal vector and the vertical Z-axis using the inverse cosine (arccos). By calculating the angle of arccos degree, the points can be classified into Flat Roof if the angle of normal is below 25°, Sloped Roof if the angle is between 25 and 60°, and Wall if the normal is more than 60 °.

3.3 Generate Synthetic Point Cloud

The wall points are generated vertically along the boundaries of the polygon from the floor to the ceiling. A grid of points is generated within the interior of polygons to create a floor and a ceiling with different heights. The height for the ground floor is calculated based on the ground point from the CSF result, while the height for the ceiling is computed based on the height of the roof point in AHN divided by the total number of floors above the ground. Their position is aligned with AHN using Iterative Closest Point (ICP). The synthetic point clouds are assigned room_id and su_id along other attributes, and exported into LAS and CSV.

3.4 Store Point Cloud to LADM

LAZ is a compressed version of standardized format for point cloud data. However, it lacks support for concepts of semantic object structures like hierarchies or aggregation. To represent the point cloud as 3D LAS, the point cloud data needs to be integrated with structured knowledge and semantics by accommodating hierarchically structured and topologically connected representations of objects with multiple attributes Poux (2019). Using PostgreSQL, as illustrated in Figure 3.8, the synthetic point clouds are stored in a Land Administration Domain Model (LADM) compliance database based on ISO 19152-2024, where five tables are created: Point cloud, LA SpatialUnit, LA BAUnit, LA RRR, and LA Party. The Unified Modeling Language (UML) model for the LADM is illustrated in **Figure 3** below.

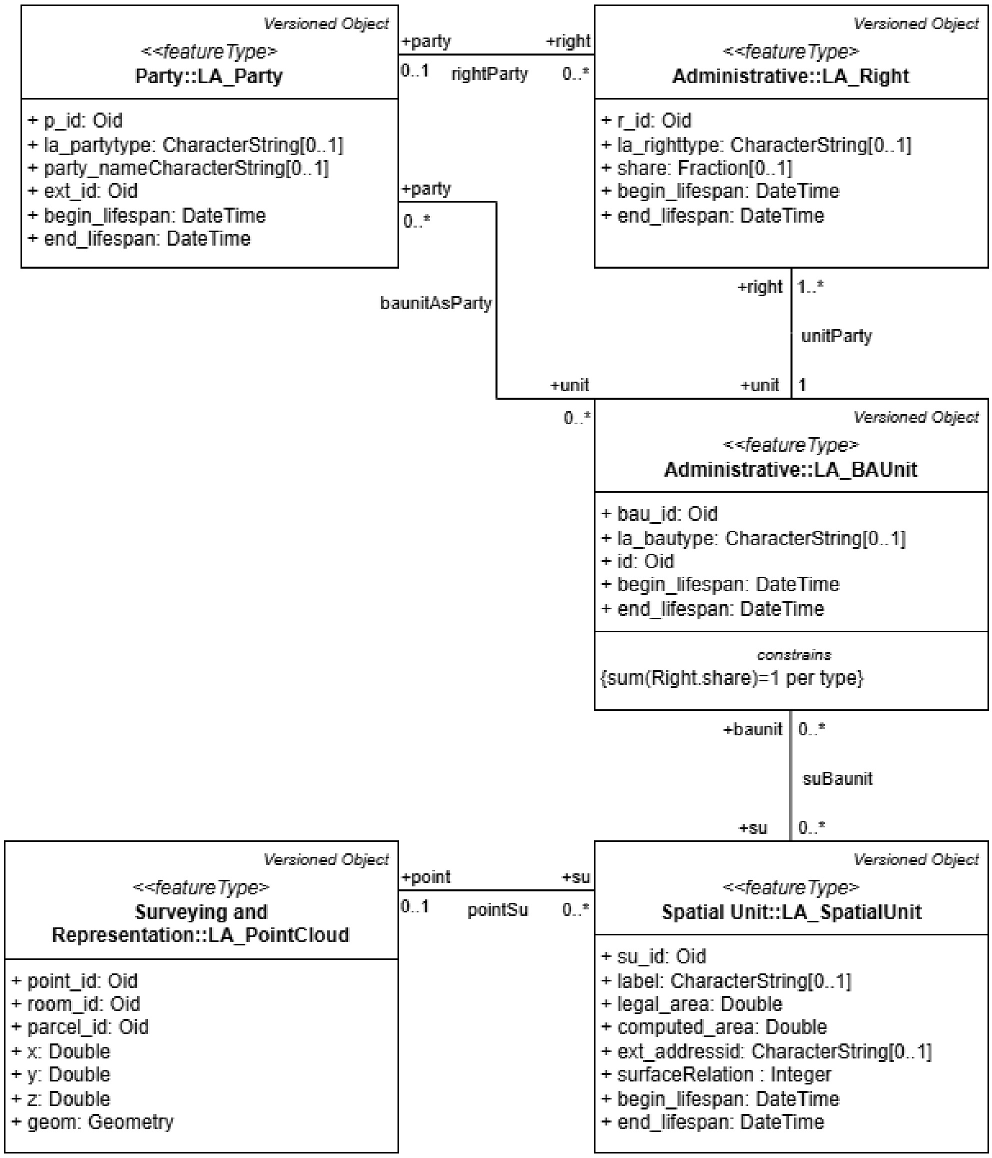

Figure 3. LADM UML Model

3.5 Visualize 3D Land Administration System

A land administration dissemination system is developed with Vue.js, Cesium, and FastAPI to represent and visualize 3D spatial units, allowing the user access and modify land administration information, including owner, right, and spatial unit. Initially, the resulting point cloud datasets from the previous step, Generating Synthetic Point Cloud, are uploaded to Cesium.ion to render the point cloud tileset from Cesium server. The web application front-end is built using the Vue.js framework based on Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript to manage user interaction. It integrates with CesiumJS to enable 3D geospatial visualization for the web. The front-end and PostgreSQL database server are connected through a RESTful Application Programming Interface (API) using FastAPI, a web framework for developing HTTP-based service APIs in Python. It manages how users retrieve and update data from the database server. The code for Vue.js or a front-end application is mostly written in a main file called App.vue with Options API style, while the back-end application is in a Python file named pgquery.py. The summary of this step is depicted in **Figure *4*** below.

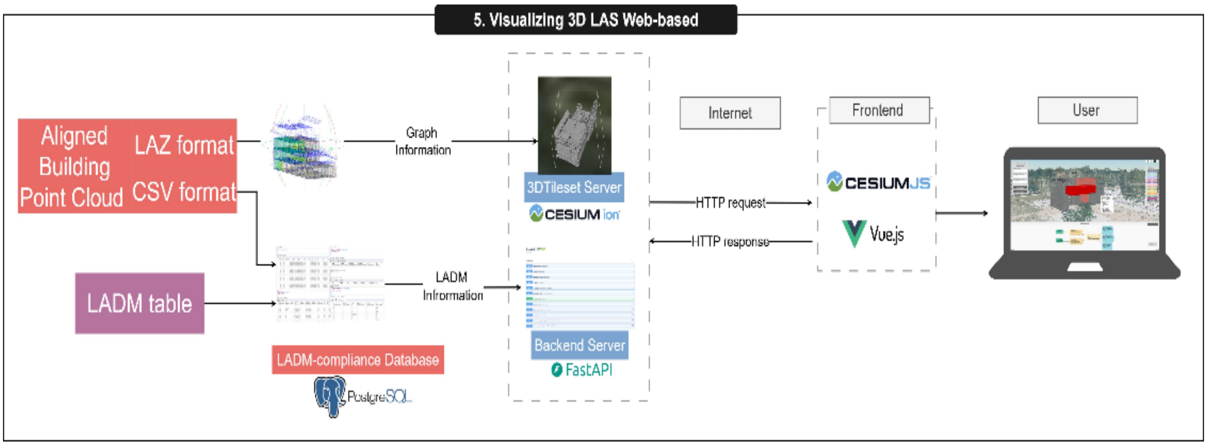

Figure 4. Visualize 3D Land Administration System

4. RESULTS AND DISCUSSION

The floor plan parsing algorithm successfully detects and vectorizes the interior layouts of all three cadastral apartment samples into geometric polygons. In these drawings, cadastral boundaries are represented by thicker lines, while internal room segmentation is depicted with thinner lines (Meulmeester, 2019). However, the algorithm can distinguish between line thicknesses only in the most recent cadastral drawing, thus generating cadastral boundaries without room segmentation in the others (**Figure *5***). Also the lines to represent the stair symbols had to be manually filtered out the detected boundaries.

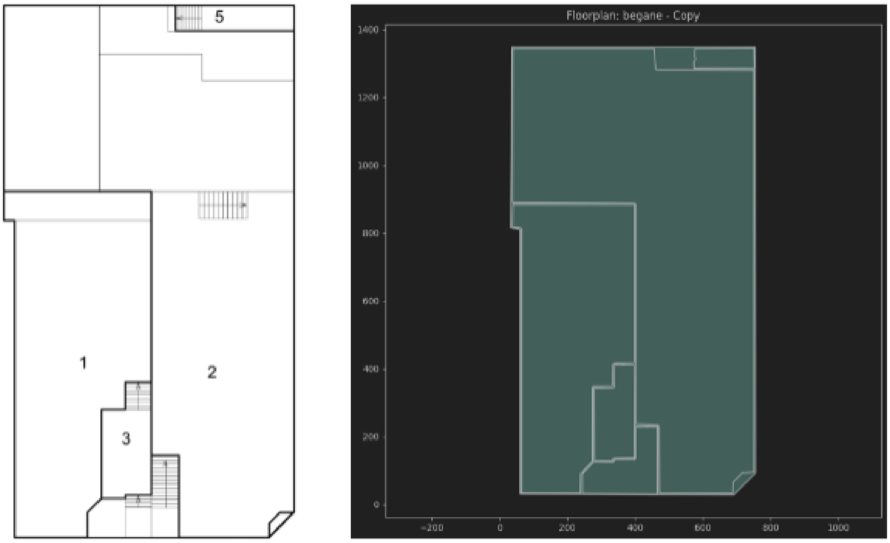

Figure 5. Input Floor Plan and the Vectorization Result (for one example floor)

The pipeline manages to georeference the vectorized polygons to the cadastral polygons with RMSEs of 18-32 cm. It aligned the generated synthetic point cloud to the combined version of AHN using ICP, achieving RMSEs between 1.48 and 1.51 cm with 62-298 matching points due to the sparse AHN points on building facades. The overall ICP result is listed in **Table *2*** below.

Table 2. RMSE of ICP

		Sample 1	Sample 2	Sample 3
Initial	Fitness	3.7e-05	6.92e-05	1.31e-04
	RMSE	1.406	1.478	1.418
	Correspondences	44	249	141
Point-to-Point ICP	Fitness	5.22e-05	8.73e-05	1.89e-04
	RMSE	1.480	1.480	1.459
	Correspondences	62	314	141
Point-to-Plane ICP	Fitness	0	7.43e-05	0
	RMSE	0	1.537	0
	Correspondences	0	267	0

The development of a 3D visualization website prioritizes optimal performance and user experience. The usability of the system for delivering LADM information is also considered to ensure the platform fulfills its intended main objective. Visualization in the Land Administration context focuses on the representation of ownership boundaries and their related legal information. With a 3D map, the visualization is upgraded to more complex 3D structures with a sense of depth that is closer to the real world representation Pouliot et al. (2018). A 3D parcel is the fundamental spatial unit in a LAS to which a unique and homogeneous set of rights, responsibilities, and restrictions (RRRs) is assigned. Homogeneous means that the same combination of RRRs applies uniformly to the entire 3D spatial unit. The 3D parcel is the largest spatial extent where this homogeneity holds; extending the parcel would introduce different RRRs, while subdividing it would create neighboring parcels with identical RRRs Oosterom et al. (2011). To deliver a real-world representation, integrating other datasets, including reference objects and a topography map, can offer a reference to interpret the parcel in terms of location and size (Cemellini, 2018; Kalogianni, 2016). Since the 3D parcel is represented as a point cloud, the AHN dataset can serve as a reference object, enabling seamless integration of spatial data, as illustrated in **Figure *6***.

To this end, several interactive features have been incorporated to facilitate user engagement and improve the effectiveness of the platform, including:

(1) LADM Instance Level Diagram

To provide a comprehensive representation of LADM information to the user, an LADM instance-level diagram is introduced. Unlike a simple information table or panel, the diagram allows users to clearly perceive the relationships between parties, rights, BAUnits, and spatial units. It also enables the visualization of cases where a single BAUnit contains multiple spatial units, as demonstrated in **Figure** *7*.

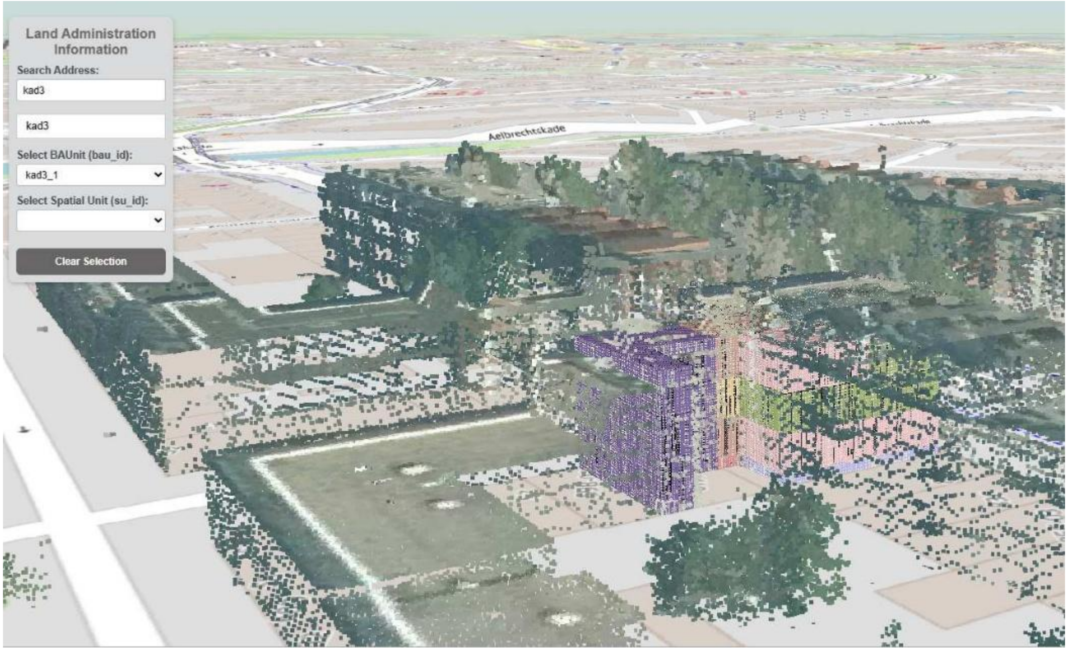

Figure 6. 3D Land Administration Visualization

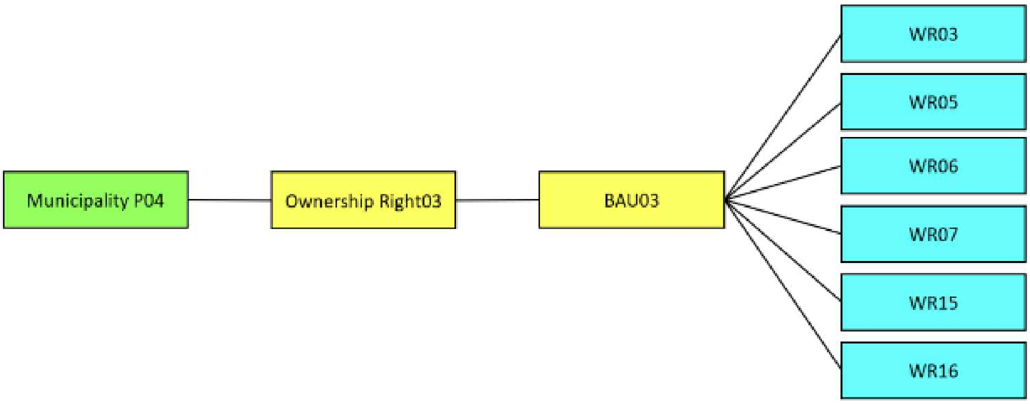

Figure 7. BAUnit with multiple spatial unit (Lemmen et al., 2025)

In her land administration web platform, Mao et al. (2024) implements this instance-level diagram to facilitate user understanding. Two types of diagrams are presented on the web, as follows:

1a. BAUnit relations diagram

This diagram shows all the parties, right, BAUnit that are linked to the specified spatial unit along with the other spatial units under the same BAUnit, as illustrated in Figure 8. It allows users to comprehend the case when there are multiple shares in one property. It can occur when the property is leased, resulting in different types and records of right linked to the same BAUnit. Another case is if the property is owned or leased by multiple persons, such as a marriage partner, resulting in multiple rights linked to the same BAUnit which can be identified in the share column from LA RRRs.

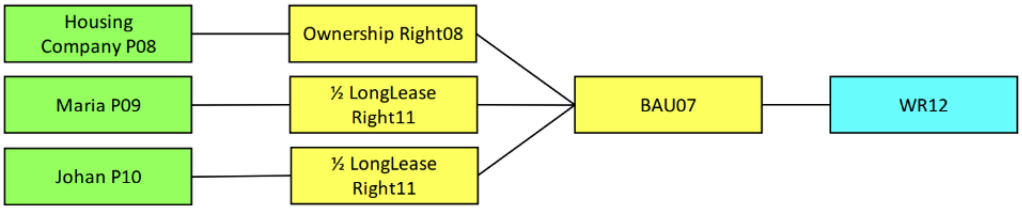

Figure 8. Multiple shares in LADM diagram (Lemmen et al., 2025)

This feature, see **Figure *10***(a), appears as the user selects the spatial unit in the dropdown or clicks a point. To increase user experience and interaction, the graph can also be resized vertically and can be clicked. Although the web can zoom as the user selects the spatial unit in the drop-down, as this graph also shows the other spatial unit with the same BAU id, the user can also check where the other spatial unit is by clicking on the box in the diagram. This will trigger the website to zoom and highlight the spatial unit points as illustrated in **Figure *13***. As the diagram also shows, all the parties that own the property, the user can also click on one of the party boxes to see whether they own another property, which leads to the second diagram.

1b. Party relations diagram
Lemmen et al. (2025) states that an LADM instance-level diagram can be used to reveal the party-to-land relationships in the LADM. In Figure 7, case (a) shows records of multiple spatial units, each with its corresponding BAUnit and right, connected separately to the same party. In contrast, case (b) resolves the repetitive layout by aggregating the party into a single node that branches out to multiple rights. By implementing this layout, it facilitates users to comprehend how many rights, BAUnits, and spatial units are associated with a specified party, as depicted in Figure 10.(b). To return to the previous graph, users can simply click the Back to Full Graph button located in the upper-right corner.

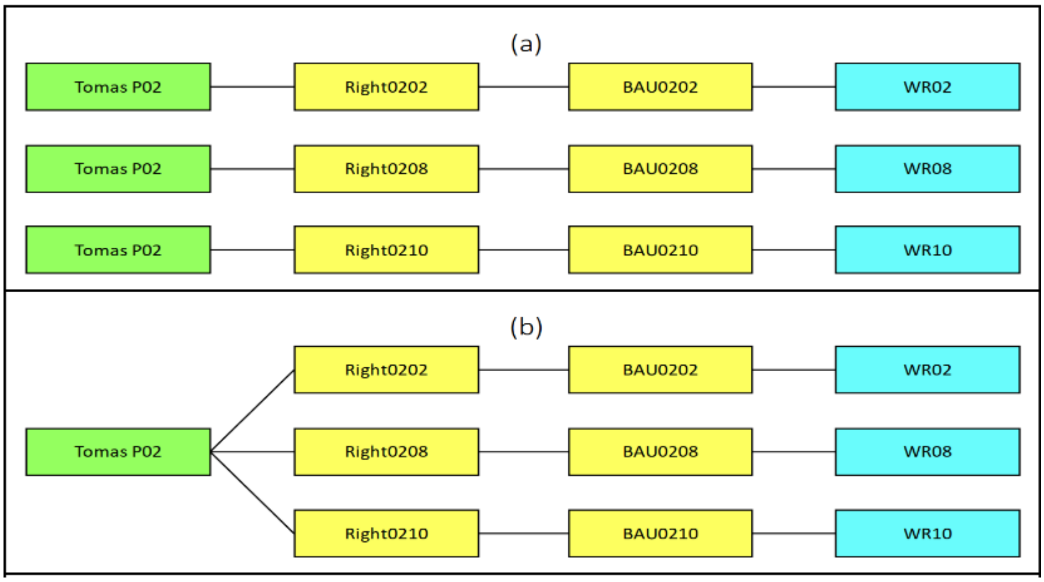

Figure 9. People to land relations represented (Lemmen et al., 2025)

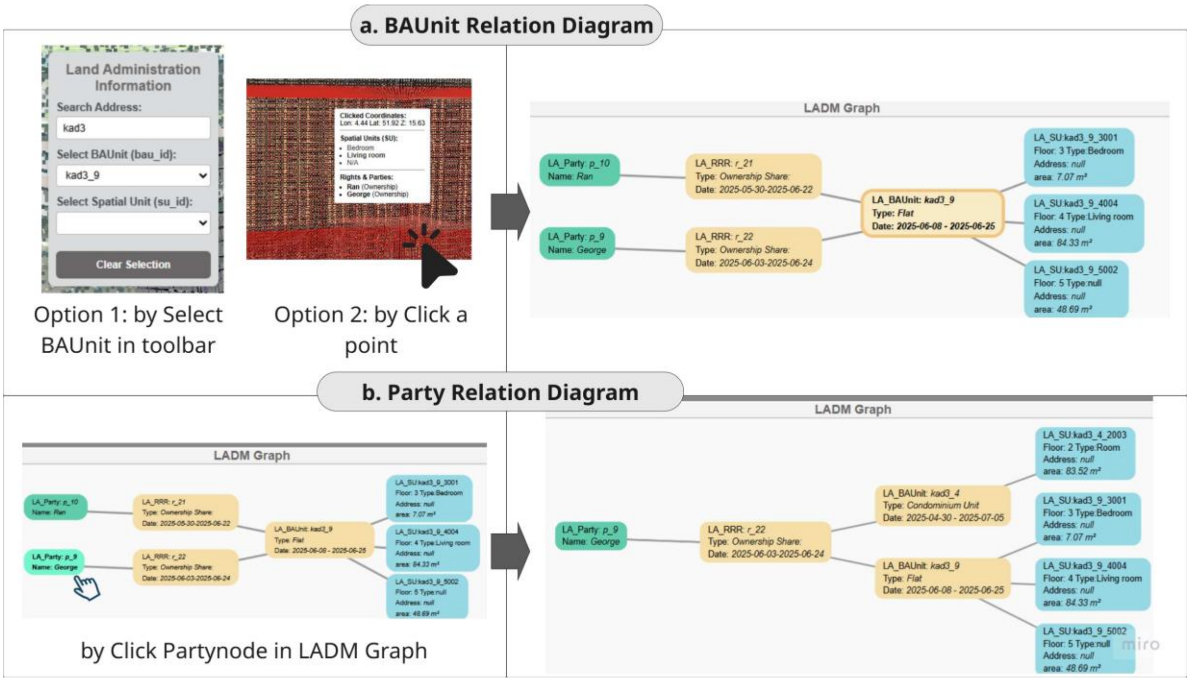

Figure 10. BAUnit relation and Party relation in Instance Level Diagram

(2) BAUnit Colorization Checkbox

The 3D point cloud building model is rendered as the user selects the address in the dropdown option, which will automatically zoom to the desired building. In the right panel, there is a checkbox list based on the Basic Administrative unit. By default, all color boxes are checked, showing all the BAUnit with different colors as shown in **Erro! Fonte de referência não e ncontrada.**. If the user unchecks, then the corresponding BAUnit points will be discolored and decreased in size as occurred in Figure 12. However, unlike in Potree, which has a built-in feature for color classification filter, in Cesium, this feature needs to be created manually, and due to restrictions on point styling, the points may not completely disappear, but still remain as small white dots. This tool enables users to identify the specific BAUnit by color and contrast certain BAUnits by their appearance, which can be selected via a checkbox. A study by Wang et al (2012) shows that visual variables, including size and color, are suitable to represent bounded and partially bounded 3D legal units. Size and color are known as the most efficient visual variables for human perception. By leveraging the change and difference in size and color, it helps users to easily identify the BAUnit. Since a single BAUnit may contain multiple spatial units, this helps users to effortlessly recognize which units in the building are owned by the same or different person. Additionally, common spaces are easily distinguished by their distinct color, which is visually separate from other private spatial units.

(3) Selection and Highlight

Cemellini et al. (2020) identified object selection and highlighting as essential client-side tools for 3D LAS visualization. Selection is one of the fundamental universal tasks in 3D user interfaces, referring to the process of identifying and selecting one or more objects within a 3D environment (Bowman et al., 2012; Steed, 2006). Highlighting, in turn, supports this interaction by enabling users to easily perceive the active or selected object. Typically, highlighting is achieved by altering the visual style or appearance of the selected object, thereby leveraging pre-attentive cognitive processing (Trapp et al., 2011). **Figure *13*** illustrates two types of highlighting mechanisms. The first type highlights the BAUnit: when the user selects a BAUnit either via the toolbar or the LADM Graph, the camera automatically zooms to the selected BAUnit, and all points belonging to it are rendered in red. The second type highlights the spatial unit: when the user selects a spatial unit via the toolbar, clicks on a point, or selects a corresponding node in the LADM Graph, the application zooms in on the selected spatial unit and renders it in red, while other spatial units within the same BAUnit are displayed in a lighter shade of red. This feature delivers dynamic visualization to focus on the specified spatial unit for the user.

(4) LADM Edit Form
To support the LAS maintenance, any update to the data needs to be facilitated for authorized users. As the land administration information records always change over time, the edit LADM form is incorporated into the 3D Web-based LAS prototype. This tool can be easily accessed by clicking the Edit Information button, like in **Figure *14***.a that appeared after the user finished selecting their desired Spatial Unit. The Edit LADM Form emerges when the user clicks the button. If the selected spatial unit already has filled data with the linked party and right, then all the available data appears as in **Figure *14***.b.2, and the user can modify the data, such as add more parties or remove an existing party. If not, then the empty LADM form is shown like in **Figure *14***b.1 and the user can add a new party and right with the Add button, and fill the BAU accordingly. Since one party may have multiple rights, the user can also select how they want to append a new party to the specified units, whether by adding a brand new party or searching for an available party, as illustrated in **Figure *14***.c. Every new party and new right will have generated a new ID that the user can use to link them together. During the editing process, any change can be seen in the LADM Graph immediately. The user simply clicks the Save All button to save any modified data, then any change is saved to the database server, **Figure *14***.e. It also allows users to remove a party or right in the corresponding BAUnit. With this tool, the troublesome process of filling the LADM information in PostgreSQL can be avoided.

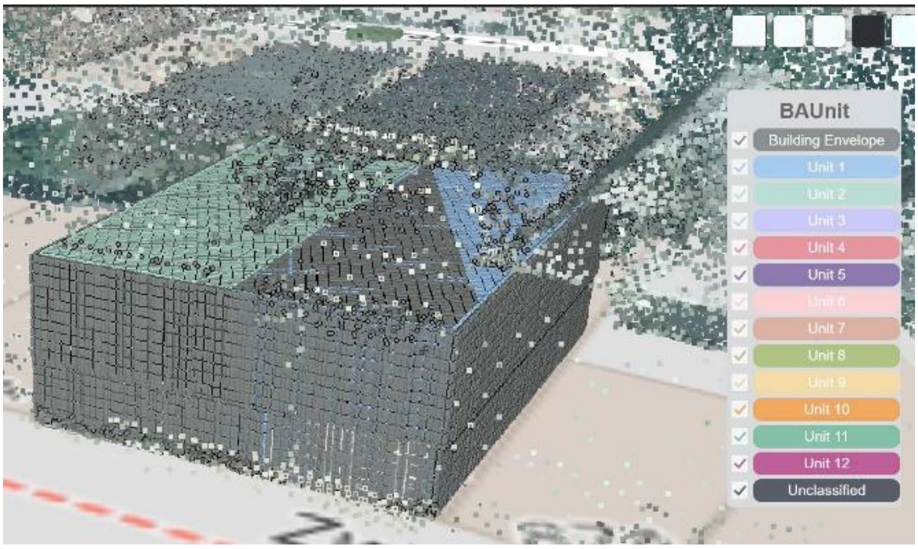

Figure 11. All Checked Colorbox

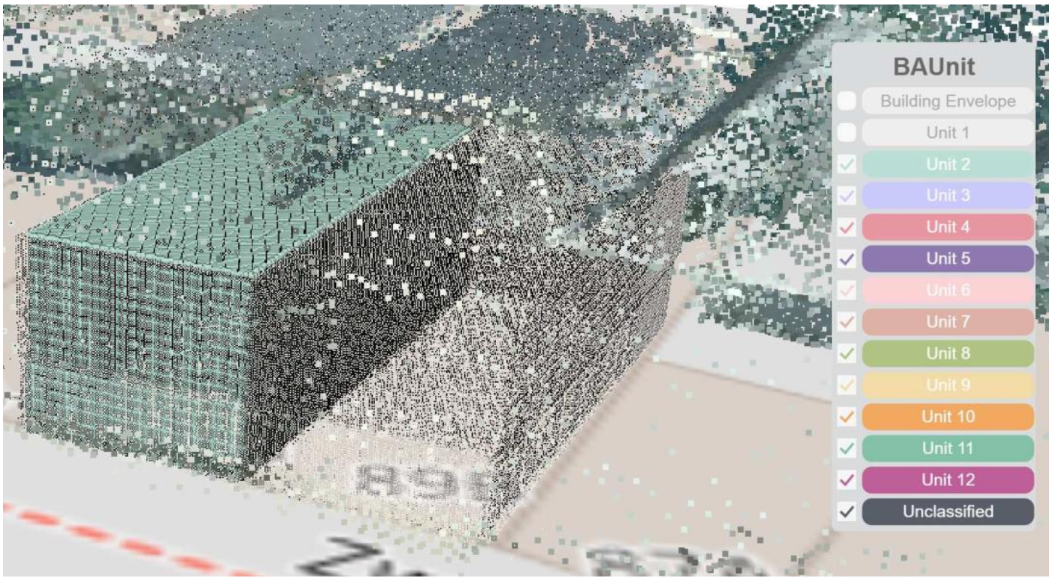

Figure 12. Unchecked Colorbox for Building Envelope and Unit 1

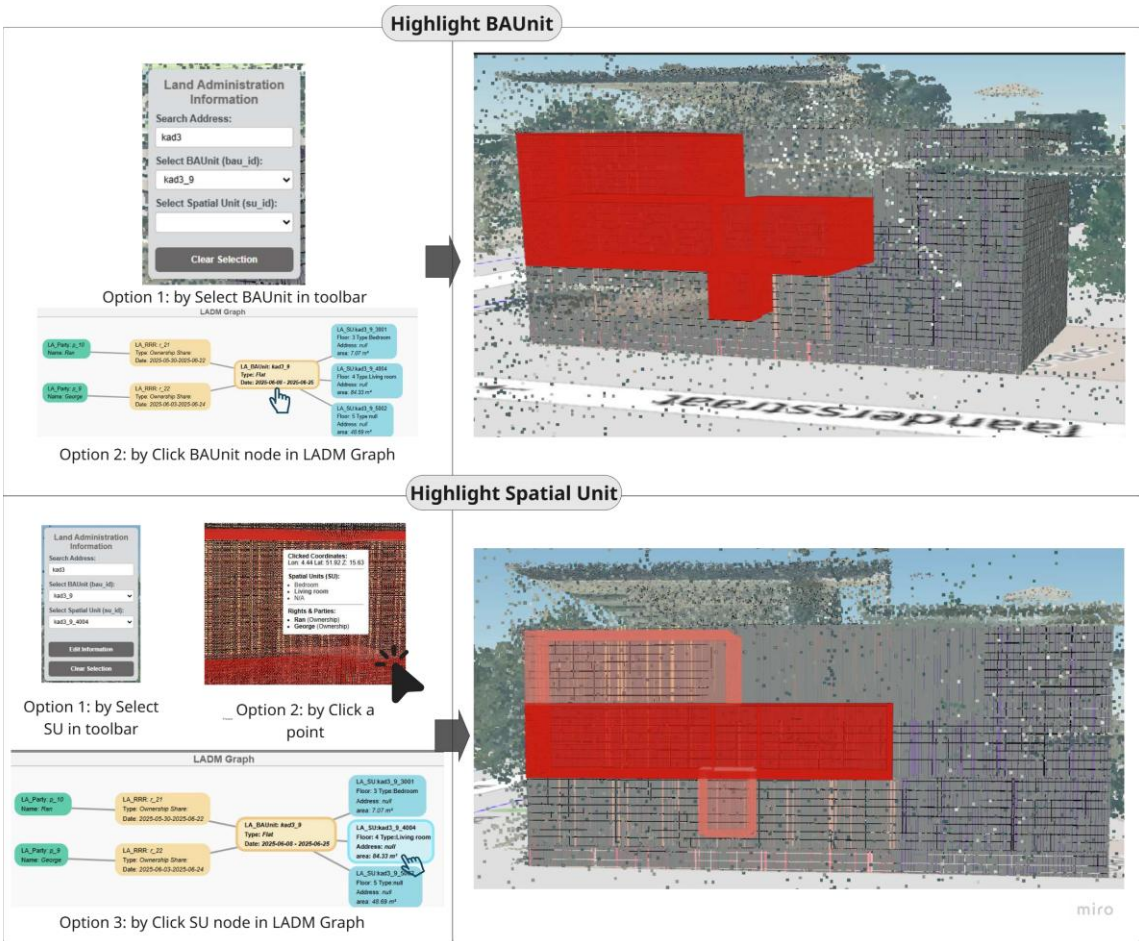

Figure 13. Highlight Features

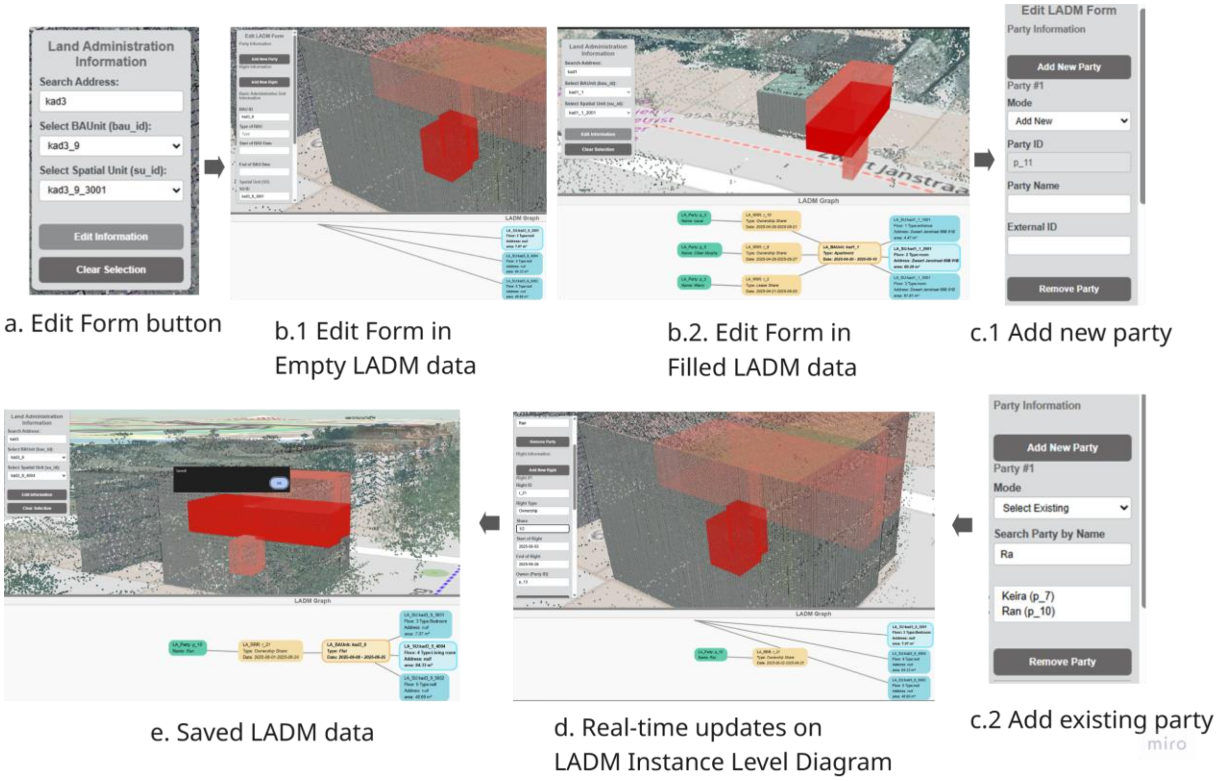

Figure 14. Edit Feature Process

(5) Underground View

As urban growth occurs not only above ground but also beneath the surface, several studies have emphasized that an underground view is an essential feature in 3D LAS visualization for revealing underground developments (Pouliot et al., 2018; Shojaei et al., 2013), such as utilities, basements, underground shopping malls, and subway stations. In the application, this feature can be activated by the user by toggling the underground mode via a control in the bottom-right corner of the interface. When enabled, the OpenStreetMap layer is hidden, allowing the user to explore the entire structure of the apartment building as shown in **Figure *16***, including all available spatial units located below ground level.

(6) Tooltip

Shojaei et al. (2013) includes a tooltip as one of the parameters for quick user recognition to improve the visualization utility. As a tool that is commonly used in GIS applications, its function is to identify the specified object and to provide the data attribute of that corresponding object. In this 3D LAS, see **Figure *16***, when the user clicks a point, it will select and highlight the points of the unit and offer brief information about the owner, right, and type of units of the corresponding unit. It displays the information of the selected spatial unit in bold, while the other spatial units within the same BAUnit are shown in regular font.

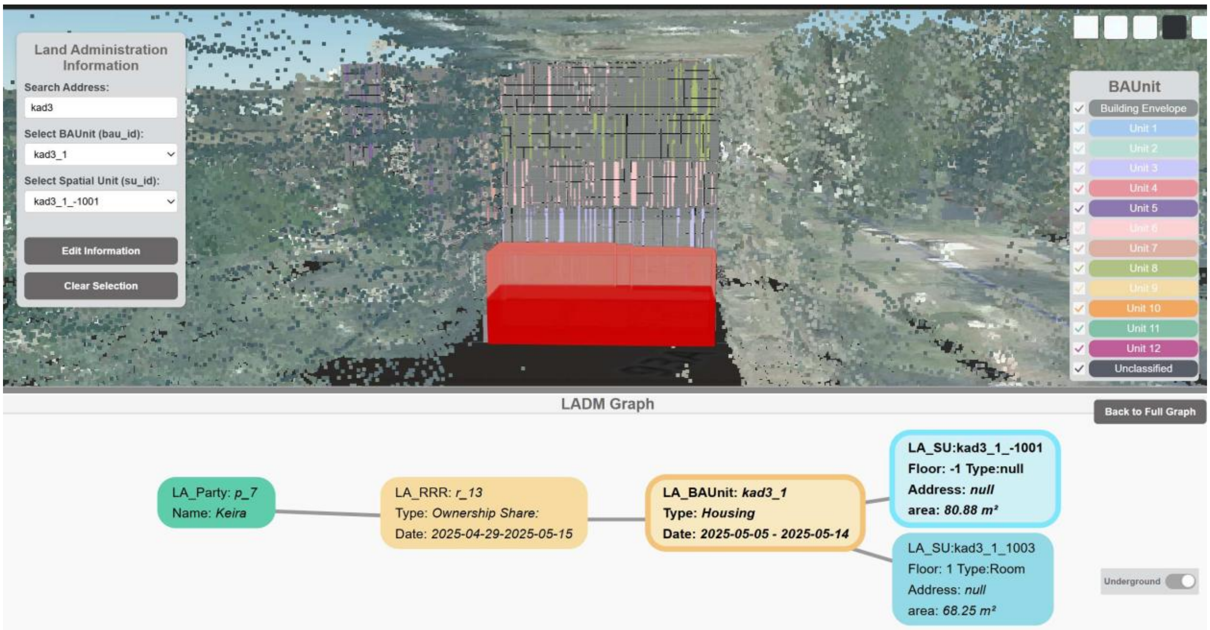

Figure 15. Underground View

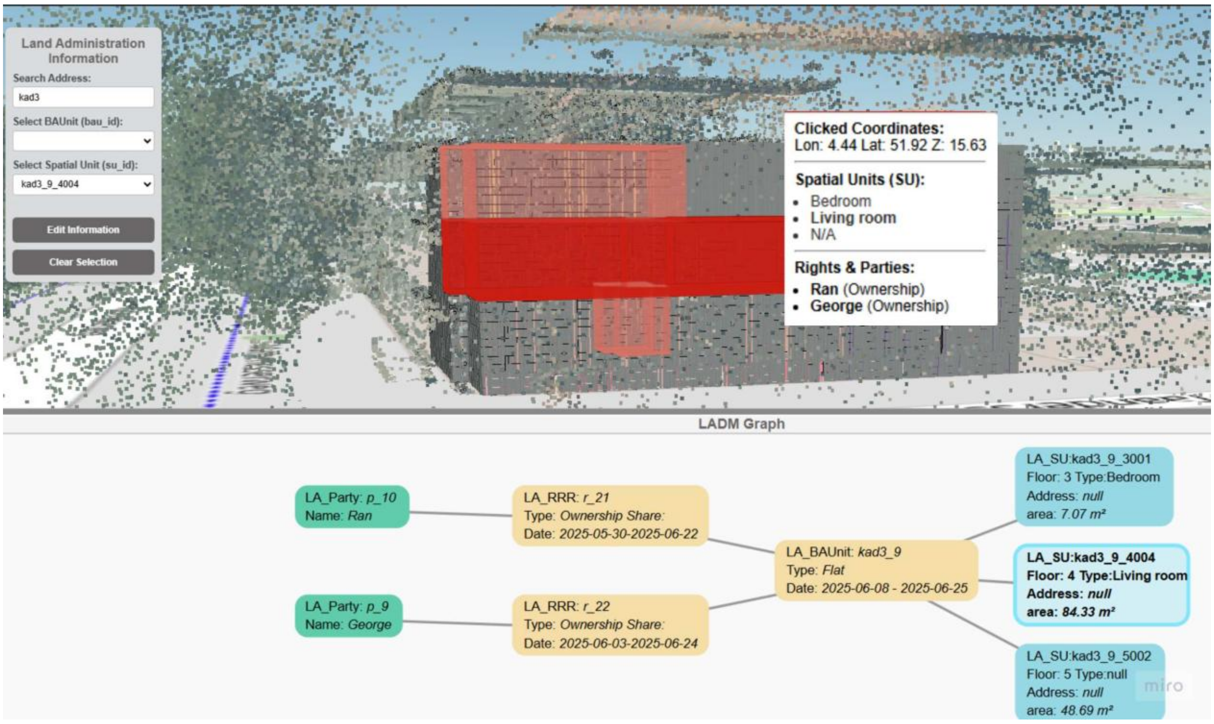

Figure 16. Tooltip

After the research, not all 3D LAS requirements listed from the literature review in **Table *1*** can be implemented in this research due to time limitations and the point cloud aspect, such as wireframe display, explode view, and sliding. Nevertheless, the majority of essential functionalities have been incorporated into the 3D LAS web prototype, as detailed in **Table *3***.

Table 3. List of Implemented Features for 3D Visualization and Web Viewer

For 3D Visualization of Land Administration Data	Implemented	For 3D Web Viewer	Implemented
Navigation tools and view controls	✓	Platform and browser independence	✓
Integrating topography and reference objects	✓	Handling massive data and caching/tiling between server and client	
Transparency		Layers control	✓
Object selection	✓	Database support	✓
Object search	✓	Support different models (vector/polyhedral, raster/voxel, point clouds)	✓
Wireframe display		Support of basic 3D topographic visualization	✓
Explode view		Support for georeferencing	✓
Sliding		Ensure spatial validity (3D vector topology)	
Cross-section view		Underground view	✓
Visualization cues	✓	Open source platform	✓
3D measurement tools		Possibility for the platform to be extended	✓
3D buffer		2D overview map (orientation)	✓
Display partly unbounded objects and 'complex' geometries	✓		
Party / RRRs visualization and selection	✓		
Point cloud-based	✓		

5. CONCLUSION

Instead of using a BIM model, this project presents an alternative using point clouds as 3D spatial units in a LAS. By combining cadastral drawings and a point cloud nationwide dataset, AHN, the apartment complexes with their own spatial units can be generated in this framework without additional survey or an existing BIM model. Although point clouds are widely used as input data, not final data, they can represent a real existing facade of buildings by integrating them with AHN, and provide land administration information by storing them in an LADM-compliant database. Moreover, the system is capable of generating a synthetic building point cloud in under two minutes per sample, indicating the feasibility of future nationwide implementation.

Some limitations are found in this study that require further improvement, particularly some manual intervention (e.g. the removal of stairs, OCR not recognizing all labels, etc.). Future research directions include the following:

- Scaling and Algorithmic Robustness: Expand to largescale pilot areas and more diverse floor plans to improverobustness. Develop deep learning methods for floor plan parsing and enhance point cloud segmentation to reconstruct more complex and realistic building geometries.
- International Applicability: Explore applicability in other countries by addressing differences in cadastral drawing formats and assessing the availability or alternatives to nationwide point cloud datasets.
- Accuracy Evaluation for 3D LAS: Conduct ground-truth validation using GNSS-based cadastral reference points. Improve accuracy through occlusion correction (e.g., (Balado et al.,

2019), alternative alignment methods, and integration of higher-resolution LiDAR (e.g., drone ALS, TLS, MLS)
- Spatial Analysis features: Future research may also explore applicability in other countries by addressing differences in cadastral drawing formats and assessing the availability or alternatives to nationwide point cloud datasets.

The code for this project is available in GitHub, while the website can be accessed in https://gist.bk.tudelft.nl/apps/LADMPointCloud/.

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