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Incorporating 3D Building Data into National Spatial Data Infrastructure: Challenges and Insights from Slovenia

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Abstract

Incorporating detailed 3D building data into national spatial data infrastructures (SDI) is associated with numerous technical and administrative challenges. This paper presents and discusses the challenges that have emerged within recent 3D mapping initiatives in Slovenia. The increasing availability and affordability of LiDAR and photogrammetric technologies have enabled the automated generation of comprehensive 3D building datasets. Despite these technological advancements, several difficulties arise in integrating these datasets with existing cadastral and topographic databases. Primary challenges include discrepancies in spatial accuracy, outdated building outlines, semantic inconsistencies, and varying classification methodologies among datasets. Moreover, maintaining these integrated datasets is complex due to differing update cycles across cadastral and topographic systems. Cadastral data requires rigorous administrative processes for updates, while 3D modelling of buildings typically relies on automated procedures. Additionally, the legal status of cadastral data further complicates the integration. The challenges identified in the case of Slovenia can largely be generalised to systems in other countries, highlighting the necessity for strategic planning in data integration processes, considering both technical specifications and administrative frameworks, to use the full potential of 3D building data within national SDIs.

1. Introduction

Having a 3D topographic dataset of buildings at a national level or at least for larger cities has become common in many countries (Lei et al., 2022). This has been driven mainly by advancements in data acquisition and processing technologies. The availability of aerial and terrestrial spatial data acquisition methods, such as LiDAR and photogrammetry, has facilitated the large-scale acquisition of detailed 3D point clouds with increasing accuracy. The 3D spatial data acquisition and modelling technology has reached a point where producing such datasets is not only feasible but also economically viable on a large-scale (Hunag et al., 2022). One of the most contributing factors is the high level of automation of both acquisition and 3D modelling processes, which has significantly reduced the need for manual input while maintaining acceptable levels of precision and consistency (Ledoux et al., 2021; Peters et al., 2022). Moreover, improvements in machine learning and artificial intelligence-based classification methods have significantly improved the ability to extract and refine 3D features from input data (Park and Guldmann, 2019; Kumar Dey et al., 2023). As a result, the integration of 3D spatial data into official national SDI is becoming more common, offering new possibilities for many applications by either improving the existing datasets or establishing new ones.

Many 3D city models may contain multiple thematic groups (e.g. buildings, trees, roads, city furniture, etc) which is reflected by the complexity of urban environments (Wang et al., 2018; Jeddoub et al., 2023). However, buildings are by far the most common entity, often serving as the primary or even the only thematic group in many datasets. This dominance is largely due to the important role of buildings in many applications like urban planning, energy simulations, and real estate management, making them the primary focus of 3D spatial data collection and analysis (Willenborg et al., 2018). In Slovenia, numerous recent initiatives have focused on 3D building modelling, making 3D buildings the primary focus of this paper. With advances in automation, large-scale 3D building datasets are now feasible, though challenges remain when higher levels of detail or specific modelling requirements are introduced. Standards from OGC, such as CityGML, support data modelling and online dissemination, but managing periodic updates adds complexity. In many countries, 3D building datasets remain loosely connected to national SDIs, often linked only by common identifiers. This isolation is partly due to the diverse and country-specific nature of SDIs, in contrast to the standardised and automated 3D city modelling domain. The paper aims to explore these integration challenges within the Slovenian context.

2. Methods and materials

This paper focuses specifically on the Slovenian context. Therefore, an analysis of existing Slovenian SDI elements that provide data on buildings is presented together with recent national activities on 3D mapping. Within these activities, the challenges, presented in the next chapter, were identified and studied.

2.1 Buildings within the Slovenian SDI

In Slovenia, two datasets containing spatial data about buildings are being maintained, namely as cadastral data and within a topographic database. They are serving different purposes within the national SDI. Since they model the same spatial phenomena, they have a significant overlap but also some specific differences. In the context of this paper, these two datasets are the most relevant for integration with the new 3D building dataset. Both

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datasets are publicly available on the official public geodetic data portal (Public Geodetic Data, 2025)

2.1.1 Cadastral data: In the past, the Slovenian land administration system consisted only of the Land cadastre, providing continuous coverage with parcels and parts of parcels, and the Land registry. Buildings were included in the cadastre as outlines of the building's contact with the ground surface, either as separate parcels or as part of the main parcel, depending on the changing legislation. In 2000, the Building cadastre was introduced as a separate system (Figure 1). It provided the necessary basis for the registration of condominiums in the Land registry. Before, the condominiums were registered solely in the Land registry, where spatial data (sketches of floorplans) was part of the registration documents.

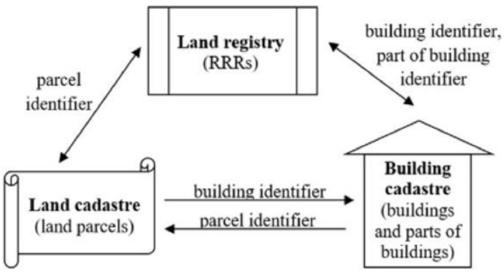

Figure 1. Slovenian land administration system (2000 – 2021) (Drobež et al., 2017).

The Building cadastre was designed as a multipurpose dataset with a national coverage of all buildings (not just condominium ones). Some data, including outlines of buildings, was collected nationwide from various sources. This included a photogrammetric acquisition of building outlines and characteristic heights from stereopairs. Some attribute data was collected from official data, and some was collected with a mass inventory of real properties. Only new buildings (built after 2006) and existing buildings where the condominium regime was established had a detailed entry, with detailed attribute data and geometry, which was surveyed in the field. Building cadastre was never a homogeneous dataset, but rather a collection of data on buildings from various sources. Recently (in 2021), there was a major reform, which joined Building and Land cadastre into one information system (Real Estate cadastre). The entry for a new building is now fully digital and contains several geometries (Figure 2). Before the reform, only the maximum extent outline was recorded in the Building cadastre, and the terrain intersection outline in the Land cadastre. Each building is also assigned 3 height attributes (min, max and height of the main entrance). These attributes enable simple 3D block (LOD 1) modelling of cadastral buildings.

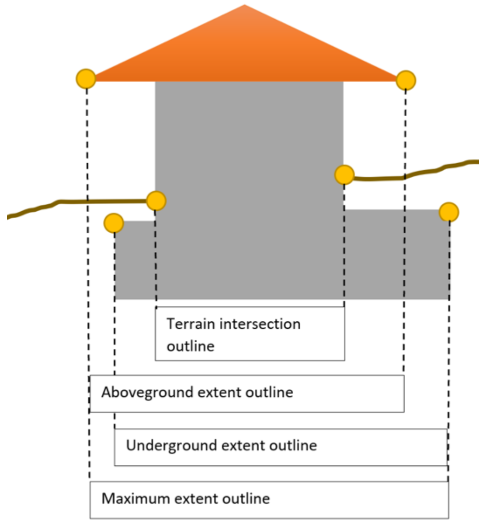

Figure 2. Outlines of a building in Real Estate cadastre.

The cadastral data on buildings has legal status. This means the data acquisition follows the official administrative process, with documentation provided by a licensed surveyor. The data cannot be changed without notifying the owner.

2.1.2 Topographic database: The Slovenian topographic database (DTM) contains generalised information on buildings for mapping and topographic purposes and does not have a legal role as cadastral data. The buildings are modelled as polygons (aboveground extent polygon) in 3D space compared to cadastral polygons, where polygons do not have Z coordinates (Figure 3).

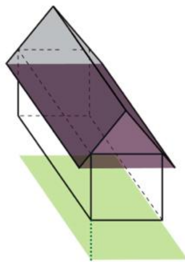

Figure 3. Building polygon in Real Estate cadastre (green) and DTM

The building outlines are derived primarily from aerial imagery interpretation and newly available LiDAR data. The positional accuracy of the geometry is declared to be better than 1 m. The primary update protocol is based on the selection of predefined tiles for each year's update. This results in a temporally non-homogeneous dataset. The update protocol was expanded in 2024 to include additional priority areas (not regular tiles) and the possibility for individual updates.

New buildings generally first arrive in the Real Estate cadastre, because official procedures require entry into the cadastral database to obtain an operational permit for the building. When the update is initiated for DTM, the cadastral polygons are taken as a supporting data source. The vertices of the polygons are given 3D coordinates and are tested against DTM specifications. The relation between cadastral and DTM buildings is therefore not 1:1 as the specifications and data sources differ (Figure 4).

Figure 4. DTM (red) and cadastral (yellow) building outlines.

DTM buildings can be separated into several parts. If the roof surfaces are not homogeneous, every independent roof surface is modelled separately as a building part. If a homogeneous building is modelled as multiple separate buildings in the Real Estate cadastre (for example, garages), DTM preserves this separation.

2.2 Recent 3D mapping activities

Slovenia's activities toward a nationwide 3D building model have entered a transformative phase. Following the initial nationwide LiDAR scanning in 2015, which is now outdated and insufficient for today's modelling standards, the country made a significant step forward in 2023. The launch of the CLSS project marked a turning point: a state-of-the-art, cyclic LiDAR and aerial imagery acquisition programme designed to deliver dense, up-to-date terrain data. This combination of technologies enables not only high-precision mapping but also the automated detection and modelling of buildings as they exist at the time of data capture. The final third of Slovenia's territory is being scanned this year, with an online portal already operational to visualise and share results (CLSS, 2025).

To ensure this rich data is put to optimal use, the Slovenian Surveying and Mapping Authority (GURS) initiated a pilot project to define the technical path toward a nationwide 3D building model. Multiple software solutions were rigorously tested for accuracy, level of detail, automation, flexibility, and standards compliance. Integration with the topographic DTM database was a key part of this evaluation. Complementary efforts have emerged to use the full potential of these datasets. One initiative (Lisec et al., 2024) is developing a national digital twin, with 3D buildings at its core. Simultaneously, the project V2-2385 (2025) explores the automatic extraction of 3D buildings from dense point clouds for use in the Real Estate cadastre and within a future GeoBIM framework. This project not only demonstrated how 3D data could enhance cadastral quality but also laid the groundwork for BIM integration into land administration systems.

While 2D cadastral data remains the legal foundation, a new parallel approach is being considered with 3D datasets that are linked to official records. Three strategic areas of integration are under development. First, alignment with the nationwide 3D dataset is being piloted at a level of detail (LoD) 2.2, using the classification proposed by Biljecki et al. (2014; 2016). Although some cadastral entries contain rich geometric detail, only about 15% of buildings can currently be modelled at LoD 2.3 using available outlines. Challenges arise when buildings deviate from the terrain intersection outline, limiting modelling accuracy. Second, the concept of individual entry is being reconsidered. New buildings will include both exterior (characteristic heights, outlines) and interior (legal parts and floor heights) geometries. This process, conducted by licensed surveyors under GURS oversight, reflects a major step towards fully 3D-enabled registration. Third, discussions are underway to introduce a differentiated approach based on building complexity. Simple, small-scale structures could follow a streamlined entry process, while larger, more complex buildings would require detailed 3D models of both exterior and interior elements. Many of the integration challenges outlined in this paper stem directly from these activities.

3. Results and Discussion

In this section, various challenges related to the integration of 3D buildings into national SDI are presented that have mainly emerged within the recent activities related to 3D mapping in Slovenia. To make the paper as clear as possible, the challenges are listed, described and discussed within one consolidated chapter.

3.1 Input data

Recent 3D mapping activities for buildings can follow many different approaches. The process of 3D building modelling can significantly benefit from having high quality 2D building outlines available as auxiliary input. If the building outlines and point cloud are aligned, this makes the integration of 3D models straightforward, at least with the dataset of building outlines. If these outlines are part of national SDI, the integration of 3D buildings into national SDI is much less complex. But usually, this is not the case. As presented, in Slovenia, we have building outlines in both cadastral and topographic databases. Figure 4 clearly shows the inconsistencies between the two. Additionally, there are significant inconsistencies between both building datasets and CLSS point cloud data, which is the main input for 3D modelling of buildings.

The challenges related to input data for 3D building modelling for integration into the national SDI can be attributed to different factors:

- Positional accuracy,
- Outdated building outlines,
- Classification of point cloud,
- Semantic differences.

3.1.1 *Positional accuracy:* Each spatial dataset has a specific accuracy, which is not always simple to interpret and understand. Some datasets have a homogeneous or nearly homogeneous accuracy for all features in the dataset. Typically, these datasets are acquired using one method from a single input data or technology. CLSS point cloud could be considered a homogeneously accurate dataset. DTM building outlines are a different example, where there are many data sources, but the acquisition methodology and data specification are just one. There are strict guidelines on how to use each input dataset and what is the target accuracy of the final dataset. Thus, while having various data sources (having different accuracies themselves), the final product is checked against uniform accuracy metrics (absolute positional error of less than 1 m). The third example is cadastral building outlines, where not only are different inputs used, but also different acquisition methods. The final dataset is therefore not homogeneous in terms of accuracy. Some outlines, acquired by the individual entry, are surveyed on the field with centimetric accuracy, while others were acquired using remote sensing technology or digitalisation, with less than 1 m accuracy.

3.1.2 *Outdated outlines:* Like accuracy, the up-to-dateness is not simple. While both datasets with building outlines cover the whole territory of the country, they also do not contain data that corresponds to a single point in time. The up-to-dateness corresponds to the maintenance methodology of the dataset. This will be presented in more detail later in Chapter 3.2 as a separate challenge for integration into SDI. From the perspective of spatial alignment, it is important to have all the datasets corresponding to the same timeframe, presuming we are dealing with a temporary changing phenomenon, which is the case for buildings. The CLSS point cloud covering 1/3 of the country each year and building outlines corresponding to various points in time lead to a certain degree of spatial mismatch.

3.1.3 *Classification of point cloud:* Depending on the method for 3D modelling, having a classified point cloud can be very beneficial. It is practically impossible to achieve 100% spatial correspondence between points classified as buildings and building outlines from another source. Points, classified as buildings, can be found outside outlines, and building outlines can cover areas where no points are classified as buildings.

3.1.4 *Semantic differences:* Different data sources may not have an aligned definition of building as a feature. Buildings are complex structures, consisting of many elements. Some of the elements may be considered part of a building according to one definition but excluded according to another. This leads to inconsistencies between building outlines. Ontology-based approaches can be used to manage and overcome these differences (Mignard and Nicolle, 2014).

3.2 Maintenance and updates

3D building models are usually created in campaigns for larger areas. The 3D models correspond to a narrow timeframe of point cloud acquisition. Integration with SDI datasets that correspond to different points in time is, therefore, challenging beyond the already mentioned spatial mismatch in 3.1. New buildings can be constructed in between, some buildings may no longer exist and some existing buildings can be changed. It would be less challenging if we could assume that one of the datasets, for example 3D buildings dataset, is always the most up-to-date. However, this is not always the case, as for newly constructed buildings, the cadastre can be more up-to-date due to mandatory entry that is stipulated by the legislation. Joining an object from one dataset to another, therefore, always yields some “orphaned records”.

3.3 Data officiality

Cadastral data on buildings is acquired and maintained according to the national legislation. The legislation defines the processes and methodologies which must be strictly followed. For new buildings, a licensed surveyor prepares the documents that are later signed by the owners and confirmed within official procedure conducted by Slovenian SMA officials. The status of this data is official, and any changes to the data need to follow official procedures, as the data is linked to the Land registry, providing data on rights, restrictions and responsibilities (RRR). The documentation for the entry has changed over time, and so has the data in the cadastral database. While the data, acquired within the entry process, can be considered very accurate, the level of detail in the geometric representation is not high. Furthermore, some changes might occur for these buildings from the time of entry. The availability of up-to-date 3D building dataset raises questions about updating the official cadastral data using 3D models. Should the inconsistencies of 3D models be used only as a warning and issuance of notification to the owners for updating the official data? Should the official processes be changed to include updates from 3D building datasets? Should owners be notified?

3.4 Data visualisation and usage

As shown, having more than one dataset representing buildings leads to inconsistencies. Nowadays, when all the data is digital, different datasets can be visualised in combination, exposing the differences and amplifying the issues related to these differences. The inconsistencies between the data on buildings within SDI can lead to several internal and external issues when users want to use the data for various applications. Questions arise, such as which data to use for a specific application, the most accurate, the most recent, or official/legal? Also, more sensitive issues related to RRRs can occur when official data is visualised in combination with other datasets.

3.5 Long-term management

The data is generally most useful if it is up-to-date. In Slovenia, the LiDAR acquisition campaigns are now designed to be cyclic. This brings challenges to the long-term data management strategy for 3D buildings. The easiest way is to change the entire dataset when the new models are modelled using the latest LiDAR data, and put the whole old dataset in the archive. This approach treats the 3D building dataset as a package. This way, we obtain more than one model of the same building that is at least slightly different each time. This can cause several issues for data users and even more if the dataset is integrated into national SDI. An alternative approach is to manage the buildings within the dataset individually and use a versioning approach to document the changes. This type of data management does not exclude campaign updates, they are just executed differently. Such a dataset is more consistent and more suitable for integration into national SDI.

3.6 Splitting the models

In Slovenia, the usability of existing topographic or cadastral building outlines for 3D modelling is limited (see 3.1.). Many buildings, especially in cities, are connected to each other with shared walls. Sometimes the roof morphology changes, and sometimes the roof and even walls may not change. In this case, the automated processes for 3D building modelling cannot detect the change and cannot create separate 3D models. This is one of the reasons why high-quality building outlines are a beneficial input for 3D modelling. Modelling the connected buildings as one 3D object can be problematic from the perspective of integration into SDI. Splitting the 3D models using the existing outlines can be as problematic as using them as auxiliary data for 3D modelling input in the first place. The initial analyses have shown that the existing outlines can only be used for splitting models to some degree, and that manual input will probably be required to achieve acceptable results.

3.7 Two-way integration

The nature of the 3D building models developed from point clouds is topographic. Logically, the dataset of 3D buildings in Slovenia will have more in common with the DTM database than with cadastral data. The challenges and also opportunities are especially in linking cadastral data and 3D buildings. As elaborated before, the cadastral database is not a homogeneous dataset, both in terms of content and accuracy. The system is hindered by the older, low-quality records acquired using various methods that lacked quality in the process and input data. Utilising 3D building models to improve the geometry and some attributes of these records seems a viable option to improve the overall quality of the cadastral database. On the other hand, the cadastral system has also something to give to the 3D building dataset. The individual entry into the cadastral database for a new building can be used to update the 3D building dataset, making it more up-to-date. This goes way beyond linking the IDs of both datasets but includes alignment of the data specifications, models, processes etc.

4. Conclusions

Integrating the soon-to-be available 3D building data into Slovenia's national SDI faces technical and administrative challenges. Based on the challenges presented, several directions for future development can be identified. The implementation of a CityGML Application Domain Extension (ADE) tailored to Slovenia's cadastral and topographic context could bridge some semantic and structural gaps between datasets. Additionally, automated change-detection pipelines leveraging AI-based LiDAR and imagery analysis should be established to routinely compare new data acquisitions with existing cadastral and 3D models. This would support timely updates and flag inconsistencies for human validation or automated processing, thereby addressing challenges of temporal misalignment and data maintenance.

On the governance side, regulatory changes would be needed to allow partial automation in updating official cadastral records based on trusted 3D datasets. This might include conditional updates via simplified procedures for small and simple buildings or provisional data integration pending owner validation. Furthermore, an update protocol should be established, distinguishing between legal cadastre and dynamic 3D topographic datasets, while clearly defining update authority, frequency, and methods. Finally, collaboration mechanisms should be formalised to support two-way data flows, versioning protocols, and standardisation of identifiers and metadata. While national SDIs can differ significantly across countries, the Slovenian case highlights several challenges, some of which may also be relevant to other countries introducing 3D data into their SDI.

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- V2-2385: Automatic acquisition of 3D buildings from dense point cloud for the purposes of real estate cadastre and GeoBIM (2023-2025),

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