Reconstructing 3D apartment models from 2D notarial deeds

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1 Introduction

The recent trend of urbanization and the growing population has let more people to move to dense cities (Broitman and Koomen, 2020). According to the Kadaster, in 2023, sales for apartment buildings have increased compared to other types of housing. These apartment buildings often have multiple owners, of which the legal rights are managed through an owners association; in the Netherlands this is the Vereniging van Eigenaars (VVE).

The use of Building Information Modeling (BIM) for apartment buildings has been gaining popularity (Bryde et al., 2013). These models can be utilzed during the enire building process acrross various levels of detail and applications.

During the development of architectural design and construction, BIM models are often created as a 3D guide throughout the process. To make use of these already existing models, and integrate this with cadastral registration, the BIM legal model was developed (Stoter et al., 2024). This model provides a framework to visualize ownership in 3D, starting from the already existing 3D BIM model. From these models, the notarial deeds can then be derived.

However, especially existing buildings do not have these BIM models, that are increasingly generated created for newer buildings. As mentioned by Lovell et al., the preservation of these existing buildings in a BIM model is important for heritage and digitization. Therefor, a reverse process should be developed. In which BIM legal models are created from existing apartment sources. This would provide better data interoperability and bring these existing buildings up to current standards,

A possible type of data source to generate these models from, is the notarial deeds. Apartment units have legal ownership right documents for the VVE, these usually also contain ownership drawings or "splitsingsaktes" in Dutch; visualizing the interior sectioning of owners in an apartment. The maintenance of building ownership and visualization can be quite complex based on 2D drawings, especially in apartment buildings where units can spread over multiple floors, and multiple owners. With the rise of 3D building information, and increased building complexity, 3D visualization and cadastral registration would be better suited (Stoter et al., 2017).

Currently there is no (open) solution available for automating the process from notarial deeds to 3D BIM models, which is needed to reduce time and cost when converting large numbers of deeds.

To address these issues (1. Complexity of analyzing deeds of apartments in 2D, 2. Lack of BIM models of existing buildings, 3. Lack of an automated reconstruction process), this research focuses on the semi-automated conversion of 2D notarial deeds into 3D BIM legal models.

This research is a collaboration with the Dutch Kadaster and builds upon their previous work, which explored the potential for for automatic 3D visualization of apartment rights from notarial deeds. While the vectorization technique to automatically digitize the deeds was promising, there where challenges, mainly: automating the georeferencing process, and addressing the differences per deed. The goal of this study is to develop an, as far as possible, automated solution to generate BIM Legal models from existing 2D notarial deeds, making it possible to to model and visualize ownership in 3D for older buildings, without the need for existing BIM data.

By developing such a process, this research contributes to the field of Geomatics, where spatial data alignment using transformation, 3D reconstruction techniques and integration of various spatial data sources are used. The output will provide stakeholders, including property managers and legal authorities, with a visualization of ownership within apartment complexes. Additionally, the developed process can benefit other fields, such as the application of georeferencing techniques to architectural floor plans.

2 Related Theory

2.1 Kadaster

Spatial data related to property is managed and collected by a central cadastral organization in the Netherlands, namely the Land Registry and Mapping Agency, or 'Kadaster'. They also manage the mapping of boundaries across various scales in the Netherlands. Using the Kadaster datasets as input and integrating the results will ensure that the data remains centralized and interoperable.

2.1.1 Apartment Rights

One of the rights managed by the Kadaster is the property ownership rights of apartments. This is described through notarial deeds, or 'splitsingsaktes' (division deeds). As summarized by Meulmeester (2019), notarial deeds are legal documents specifying how buildings are separated into private units, according to their function. These notarial deeds include a written section containing the separation details and regulations of the owners' association (VvE). Since 1973 they also require the attachment of a 'splitsingstekening' (division drawing) (Kadaster). These drawings display the ownership in 2D. Over the years, the format requirements for these drawings have changed.

2.1.2 Previous Work

The Kadaster has done a pilot research on creating 3D models from notarial deeds. This study build upon another application developed for the Kadastrale Kaart Next (KKN), called VeCToR. For this application, AI was trained to vectorize and georeference field sketches, in order to re-align the cadastral map (Franken et al., 2021).

The pilot on 3D reconstruction utilized the vectorization, and made changes to detect closed line sequences and store these geometries as "rooms". The AI model was trained to identify apartments by recognizing the thick lines and numbering used in notarial division drawings to distinguish individual units. During vectorization, each room is recognized and given a functional description, and the corresponding apartment number.

The georeferencing step was performed manually using QGIS and aerial imagery. The floor heights were determined based on the 3D Basisvoorzieningen dataset, which holds height information for buildings and terrain. They were then extruded from the roof downwards, to account for the possibility of having basements, and thus not starting from ground floor height (Baving et al., 2023).

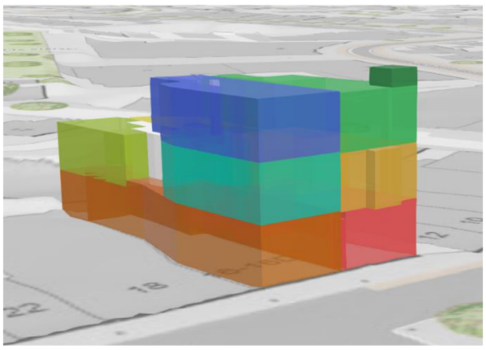

Figure 1: A result of the 3D visualization of apartment rights, colored according to their apartment number. (Adapted from: Baving et al. (2023)

2.2 3D Property Rights

The use of 3D for property management and visualization has become an increasingly popular topic of research for cadastral systems. Especially for complex buildings like apartments, the use of 3D can provide clarity in the division of property. In this section, several studies on 3D cadastral legal property rights are reviewed.

Döner and Şirin (2020) reviewed the use of 3D models for their apartment representation in Turkey, focusing on the transition from a 2D cadastral system. Their method involves creating LoD(Level of Detail)2 from photogrammetric data, and then providing more detail and interior spaces based on architectural projects. As they compare in their research, the Netherlands 3D reconstruction from notarial deeds has the advantage of being connected to the 2D cadastral objects and having a distinction between legal and physical spaces.

In the Netherlands, Stoter et al. (2017) explored the registration of 3D legal volumes, which is especially relevant in situations with multiple owners. This includes the right to an air space like a view, but also apartment rights. The use of real world cases proved that the 3D visualization provides better insight into the ownership in case of multiple owners.

Also in the Netherlands, a study was done by Broekhuizen et al. (2025) to assess the value of reusing real world BIM models for 3D cadastral registration. Various studies had been done before based on specifically adapted BIM models, but not on real world BIM models. They concluded that these models lacked a link to their legal units, attributes to georeference, and rooms of IfcSpace. However, this link to the legal units is present in the notarial deeds, as well as a connection to the parcel for georeferencing.

2.3 BIM Legal

The use of a standard BIM data model for 3D legal property registration was proposed by Meulmeester (2019). It is based on the idea of enriching existing BIM models with legal property information such as defining the individual property units as legal IfcSpace. This laid the groundwork for defining the BIM Legal standard.

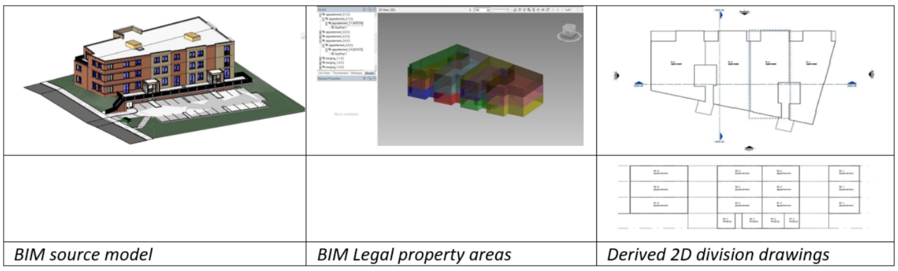

Figure 2: BIM Legal and its derived division drawings Source: VDNDP Construction Engineers (adapted from Stoter et al. (2012)

A more recent study by Stoter et al. (2024) investigates the development of the BIM Legal model to integrate BIM models with cadastral registration. The goal is to visualize the building ownership in apartment complexes. The described phase 1 focuses on a method to derive 2D notarial division drawings from 3D BIM models of apartment complexes. Which is the reverse process of this research.

2.4 3D Reconstruction

Gimenez et al. (2015) reviewed the available solutions for reconstructing 3D BIM models of buildings from both on-site acquisition and from building documentation. Herein, the use of

2D paper plans of these buildings was identified as being most promising, due to their low cost, high availability, and high accuracy, though dependent on the completeness and reliability of the plans themselves. They identified several issues: the lack of a method for the full reconstruction process, interoperability issues of the used data model, a lack of information in the source data, not recognizing all building elements due to the difficulty of symbol recognition, and 3D models being incomplete due to missing semantics or the height being manually set or defaulted.

They also name several topics for future research, as seen in figure 3. These topics closely align with this research.

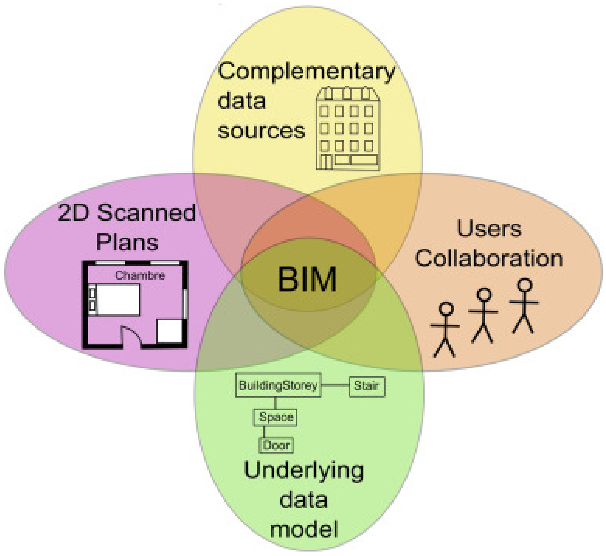

Figure 3: Potential topics for future research, adapted from Gimenez et al. (2015)

- Using complementary data sources: they mainly mention the use of aerial imagery or facade photographs. However, in 2015 the use of existing 3D models was not widely available in 2015 and thus not considered, such as the 3DBAG which is available now. Laser scanning was identified as another very useful data source to use for 3D reconstruction but also has high cost and time for individual use. However, the point cloud model of the Netherlands *Actueel Hoogtebestand Nederland* (AHN) and its already processed 3DBAG model, are readily available as additional information.

- Keeping the user in the loop: This includes giving them feedback on the reliability of the input and output, as well as the required information for the BIM model. They also name the possibility of creating a semi-automatic reconstruction process to aid the non-expert user.

- Underlying data model: IFC is regarded as the most complete building model. However, this also allows numerous ways of modeling the same relationship. Using a simpler compatible model would make the process more straightforward. For this, the BIM legal model is well suited as a simpler model, that is also domain specific and IFC compatible.

- The use of 2D scanned architectural plans: Instead of using the 2D scanned plans as proposed in this review, this research will focus on the use of 2D scanned deeds. These plans are also readily available and are more suited for large scale projects involving numerous reconstructions, due to the availability of these deeds by the Kadaster, instead of the architectural plans.

Another company called PDF2GIS (2025) has developed a semi-automatic tool to reconstruct 3D models from notarial deeds, aligning with the WOZ. However, their application and research are not open and therefore cannot be taken into account in this study.

3 Research Objectives

The objective of this research is to develop a (semi-)automatic method of reconstructing 3D BIM legal apartments from 2D vectorized notarial deeds. These BIM models should be accurately georeferenced, extruded to a certain height, and created according to BIM legal standard. This research strives to create an inventory of valuable information in the notarial deeds, or the lack thereof, that is necessary for the 3D reconstruction. For instance, by making use of the north arrow or the apartment section drawing.

3.1 Objectives

The topic is further divided in the following research objectives:

- **Georeferencing**
  - **Data Utilization:** What data can be utilized from the notarial deeds to aid in the georeferencing process, and what is their value?
  - **Initialization and Optimization:** Which initialization and optimization techniques are most suited to align the notarial deed footprints to the Basisregistratie Grootschalige Topografie (BGT)? How accurately have the footprints been georeferenced?
- **3D Reconstruction**
  - **Data Utilization:** What data can be utilized from the notarial deeds to aid in the 3D reconstruction, and what is their value?
  - **Extrusion and Positioning:** How can the floor heights be estimated? How can the floor plans be positioned in 3D? What is the accuracy of the resulting model?

3.2 Scope

Vectorization, including the improvement of the existing VeCToR application, will not be considered in this research. The use of aerial or street view imagery for the 3D reconstruction will not be considered, as imagery linked to the apartments on a large scale is unavailable. Additionally, the extent to which the process will be automatic, will depend on the accuracy that can be achieved without human intervention. The visualization of the resulting 3D apartment model will only be explored if time allows.

The focus of the study lies in the exploration of methods to accurately georeference and reconstruct the 3D apartment models from notarial deeds, with the goal of producing a semi-automated process.

4 Methodology

To achieve the objectives, the following methodology is proposed. There will be two major steps: Georeferencing and 3D reconstruction.

4.1 Georeferencing

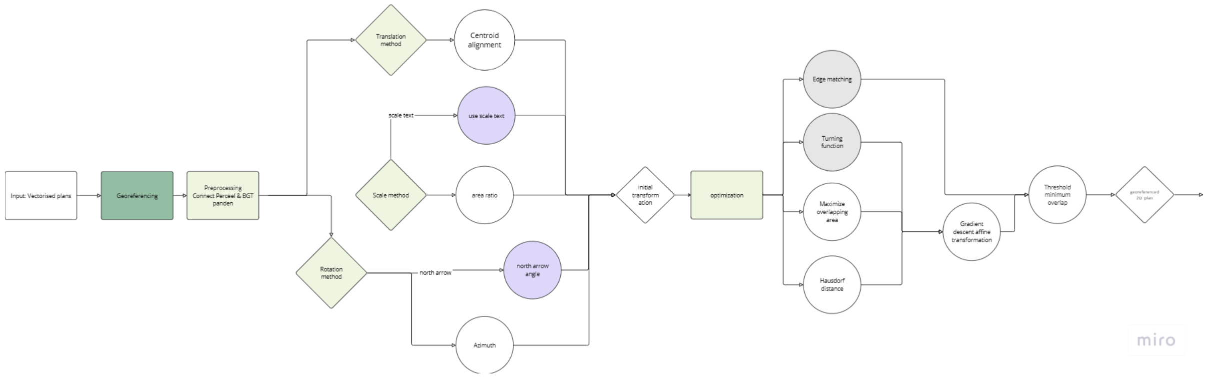

Figure 4: Georeferencing Workflow

Georeferencing will require preprocessing the input vectorized deeds, followed by an initialization, after which the position, scale and rotation can be optimized to the BGT geometry.

4.1.1 Preprocessing

The input deeds contain references to specific parcels, which provides the initial connection to the location of the building. To link the deed to its corresponding building's polygon, the parcels geometry is first retrieved by querying the Kadastrale Kaart OGC API.

Next, the BGT is queried to find the buildings which are on the parcels. However, the BGT API accepts only bounding boxes as input, not the polygon geometry. Therefore, the bounding box of the parcel is used as the query parameter. Once the BGT data is obtained, any BGT building whose polygon geometry does not intersect with the parcel's boundaries are filtered out.

4.1.2 Initialization

Then, the geometries of the vectorized deeds can be transformed to fit to the corresponding buildings. However, it requires several affine transformations to be correctly georeferenced. This process begins with an approximate initial positioning, followed by more complex and computationally intensive methods of aligning, as discussed in section 4.1.3.

- **Translation**: Firstly, the translation is performed by overlaying the centroids of the building and the deed to match their positions.
- **Scale**: The scale can be approximated based on the difference in the area ratio between the building and the deed. Another option would be to use the scale text (e.g. 1:100) that is (not always) provided in the deed.
- **Rotation**: To determine the rotation angle, the difference in azimuth can be used. The angle of the north arrow on the deed might also be useful, but this would require more intensive machine learning algorithms to acquire.

4.1.3 Optimization

The problem that will be tackled is an optimization problem of shape alignment and registrationVeltkamp (2001). This means that the best transformation must be found to match one polygon, the deed, to a reference polygon, the BGT footprint. In this case, point-to-point based methods are not applicable, as the polygons differ in terms of number of points and shape. Two of the most frequently mentioned techniques in literature are the Hausdorff distance and the turning function (Ruiz-Lendínez et al., 2017), (Veltkamp, 2001), (Ryu and Kamata, 2021).

- **Turning Function**: The turning function is used to compare polygon contours by analyzing their turn angles along the boundary. It minimizes the difference in shape by adjusting the rotation angle. However, it does not take into account the translation and scaling, which must be estimated (Ruiz-Lendínez et al., 2017).
- **Hausdorff Distance**: The Hausdorff method focuses on minimizing the distance between the contours of the two polygons. It calculates the maximum distance between the closest points of the polygons (Ryu and Kamata, 2021). Since this method is based on the contours, the accuracy depends on how similar the contours are.
- **Edge Matching**: Edge matching is used by the KKN to match and align field sketch polygons to reference polygons (Franken et al., 2021). However, this method is limited when polygons differ significantly. For example if one polygon contains many small edges instead of one long edge. This would require preprocessing (Long et al., 2016).
- **Area-Based Overlap**: An alternative approach that takes into account the global fitting is to use an area-based metric. This method uses gradient descent to iteratively optimize the alignment by maximizing the goodness-of-fit metric, as proposed by Hargrove et al. (2006). This approach can handle cases where polygons do not have closely matching contours, but may struggle with properly aligning local variations, as it prioritizes the total overlap.

To account for both local contour alignment and global area overlap, a combination of the Hausdoff distance and area-based overlap metrics is proposed. This would require the minimizing of the Hausdorff distance and maximizing of area overlap, in order to find the optimal transformation to align the deed footprint to the BGT footprint. Depending on time constraints, this will also be compared to using the edge matching algorithm.

4.2 3D reconstruction

This section describes the methodology used to extrude the georeferenced polygons to 3D and position the floors accordingly.

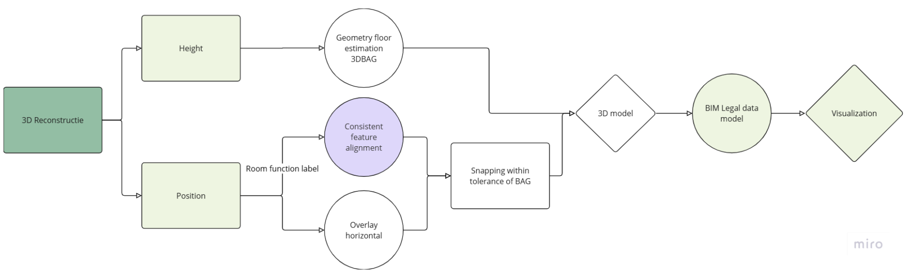

Figure 5: 3D reconstruction method

4.2.1 Height estimation

For a more precise estimation of floor heights than simply dividing the building height by the amount of floors, a similar methodology as proposed by Boeters et al. (2015) will be used.

In this method, the geometry provides insights into the possible position of a floor. Combined with the machine learning-based floor count estimated by Roy (2022), as included in the 3DBAG, floor heights can be determined.

4.2.2 Positioning in 3D

Since individual floors may have varying rotations or misalignments, it is necessary to position these floors independently. This step can re-use the method for georeferencing the ground floor, except with the usage of the BAG instead of the BGT, to account for possible overhangs on these floors. Again they will need to be snapped to this BAG outline.

Another approach that will be tested is to use consistent features across floors as anchors. For instance, vertical elements such as elevator shafts or staircase rooms should be consistently positioned on each floor. Using these geometries as anchors, the complete floor geometries can be positioned accordingly.

4.2.3 Format and Visualization

The resulting 3D models will be validated by comparing their volume to the 3DBAG LoD1.3. The georeferencing of the notary deed drawings is assessed according to their goodness-of-fit and Hausdorff distance metrics relative to the BGT building footprints.

Finally, the apartment units and their rooms need to be refined to comply with the BIM Legal data model requirements. To achieve this, the thickness of walls and floors must first be estimated and subtracted from the reconstructed room geometries. Additionally, the rooms need to be grouped into apartment units.

5 Time planning

The thesis planning is visualized in the Gantt chart in image 6.

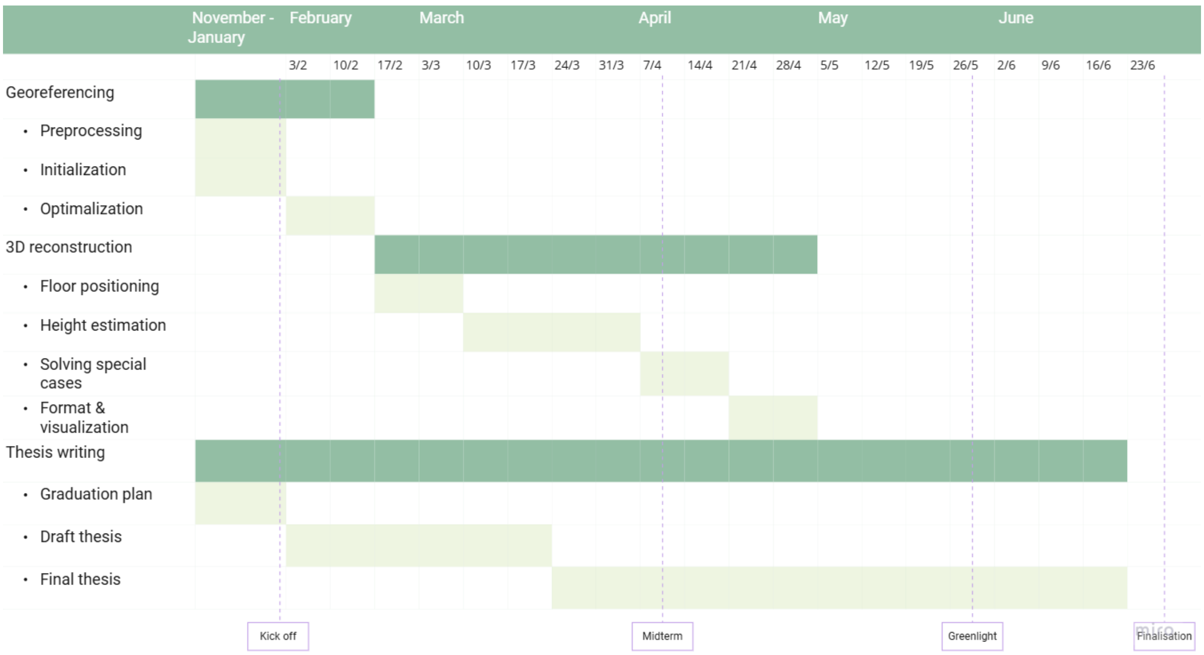

Figure 6: Thesis planning Gantt chart

6 Tools and Datasets

6.1 Tools

For this project, Python will be used to develop the full proces from georeferencing to 3D reconstruction. The *geopandas* library will be used to work with the spatial data, together with *shapely* for performing geospatial operations. Additionally the *matplotlib* library is utilized for visualizing, as well as *QGIS*.

6.2 Datasets

The input datasets required for this project were acquired through Kadaster. The starting data is the output from their pilot research. This includes the vectorized data in JSON format, as well as the original PDFs of the scanned deeds. The shapefile results of their previous work on manually georeferencing and 3D reconstruction are also available.

Due to the inclusion of personal data, the notarial deeds themselves will not be provided in the submission of this thesis. However, the implementation will be openly available.

Additionally, in order to perform the georeferencing, the deeds are connected to corresponding cadastral datasets through their parcel or building ID:

- **BRK**: The *Basisregistratie Kadaster* provides cadastral maps showing parcel details and administrative boundaries, along with associated data like ownership.
- **BGT**: The *Basisregistratie Grootschalige Topografie* represents the physical environment. The building geometries in the BGT refer to the footprints of the buildings.
- **BAG**: The *Basisregistratie Adressen en Gebouwen* contains information on all addresses and buildings in the Netherlands, such as construction year, area, purpose, and location. Its building geometries are represented from a top-down view.

The resulting models will contain a reference to their corresponding BAG, BGT and BRK parcels and buildings.

In the 3D reconstruction step, the deeds are also connected to the 3DBAG through their BAG ID. The 3DBAG is an open data set containing 3D building models of the Netherlands, reconstructed by combining building data from the BAG with the AHN (Peters et al., 2022).

References

T. Baving, P. Brouwer, V. Liem, and I. Reimerink. Bevindingen pilot 3d visualisatie appartementsrechten, 2023.

R. Boeters, K. A. Ohori, F. Biljecki, and S. Zlatanova. Automatically enhancing CityGML LOD2 models with a corresponding indoor geometry. 2015. ISSN 1365-8816. URL https://www.tandfonline.com/doi/abs/10.1080/13658816.2015.1072201. Publisher: Taylor & Francis.

M. Broekhuizen, E. Kalogianni, and P. V. Oosterom. Bim/ifc as input for registering apartment rights in a 3d land administration systems – a prototype webservice. *Land Use Policy*, 148: 107368, Jan. 2025. ISSN 02648377. doi: 10.1016/j.landusepol.2024.107368.

D. Broitman and E. Koomen. The attraction of urban cores: Densification in dutch city centres. *Urban Studies*, 57(9):1920–1939, July 2020. ISSN 0042-0980, 1360-063X. doi: 10.1177/0042098019864019.

D. Bryde, M. Broquetas, and J. M. Volm. The project benefits of building information modelling (bim). *International Journal of Project Management*, 31(7):971–980, Oct. 2013. ISSN 02637863. doi: 10.1016/j.ijproman.2012.12.001.

Coders Co. Pdf2gis, 2025. URL https://codersco.com/pdf2gis/.

F. Döner and S. Şirin. 3d digital representation of cadastral data in turkey—apartments case. *Land*, 9(66):179, June 2020. ISSN 2073-445X. doi: 10.3390/land9060179.

J. Franken, W. Florijn, M. Hoekstra, and E. Hagemans. Rebuilding the cadastral map of the netherlands: The artificial intelligence solution. 2021.

L. Gimenez, J.-L. Hippolyte, S. Robert, F. Suard, and K. Zreik. Review: reconstruction of 3d building information models from 2d scanned plans. 2:24–35, 2015. ISSN 2352-7102. doi: 10.1016/j.jobe.2015.04.002. URL https://www.sciencedirect.com/science/article/pii/S2352710215000145.

W. W. Hargrove, F. M. Hoffman, and P. F. Hessburg. Mapcurves: a quantitative method for comparing categorical maps. 8(2):187–208, 2006. ISSN 1435-5949. doi: 10.1007/s10109-006-0025-x. URL https://doi.org/10.1007/s10109-006-0025-x.

Kadaster. Wat is een splitsingstekening? - kadaster.nl particulier. URL https://www.kadaster.nl/-/wat-is-een-splitsingstekening-.

Kadaster. Woningmarkt 3e kwartaal 2023: stedelijke appartementen in trek bij jongeren, 2023. URL https://www.kadaster.nl/-/woningmarkt-3e-kwartaal-2023-stedelijke-appartementen-in-trek-bij-jongeren.

T. Long, W. Jiao, G. He, and Z. Zhang. A fast and reliable matching method for automated georeferencing of remotely-sensed imagery. *Remote Sensing*, 8(1):56, 2016. doi: 10.3390/rs8010056. URL https://www.mdpi.com/2072-4292/8/1/56.

L. J. Lovell, R. J. Davies, and D. V. L. Hunt. The application of historic building information modelling (HBIM) to cultural heritage: A review. 6(10):6691–6717. ISSN 2571-9408. doi: 10.3390/heritage6100350. URL https://www.mdpi.com/2571-9408/6/10/350. Number: 10.

R. W. E. Meulmeester. Bim legal: Proposal for defining legal spaces for apartment rights in the dutch cadastre using the ifc data model. 2019.

R. Peters, B. Dukai, S. Vitalis, J. van Liempt, and J. Stoter. Automated 3d reconstruction of lod2 and lod1 models for all 10 million buildings of the netherlands, 2022. ISSN 0099-1112.

E. I. Roy. Inferring the number of floors of building footprints in the netherlands. 2022. URL https://repository.tudelft.nl/record/uuid:6de4255c-ab2b-49c2-a282-ed779de092a1.

J. J. Ruiz-Lendínez, M. A. Ureña-Cámara, and F. J. Ariza-López. A polygon and point-based approach to matching geospatial features. 6(12):399, 2017. ISSN 2220-9964. doi: 10.3390/ijgi6120399. URL https://www.mdpi.com/2220-9964/6/12/399. Number: 12 Publisher: Multidisciplinary Digital Publishing Institute.

J. Ryu and S.-i. Kamata. An efficient computational algorithm for hausdorff distance based on points-ruling-out and systematic random sampling. *Pattern Recognition*, 114:107857, 02 2021. doi: 10.1016/j.patcog.2021.107857.

J. Stoter, P. V. Oosterom, and H. Ploeger. The phased 3d cadastre implementation in the netherlands. 2012.

J. Stoter, H. Ploeger, R. Roes, E. v. d. Riet, F. Biljecki, H. Ledoux, D. Kok, and S. Kim. Registration of multi-level property rights in 3d in the netherlands: Two cases and next steps in further implementation. *ISPRS International Journal of Geo-Information*, 6(66):158, June 2017. ISSN 2220-9964. doi: 10.3390/ijgi6060158.

J. Stoter, A. Diakité, M. Reuvers, D. Smudde, J. Vos, R. Roes, J. van der Vaart, A. Hakim, and S. El Yamani. BIM legal: 19th 3d GeoInfo conference 2024. 48(4):111–120, 2024. ISSN 1682-1750. doi: 10.5194/isprs-archives-XLVIII-4-W11-2024-111-2024. URL http://www.scopus.com/inward/record.url?scp=85198624476&partnerID=8YFLogxK.

R. Veltkamp. Shape matching: similarity measures and algorithms. In *Proceedings International Conference on Shape Modeling and Applications*, pages 188–197, 2001. doi: 10.1109/SMA.2001.923389.