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PODATKI DALJINSKEGA ZAZNAVANJA KOT MOGOČ VIR ZA VZPOSTAVITEV 3D-KATASTRA V SLOVENIJI

REMOTE SENSING DATA AS A POTENTIAL SOURCE FOR ESTABLISHMENT OF THE 3D CADASTRE IN SLOVENIA

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IZVLEČEK

V prispevku obravnavamo tehnologije daljinskega zaznavanja kot enega izmed mogočih virov podatkov za vzpostavitev 3D-katastra nepremičnin v Sloveniji. V naši državi smo pred nekoliko več kot desetletjem dobili pravno podlago za registracijo pravic na stavbah in delih stavb, v ta namen je bil tudi vzpostavljen kataster stavb. Pri pregledu obstoječih podatkov zemljiškega katastra in katastra stavb smo ugotovili, da je treba za vzpostavitev 3D-katastra že za drugo raven podrobnosti (LoD 2), to je za 3D-grafično predstavitev zunanjosti stavbe, dodatno zajeti nekatere značilne točke streh stavb. V ta namen smo na praktičnem primeru preizkusili obstoječe državne podatke, ki pokrivajo celotno območje države, to so stereopari letalskih posnetkov cikličnega aerosnemanja (CAS) in podatki aerolaserskega skeniranja. Ugotovili smo, da so lahko podatki državnega aerolaserskega skeniranja pomemben vir za zajem značilnih točk stavb, ki so poleg že obstoječih katastrskih podatkov potrebni za izdelavo 3D-modelov stavb na drugi ravni podrobnosti, kar je pomembno tako za katastrsko kot za topografsko področje.

ABSTRACT

The topic of this paper is the challenges of using remote sensing technologies as one of the potential data sources for the establishment of a 3D real property cadastre in Slovenia. More than a decade ago, the legal basis for the registration of property rights on the buildings and parts of buildings was provided in Slovenia, and for this purpose, the Building Cadastre was established. The analyses of the current data within the Land Cadastre and the Building Cadastre revealed that the 3D graphical representation of buildings, where the second level of detail (LoD 2) was discussed, requires additional data in which significant roof points should be additionally acquired. For this purpose, i.e. the creation of a graphical 3D-model of a building at the level LoD 2, we use the cadastral and national topographic data that covers the entire state territory, which are stereopairs of aerial photographs of the cyclic aerial survey (CAS) and airborne laser scanning data. Using a case study, we have analysed and discussed the appropriateness of the state airborne laser scanning data as an additional data source, along with the current cadastral data, for the creation of 3D-building model at the second level of detail, which is important from the cadastral as well as topographic perspective.

KLJUČNE BESEDE

daljinsko zaznavanje, zemljiški kataster, kataster stavb, 3D-kataster, ciklično aerosnemanje, aerolasersko skeniranje, Slovenija

KEY WORDS

remote sensing, land cadastre, building cadastre, 3D cadastre, cyclic aerial survey, airborne laser scanning, Slovenia

1 INTRODUCTION

The complex patterns of the use of physical space, primarily in urban areas, require the establishment of a 3D real property cadastre that in addition to land registration and graphic representation also enables 3D registration and graphic representation of buildings, parts of buildings, buildings above and under the ground, as well as traffic and other infrastructure (Stoter in Ploeger, 2003; Lemmen in Van Oosterom, 2003, Van Oosterom et al., 2006: Paasch et al., 2016). The basic registration unit of the 3D real property cadastre is a 3D property unit that is delineated also in height and depth (Stoter, 2004). In the majority of European countries land parcel is traditionally considered as a solid, unlimited by height and depth and defined by vertical surfaces that are delineated by land parcel boundary lines on the Earth's surface (Lemmen, 2012). In comparison with a 2D parcel cadastre, a 3D cadastre with a 3D graphic representation of a property unit is significantly more versatile and offers registration of more complex examples of property units in regard to physical space (Figure 1). The use of 3D models allows us to represent data on 3D property units (e. g. buildings) in a clear and unambiguous manner; in current cadastres these units are normally represented with the use of 2D plans (Kalantari et al., 2008; Aien et al., 2013).

Figure 1: A multi-storey use of physical space in central Slovenia (personal archive, 2016).

The cadastre primary task still remains to best serve the needs of society; it is also important to point out that only data which is accurate in terms of position and time and provides a comprehensive presentation of the factual situation in regard to physical space can offer support in decision-making in terms of society's challenging tasks (Kalantari et al., 2008; Bennett et al., 2011; Paulsson, 2013; Zupan et al., 2014). Remote sensing technologies offer a fast and mass 3D data acquisition at an affordable cost; this information can be put to good use also in land administration systems (Lemmen in Van Oosterom, 2003; Jazayeri et al., 2014).

In this article the selected data of remote sensing is regarded an important source of building the 3D real property cadastre in Slovenia. Special focus was put on establishing a 3D building model at the level of detail LoD 2, as proposed by Zhu and Hu (2010), which refers to the exterior of buildings. This type of building model which includes spatial building representation and roof type information can also be proposed for topographic models (Kolbe, 2009). The aim of the research was to conclude whether relevant official and authorized data that could be used for this purpose is available already. First of all, the current topographic and cadastral data was represented; the model of transition to a 3D Land Cadastre was then proposed, focusing on data which needs to be further acquired. A case study was used to examine the possibility of acquisition of missing data for a 3D property model; the study included data of cyclic aerial survey of Slovenia (CAS) and data of laser scanning of Slovenia (LSS), covering the entire territory of the country.

2 OVERVIEW OF CURRENT RESEARCH

The use of photogrammetry in Land Cadastre started in the 1950s (Weissmann, 1971; Dale, 1979). During this period photogrammetry started to emerge also in Slovenia in the field of cadastres; among other things, aerophotogrammetric detailed Land Cadastre survey took place in sixteen cadastral municipalities already in 1959 in the east of Prekmurje (Triglav, 2015). Nowadays modern technologies of remote sensing, including satellite systems and laser scanning, offer a mass 3D spatial data acquisition of large parts of terrain. A 3D extraction of buildings and traffic routes is being carried out with the use of stereopairs of aerial and satellite high resolution imagery with automatic and semi-automatic processing systems (Long in Zhao, 2005; Gerke in Heipke, 2008; Trinder in Sowmya, 2009; Dornaika in Hammoudi, 2010; Akca et al., 2010; Vasile et al., 2010; Shi et al., 2011; Weng, 2012) or with the use of airborne laser scanning data (Pfeifer et al., 2007; Kada in McKinley, 2009; Pu in Vosselman, 2009; Elberink in Vosselman, 2009; Chen et al., 2009; Tiwari et al., 2009; Wang in Sohn, 2011; Elberink in Vosselman, 2011) that offers a more accurate height determination in comparison to a stereophotogrammetric method (Vosselman in Maas, 2010). On the basis of data from laser scanning, regarded in this paper, this technology proved to be very precise in showing detail on buildings, traffic routes and other objects (Jazayeri et al., 2014), however, it is not appropriate for the determination of property boundary alignment without additional signalizing, except in the case of high point density when it is possible to plot a digital model of terrain of a cell size of no more than 10 cm. In this case laser scanning in property boundary alignment is comparable to the method of imaging, however only if the alignment of property boundaries is clearly visible (materialized) on land.

A combination of various technologies of spatial data extraction is often applied in research with the intention of establishing a 3D model of buildings and other objects; in this regard data on property boundaries and building interiors is often collected from current cadastral and floor plans.

Hammoudi et al. (2010) combined data of mobile laser scanning and the current cadastral plan and built object facade models. Hao et al. (2011) used a combination of mobile laser scanning data and photogrammetric images for a 3D extraction of buildings. Point clouds offered a detailed description of building facades and in combination with facade images the building heights, floor heights and the building and floor volume were collected. The approach proved appropriate for the extraction of buildings and the establishment of a 3D cadastre, but excluding glass buildings where mobile laser scanning was not effective due to a multi-path. The information from terrestrial and airborne laser scanning and floor plans provided Wang and Sohn (2011) with an opportunity to introduce an approach to establish a complete 3D building model, including data on building parts and data on building interior. In order to establish a 3D cadastre Taneja et al. (2012) used a combination of mobile systems and cadastral plans; spherical panoramic images, taken from a vehicle, were supplemented by cadastral plans and their result were geo-referenced buildings on land parcels with photorealistic facade display. Tack et al. (2012) developed a 3D surface model which was established on the basis of a stereopair of satellite imagery; a cadastral plan was used for the extraction of buildings. Unmanned aerial systems are already applied in the cadastre with vast advantages; these offer detailed models of buildings and surface, as well as the determination of property boundaries with an accuracy that is meeting the cadastre requirements of most countries of the world (Cunningham et al., 2011; Eisenbeiss, 2011; Manyoky et al., 2011; Van Hinsbergh et al., 2013). Gruen (2012) established a detailed 3D building model by combining unmanned aerial system data with photographs and point clouds from mobile scanning. Jazayeri et al. (2014) studied the suitability of various remote sensing technologies for the cadastral data acquisition. They determined that current research place great emphasis on the data acquisition of building exterior, while research on the acquisition of data on building exteriors and interiors are scarce and the same applies to research on simultaneous data acquisition on buildings and property boundaries.

In the field of 3D property registration it is worth mentioning Queensland, Australia's second largest state, where 3D property units have been forming a part of their cadastre already since the 1960s and from 1997 it is possible to register the so called volume (solid) parcels with the use of spatial geometric models (Karki, 2013). A 3D real property cadastre is being developed in other countries as well: in the Canadian province of British Columbia property can be defined as a 3D property unit, solid, which can also refer to free airspace (Pouliot et al., 2011), while in Norway (Onsrud, 2003) and Sweden (Paulsson, 2013) it can only refer to a built entity (buildings and traffic routes). A 3D cadastre is being introduced experimentally also in Italy, as an upgrade of the Building Cadastre, in Germany, as a link between cadastral and topographic models (Lisec et al., 2015) and in the Netherlands (Stoter in sod., 2013), generally in the form of pilot projects (see also Paasch et al., 2016).

3 NATIONAL DATA AVAILABLE FOR BUILDING A 3D CADASTRE

In Slovenia the jurisdiction of the Surveying and Mapping Authority of the Republic of Slovenia also refers to the field of property registration and topography; the mentioned institution official property data is available and can be, among other cadastral information, used for the building of the 3D real property cadastre. In this paper an examination of two types of data was conducted, namely data of cyclic aerial survey and laser scanning and data on current property records.

3.1 Topographic data

The main photogrammetric source for the extraction of national topographic data are stereopairs of cyclic aerial survey (CAS). On the Slovenian territory the project has been carried out continuously since 1975 (Perko, 2005). As a result of the development of aerial surveying technology and photogrammetric data extraction technology the project has constantly been updated as well, however the main principles remain unaltered – periodic surveying repetitiveness for the purpose of ensuring large scale spatial data at the level of the entire country (Petrovič et al., 2011). In 2006 digital photogrammetric system has been used for the first time which allows data extraction in the visible and near infrared range of the electromagnetic field. The surveying result is colour and infrared imagery with corresponding external orientation parameters. The spatial imagery data resolution equals 25 cm, the positional accuracy of imagery equals 30 cm and the accuracy of heights 40 cm. The radiometric resolution equals 24 bits, namely 8 bits for the red, blue and green data layer each (Bric et al., 2015). Stereopairs are used for the 3D topographic data extraction, registration of other spatial entities and as an input for building a digital terrain model and an ortophoto; among other things they were also used for building extraction when establishing the Building Cadastre.

In 2011 a project called Laser Scanning of Slovenia was launched and was finalized by the end of 2015. The project resulted in the extraction of the most precise land data thus far of the entire territory of Slovenia. According to the average density of laser scanning points per square metre the entire Slovenia was divided into zones A, B and C during the recording; namely, zone A that includes landslides and areas of the highest flood risk, with density of 10 points/m^2, zone B with density of 5 points/m^2, enabling quality hydrologic and hydrotechnical analyses, and zone C that covers highlands and forests, with density of 2 points/m^2. The results of airborne laser scanning are georeferenced ground point cloud, georeferenced and classified point cloud where points are classified to ground, buildings, low, medium and high vegetation, and digital terrain model, built with the use of interpolation of ground point cloud (Pegan Žvokelj et al., 2014). Data with density of 5 points/m^2 was used in the analysis.

3.2 Cadastral data

The Slovenian land administration system consists of a Land Registry and a Cadastre; the latter is further divided into the Land Cadastre and the Building Cadastre. Property registration is regulated by Real-Estate Recording Act (ZEN, Official Gazette of the Republic of Slovenia no. 47/2006, hereinafter ZEN) where Article 2 defines property as *"land with dedicated constituents"*, while land stands for *"land parcel, registered in Land Cadastre*", and the dedicated constituents refer to *"buildings and parts of buildings, registered in the Building Cadastre".*

The Land Cadastre is a fundamental record of land with land parcel as a basic unit where data on parcel number, property boundary, area, owner (by default from the Land Registry), operator, actual use, land under the building and land credit is kept (ZEN, Article 17). Parcel boundary is constituted by *"several line segments that together form a closed range"* and where the endpoints of line segments represent the Land Cadastre points which are defined as *"points which coordinates are defined in the national coordinate system"* (ZEN, Article 19).

Article 28 of the Rules on boundary regulation and data alteration and registration in the Land Cadastre (Official Gazette of the Republic of Slovenia, no. 8/2007 and 26/2007) provides that the position of each Land Cadastre point shall be determined with surveying in the national coordinate system and the elevation coordinate shall be determined if permitted by the surveying method. The coordinates shall be rounded off to two decimal places. Article 35 of the Rules defines coordinate precision of land cadastre points as *"the longer half-axis of the standard error ellipse in a point coordinate".* In the event that the Land Cadastre point coordinates are obtained by field surveying, the longer half-axis of the standard error ellipse of Land Cadastre point coordinates must be equal to or longer than four centimetres. The elevation coordinate precision is not prescribed. With regard to buildings, in the Land Cadastre the land under a building which is a *"vertical projection of a cross section of a building with land on a reference plane"* (ZEN, Article 24) shall be registered; the building surface and number is determined to the land under a building, used to connect the records of the Land Cadastre and the Building Cadastre.

The Building Cadastre is a fundamental record of buildings and parts of buildings, while every building is composed of at least one part. In Slovenia it was introduced by the Law on Registration of Real Estate, State Border and Spatial Units (ZENDMPE, Official Gazette of the Republic of Slovenia, no. 52/2000), namely the Article 99 enabled temporary data extraction on buildings and parts of buildings. Upon the establishment of the Building Cadastre the data on building exterior, namely the building footprint, the highest building point and the point representing the terrain around the building (however the latter is not clearly defined), was extracted photogrammetrically from stereopairs of aerial images CAS. The project of the building extraction has already been introduced by the Surveying and Mapping Authority in 1998 and within the framework of the project Property registration update (PEN) all buildings in the entire territory of Slovenia between 2000 and 2002 have been taken into account; the extraction was carried out on black and white analogue imagery and aerotriangulation was carried out only on the basis of ground control points. Since 2006 CAS is performed with digital cameras and aerotriangulation is more efficient with the application of approximate values of exterior orientation, generally obtained with GNSS (Global Navigation Satellity Systems) and INS (Inertial Navigation Systems). Subsequently, in 2003 and 2004 the Implementation of the Building Cadastre (LREST) project attributed descriptive data on buildings and parts of buildings from the current available records to above-mentioned buildings (Grilc et al., 2003). Buildings were extracted in accordance with the Operational instruction for building data extraction (2001), provided by the Surveying and Mapping Authority of the Republic of Slovenia and in accordance with subsequent updated instructions. In compliance with the instructions relatively permanent buildings are intended to be extracted, normally with walls, a roof and a surface area of more than 4 m^2 which were designated for purposes of specific use and which extend at least 2 m above the Earth's surface. The required positional accuracy of the building extraction was 50 cm. After establishing the Building Cadastre an assessment of precision of building ground plans with the corresponding heights was performed. The actual estimated standard positioning deviation of the Building Cadastre ground plan amounted to 0.85 m and the standard deviation of the building reference point height 0.65 m (see Opredelitev natančnosti v katastru stavb, 2009).

For every building or part of a building in accordance with Article 73 of ZEN, the Building Cadastre keeps and maintains data on the building number, the owner (by default from land register), the operator, location and form, area, actual use and the number of the apartment or the business premise. Article 77 of ZEN stipulates the location and the form of a building or the form of parts of a building (Figure 2), namely it defines the building footprint as a *"vertical projection of the external contour on a horizontal plane, defined by the national coordinate system"* and the height of the building as *"the difference between the altitude of the building highest point and the altitude of the building lowest point"*. The floor number and the ground plan of a specific part of a building that is a "*vertical projection of the external contours of a specific part of a building on a horizontal plane of the floor"* are defined by the position and the form of a specific part of a building (ZEN, Article 77). Article 4 of the Rules of Building Cadastre Registration (Official Gazette of the Republic of Slovenia, no. 73/202) provides that the three characteristic altitudes shall be determined to all buildings in the Building Cadastre: the height of the lowest building point (H_1), the height of the highest building point (H_2) and the characteristic building height (H_3); all are specified in the national height system and shall be rounded off to one decimal place. The height of the lowest building point is defined as the *"pavement height on the first floor"*, the height of the highest building point as the *"maximum height of the roof or the maximum height of the built part of the building"* and the characteristic building height as the *"height of the terrain, generally at the building entrance and designating the building position in regard to the land area"* (Rules of Building Cadastre Registration, Article 4). In the case of cadastral building entries, the data on the highest building point and the characteristic height, that was extracted photogrammetrically from stereopairs of aerial imagery CAS upon establishing the Building Cadastre, shall be replaced with more accurate data, obtained from the GNSS surveying and/or the tacheometric surveying (Lisec et al., 2015).

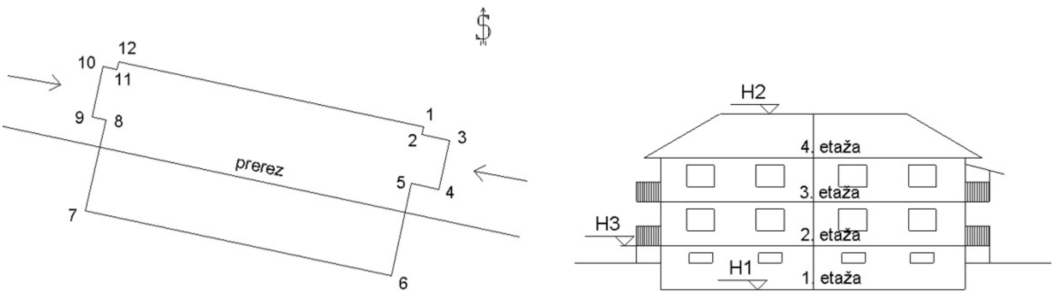

Figure 2: The current building exterior registration in the Building Cadastre: building ground plan (left) and building cross section drawing (right) (Surveying and Mapping Authority of the Republic of Slovenia).

4 THE PROPOSAL FOR THE MODEL OF A 3D REAL PROPERTY CADASTRE ESTABLISHMENT

Following the example of the data model CityGML, which has been adopted as a standard for topographic objects by the consortium OGC (Open Geospatial Consortium) already in mid-2008, a five level model of detail (LoD) was proposed by Zhu and Hu (2010) for the registration of buildings and parts of buildings in a real property cadastre (Figure 3). Levels LoD 1 and 2 describe the exterior of properties and levels LoD 3, 4 and 5 describe the interior of buildings. In LoD 1 a horizontal space division on separate lands, as registered in the Land Cadastre in Slovenia, is presented. In LoD 2 buildings are presented as separate property units in the form of 3D graphic models of external dimensions of buildings. The level LoD 3 also shows individual floors, LoD 4 presents models of parts of buildings and LoD 5 displays separate spaces or building elements in a particular part of a building.

In the case of upgrading the current cadastre into a 3D real property cadastre, the focus is put on the level of detail LoD 2 with attention to data (Figure 4) which is necessary for a 3D graphic presentation of exterior dimensions of buildings (Navratil in Unger, 2013; Jazayeri et al., 2014). External representation of buildings in the form of 3D models is considered the first step in a 3D cadastre establishment (Navratil in Unger, 2013; Jazayeri et al., 2014; Gruber et al., 2014). An upgrade from level LoD 2 to level LoD 3 is possible; the latter includes an internal 3D representation of buildings with data on floors and parts of buildings – countries which already have an established Building Cadastre, like Slovenia, certainly have a great deal of advantage in this regard.

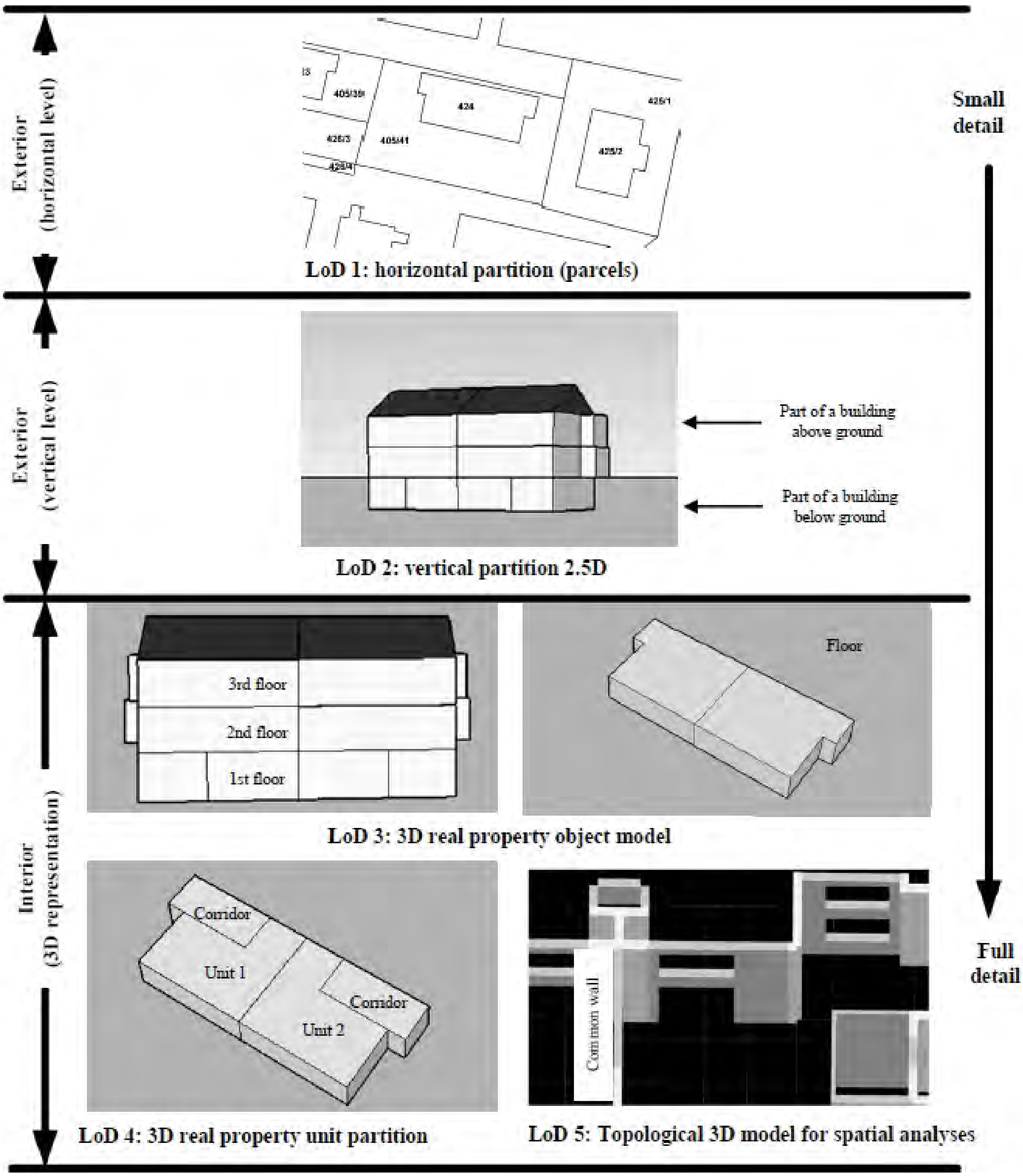

Figure 3: The five levels of detail LoD in the registration of buildings and parts of buildings in a cadastre (according to Zhu and Hu, 2010).

Firstly, property units that shall be included into a 3D real property cadastre are determined. In Slovenia these are properties, buildings and parts of buildings (in this article parts of buildings are not addressed individually and the focus is put solely on the exterior model of a building) that already form a part of the current land administration system. Today these units have not been registered yet in a way which would enable the geometric presentation in a 3D environment. In the second phase all interpretations come mainly from data of the current land cadastre and the Building Cadastre. In the Land Cadastre land parcels on the Earth's surface and land under buildings are registered. Buildings in the Building Cadastre are registered by 2D plans, where building ground plan and building cross section drawing, as well as building ground plans of individual floors are shown. For each individual building information on the maximum and the minimum building height and the characteristic land height against the building is presented.

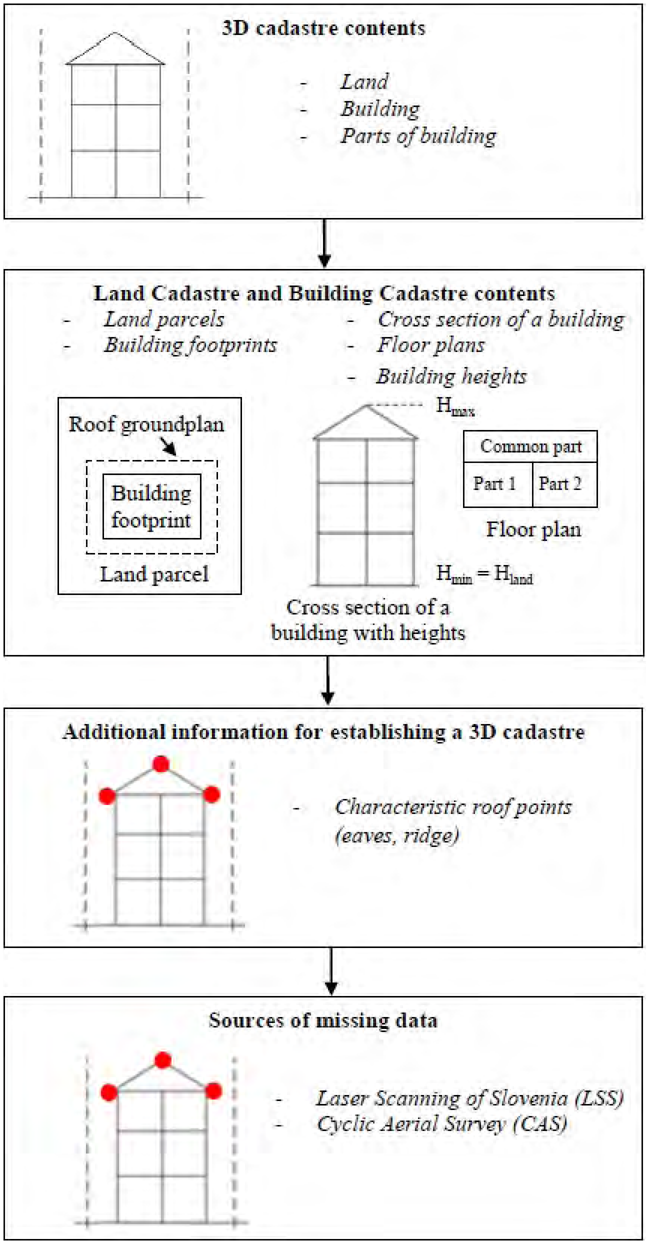

Figure 4: The proposal of the model of transition from the current real property cadastre to a 3D cadastre for the level LoD 2 in Slovenia.

In the third phase the missing data in the current cadastral system is determined that must be further acquired for establishing a 3D real property cadastre for the level LoD 2 (Figure 5). These are 3D positions of the characteristic roof points (eaves, ridge). As mentioned above, the present article is based on 3D modelling of a building as a whole (its exterior), however, it should be emphasized that in Slovenia the data, provided by the Building Cadastre, is an important data source for future development of 3D models of the building interior (parts of a building) on higher levels of detail, namely LoD 3, LoD 4 and LoD 5.

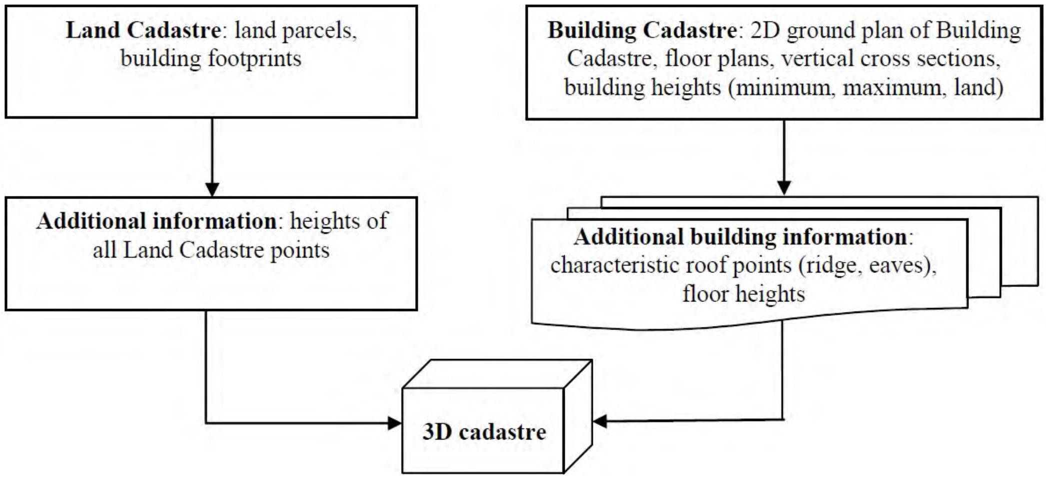

Figure 5: A proposal for an upgrade of the current real property cadastre in Slovenia - in addition to current cadastral data, additional information is also required for the production of 3D models of property units.

For the purpose of establishing a 3D real property cadastre on the level of detail LoD 2, as suggested in this article, data of cyclic aerial survey and airborne laser scanning for the entire territory of Slovenia is available; according to current foreign research this data has the potential for 3D data registration of buildings and other above-ground facilities.

5 CASE STUDY METHODOLOGY AND RESULTS

Theoretical findings have been tested using a practical example, namely in the testing area in the surrounding area of the Anton Tomaž Linhart Primary School in Radovljica, located west of the motorway Ljubljana-Jesenice, where part of the motorway, a motorway junction, a local road, a shopping centre, a primary school, a sports stadium and single-family houses are located.

The following national topographic data was obtained for the area concerned:

- a stereopair of colour aerial images CAS 2011 with elements of exterior orientation, a radiometric resolution of 12 bits and an average spatial resolution of 21 cm (source: Slovene Public Information, The Surveying and Mapping Authority of the Republic of Slovenia, stereopair of aerial images of Radovljica);
- georeferenced and classified point cloud of airborne laser scanning with an average density of 5 points/m^2 (source: web portal eVode, Slovenian Environment Agency).

The data and surveying are presented in the national coordinate system D96/TM and ellipsoidal heights are used. A combination of GNSS surveying and the tacheometric surveying method represented the reference source. The coordinates of geodetic network points were established using a Real Time Kinematic technique (RTK) of the GNSS surveying in real time, with every network point measured independently twice with 100 epochs. The characteristic points, defined by roof ridges and eaves, were extracted with a tacheometric surveying without the use of a prism in measuring oblique lengths. The absolute positional accuracy of reference values has been estimated to 5 cm.

30 characteristic roof points were selected in the testing area (Figure 6), of which 11 points on ridges and 19 on eaves. Depending on the roof type, 23 points were situated on gables, 4 points on gables with a front hip and 3 points on flat roofs.

Figure 6: Characteristic roof points in testing area in Radovljica (The Surveying and Mapping Authority of the Republic of Slovenia).

3D building roofs were extracted stereoscopically from stereopairs of aerial images CAS in SOCET SET of the company BAE Systems, a software for digital photogrammetry and geospatial analysis. The same roofs were extracted in a point cloud of airborne laser scanning with RiSCAN PRO from the company RIEGL, a software tool for managing and processing laser scanner data (Figure 7). The characteristic roof points coordinates represented refractive points (vertexes) on the extracted 3D building roof models which were later on compared with reference values. For the calculation of the root mean square error (RMSE) of characteristic roof points for each coordinate axis the following equations were used:

$$RMSE(e) = \sqrt{\frac{\sum \Delta e^2}{k}}, RMSE(n) = \sqrt{\frac{\sum \Delta n^2}{k}}, RMSE(H) = \sqrt{\frac{\sum \Delta H^2}{k}},$$

where k represents the number of points, e is the position of a point in the east – westerly direction, n stands for the position of a point in the north – southerly direction and H refers to the ellipsoidal height of a point.

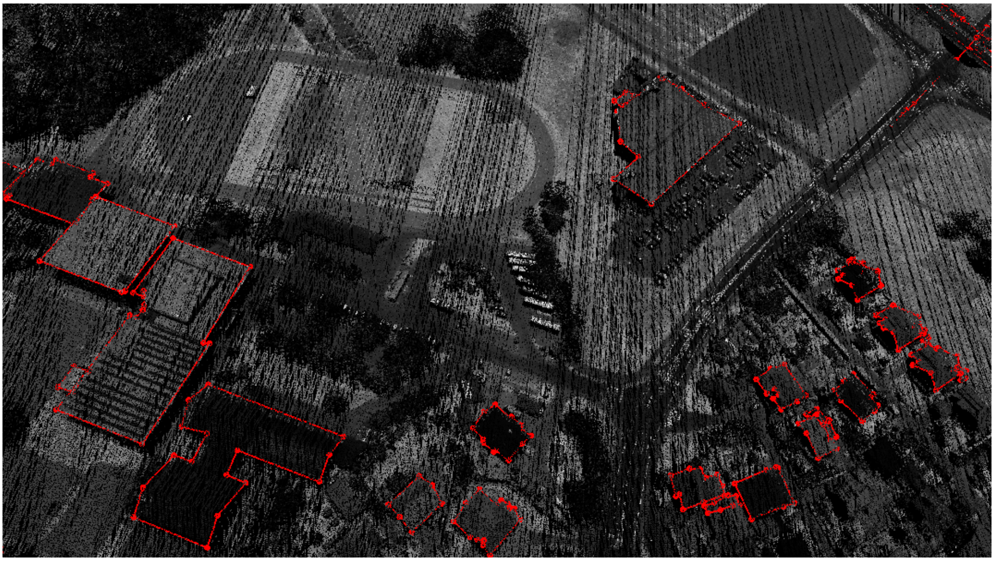

Figure 7: The extraction of building roofs (red) from a point cloud of airborne laser scanning with an average resolution of 5 points/ m^2 (Data source: Slovenian Environment Agency).

Table 1 shows coordinate discrepancy of individual roof points between the reference values and the values obtained from a stereopair of aerial images CAS and the values obtained from a point cloud of airborne laser scanning LSS, respectively.

Table 1: Coordinate discrepancy of individual characteristic roof points between "reference" values and the values obtained from various sources of national remote sensing data .

Point Number	Stereopairs of aerial images CAS			Airborne laser scanning LSS			Characteristic roof point	Roof type
	Δe [m]	Δn [m]	ΔH [m]	Δe [m]	Δn [m]	ΔH [m]		
1	-0.2	-0.4	-0.61	-0.52	0	0.09	eaves	flat
2	-0.16	-0.32	-0.83	-1.28	0.23	0.06	eaves	flat
3	0.34	-0.2	-0.57	0.22	-0.04	0.07	eaves	flat
4	0.36	-0.27	-0.61	0.14	0.08	-0.06	ridge	gable
5	0.01	0.02	-0.62	0.13	0.31	-0.09	ridge	gable
6	0.27	0.36	-0.13	-0.14	0.32	0.12	eaves	gable
7	0.1	0.08	-0.2	0.09	0.25	-0.04	eaves	gable
8	-0.45	-0.18	-0.27	-0.52	0.13	0.18	eaves	gable
9	0.28	0.07	-0.77	-0.05	0.03	0.07	eaves	gable
10	-0.18	-0.52	-0.8	-0.01	-0.28	0.06	eaves	gable
11	0.04	-0.33	-0.72	0.17	0.27	-0.19	eaves	gable (hip)
12	0.22	-0.18	-0.74	0.07	0.29	-0.02	ridge	gable (hip)
13	0.12	-0.25	-0.57	-0.13	0.3	-0.26	eaves	gable (hip)
14	0.29	-0.73	-0.89	-0.05	-0.65	-0.55	ridge	gable (hip)

Point Number	Stereopairs of aerial images CAS			Airborne laser scanning LSS			Characteristic roof point	Roof type
	Δe [m]	Δn [m]	ΔH [m]	Δe [m]	Δn [m]	ΔH [m]		
15	0.47	-0.35	-0.49	0.33	-0.37	0.04	eaves	gable
16	0.34	-0.23	-0.16	0.3	-0.15	-0.01	ridge	gable
17	0.35	0.12	-0.76	0.17	0.47	0.35	eaves	gable
18	0.08	0.19	-0.42	0.2	0.08	-0.02	ridge	gable
19	0.51	-0.04	-0.23	0.23	-0.12	0.04	eaves	gable
20	0.69	-0.04	-0.69	0.24	0.13	-0.09	ridge	gable
21	0.57	-0.27	-0.43	0.32	0.37	0.13	eaves	gable
22	0.32	-0.14	-0.45	-0.27	0.29	-0.25	ridge	gable
23	0.32	0.22	-0.22	0.15	0.37	0.08	eaves	gable
24	0.49	-0.09	-0.21	0.13	-0.23	-0.18	eaves	gable
25	0.27	-0.13	-0.23	0.24	-0.72	-0.15	eaves	gable
26	0.36	-0.07	-0.52	-0.65	-0.36	-0.18	ridge	gable
27	0.47	-0.07	-0.88	0.56	-0.3	-0.02	eaves	gable
28	0.44	-0.23	-1.00	0.08	-0.28	-0.16	ridge	gable
29	0.49	-0.24	-0.77	0.06	0.02	0.05	ridge	gable
30	0.41	-0.09	-0.6	-0.08	-0.09	0.14	eaves	gable

Tables 2 and 3 show the root mean square error and the maximum discrepancy for each coordinate in the extraction of characteristic roof points from a stereopair of aerial images CAS and from a point cloud of airborne laser scanning LSS.

Table 2: Root mean square error of characteristic roof points in the use of various sources of remote sensing.

Resource of remote sensing	RMSE (e) [m]	RMSE (n) [m]	RMSE (H) [m]
Airborne laser scanning (5 points/m²)	0.36	0.30	0.17
Stereopair of aerial images CAS	0.36	0.26	0.61

Table 3: Maximum coordinate deviation of characteristic roof points in the use of various sources of remote sensing.

Resource of remote sensing	Δe_{MAX} [m]	Δn_{MAX} [m]	ΔH_{MAX} [m]
Airborne laser scanning (5 points/m²)	-1.28	-0.65	-0.55
Stereopair of aerial images CAS	0.69	-0.73	-1.00

5.1 Results analysis

The table 2, containing root mean square errors of RMSE characteristic roof points coordinates from reference values in the use of various sources of remote sensing, shows that the positional accuracy in the use of both sources is comparable, as it amounts to 0.36 m in an east-westerly direction and to 0.30 m in the north-southerly direction in the extraction of airborne laser scanning data and to 0.36 m in the east-westerly direction and to 0.26 m in the north-southerly direction when using the method of stereopair extraction. However, in the case of data, extracted from airborne laser scanning, the height accuracy is better than the positioning accuracy and amounts to 17 cm, while the height accuracy of points, extracted from a stereopair CAS, is lower than the positioning one and amounts to 61 cm. Despite the small sample size, it is noted that airborne laser scanning is a better source for the extraction of positional data on building roofs than stereopairs CAS. The table 3 which shows the largest deviations of characteristic roof points coordinates from" reference" values indicates that the largest positioning deviation occurred in airborne laser scanning data and the largest height deviation in the extraction with a stereopair CAS. With the use of airborne laser scanning the details, specific to building roofs, are extracted more easily, resulting in primarily high height accuracy, as confirmed also by foreign research so far (see Vosselman and Maas, 2010). No difference has been identified in regard to roof type nor in regard to the position of a particular point on ridge or eaves. However, the interpretation of details that determine the characteristic roof points in roof extraction is troublesome; this is due to the fact that ridges and eaves are not depicted in sharp and straight lines, but ridges are rather elongated and round in shape, while eaves often have unclearly defined edges due to the shape of roofing tiles and gutters. Consequently, there may be difficulties in ensuring that in the case of the same roof in determining the roof position from two different sources identical points or lines are recovered.

When comparing roof extraction data with quality of results in mass building data acquisition in the establishment of the Building Cadastre, it is concluded that the standard height deviation of a reference building point 0.65 (see Opredelitev natančnosti v katastru stavb, 2009) is comparable to our result, acquired by data extraction with the use of a stereopair CAS which amounts to 0.61 m. The positional precision reached of 0.36 m in the east-westerly direction and that of 0.26 m in the north-southerly direction is much better from a mass volume extraction from more than a decade ago, of its total of 0.85 m (see Opredelitev natančnosti v katastru stavb, 2009). It is important to add that in the assessment of precision of a mass building data acquisition the sample included 118 points on roof eaves in the case of the positional precision and 21 points on roof ridges in the case of the height precision (see Opredelitev natančnosti v katastru stavb, 2009) and our sample covered only 30 points. A second difference is that in the assessment of precision one stereopair has been used, while in the assessment of precision of a mass volume extraction 35 buildings in the entire territory of Slovenia have been incorporated (see Opredelitev natančnosti v katastru stavb, 2009). Also, in mass building data acquisition, other technology was used (analogue black and white imagery, aerotriangulation was carried out only on the basis of ground control points) than today. Due to different samples and the use of other type of technology, the obtained deviations between mass volume extraction and today's results are expected.

According to the results achieved and the current data of mass building data acquisition it can be concluded that the height accuracy of airborne laser scanning, estimated to 17 cm, is sufficient for mass acquisition of building roofs which represent missing data for the building of a 3D model of buildings on the level of detail LoD 2. More accurate results could be achieved with the use of a field GNSS surveying and a tacheometric surveying that can, within regular cadastral proceedings, substitute data, obtained via mass volume extraction with the use of remote sensing sources. At this point it is important to note that, due to a multi-constellation laser beam and poor visibility at ground level, tacheometric surveying in data extraction of the position of characteristic roof points and lines can sometimes also be unreliable.

6 CONCLUDING OBSERVATIONS

The topic of this paper are remote sensing technologies as a potential data source for the establishment of the 3D real property cadastre in Slovenia with an emphasis on official national data of remote sensing. It was established that in Slovenia also national topographic data is already available, alongside cadastral data that covers the entire territory of the country and are key for the establishment of the 3D real property cadastre. The review of the current Land Cadastre and Building Cadastre data revealed that in order to establish a 3D building model for the second level of detail (LoD 2) the characteristic roof points in regard to physical space should be additionally acquired and the most appropriate extraction mode, among the available official data, is airborne laser scanning data, already with an average resolution of 5 points/m^2 and provided that data are updated on a regular basis. Another advantage of airborne laser scanning is the data extraction of facilities in overgrown areas. The data extraction with the use of unmanned aerial system could offer an additional source of remote sensing data. These are also important for the acquisition of other missing data in a cadastral system; due to the cadastre emergence history for example the position and height of many Land Cadastre points in the reference national coordinate system are not defined. However, the usefulness of remote sensing aerial technologies in a cadastre is limited to facility exteriors and to open areas without physical barriers; due to this in the case of geometric obstacles the application of other technologies of geodetic survey is advisable.

The enforcement of the suggested 3D real property model at the second level of detail (LoD 2) would be important from a topographic viewpoint as well as from a viewpoint of real property records; this is why the importance of establishing a 3D real property cadastre at least at this level of detail is emphasized to such an extent. Further development of 3D real property models on higher levels of detail (LoD 3, LoD 4 in LoD 5) undoubtedly poses a challenge of great importance; on this level valuable data (Building Cadastre) is already available in Slovenia which is a major benefit for Slovenia in comparison with other countries in the region. Finally, it should also be emphasized that the registration of properties in the Slovenian system of land administration is currently limited only to the Earth's surface and buildings (and parts of buildings) and that there is no legal basis yet for the registration of other building engineering facilities which are not classified as buildings and are located on or under the Earth's surface, such as traffic routes, groundwater, mineral reserves, etc.

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PODATKI DALJINSKEGA ZAZNAVANJA KOT MOGOČ VIR ZA VZPOSTAVITEV 3D-KATASTRA V SLOVENIJI

OSNOVNE INFORMACIJE O ČLANKU:

GLEJ STRAN 392

1 UVOD

Zapleteni vzorci rabe prostora, predvsem na urbanih območjih, zahtevajo vzpostavitev 3D-katastra nepremičnin, ki poleg evidentiranja in grafične predstavitve zemljišč omogoča trirazsežno evidentiranje in grafično predstavitev stavb, delov stavb, podzemnih in nadzemnih objektov ter prometne in druge infrastrukture (Stoter in Ploeger, 2003; Lemmen in Van Oosterom, 2003; Van Oosterom et al., 2006; Paasch et al., 2016). Osnovna enota evidentiranja v 3D-katastru nepremičnin je 3D-nepremičninska enota, ki je prostorsko omejena tudi v višino in globino (Stoter, 2004). Zemljiška parcela namreč v večini evropskih držav že tradicionalno velja za telo, neomejeno v višino in globino ter omejeno z navpičnimi ploskvami, ki jih določajo linije meje zemljiške parcele na površju Zemlje (Lemmen, 2012). 3D-kataster s trirazsežno grafično predstavitvijo nepremičninskih enot je veliko bolj vsestranski od dvorazsežnega parcelnega katastra in omogoča evidentiranje zapletenih primerov nepremičninskih enot v prostoru (slika 1). S trirazsežnimi modeli lahko jasno in nedvoumno predstavimo podatke o 3D-nepremičninskih enotah (na primer stavbah), ki so v obstoječih katastrih običajno prikazani na 2D-načrtih (Kalantari et al., 2008; Aien et al., 2013).

Slika 1: Večnivojska raba prostora v osrednji Sloveniji (osebni arhiv, 2016).

Glavna naloga katastra še vedno ostaja kar najbolje služiti potrebam družbe, pri tem pa je pomembno izpostaviti, da lahko zagotavljajo podporo pri odločanju v zahtevnih nalogah družbe samo podatki, ki so položajno in časovno točni ter celovito predstavljajo dejansko stanje v prostoru (Kalantari et al., 2008; Bennett et al., 2011; Paulsson, 2013; Zupan et al., 2014). Tehnologije daljinskega zaznavanja omogočajo hiter, množičen in stroškovno sprejemljiv zajem 3D-podatkov, ki se lahko koristno uporabijo tudi v sistemih zemljiške administracije (Lemmen in Van Oosterom, 2003; Jazayeri et al., 2014).

V prispevku obravnavamo izbrane podatke daljinskega zaznavanja kot enega od pomembnih virov za vzpostavitev 3D-katastra nepremičnin v Sloveniji. Pri tem se omejimo na izdelavo 3D-modela stavb na ravni podrobnosti LoD 2, kot ga predlagata Zhu in Hu (2010) in ki se nanaša na zunanjost stavb. Tak model stavb, ki vključuje prostorsko predstavitev stavb, vključno s strehami, je lahko predlagan tudi za topografske modele (Kolbe, 2009). Z raziskavo smo želeli ugotoviti, ali so v Sloveniji že na voljo ustrezni uradni in avtorizirani podatki, ki bi jih lahko uporabili v ta namen. Najprej bomo predstavili obstoječe topografske in katastrske podatke ter nato predlagali model prehoda na 3D-kataster nepremičnin, pri čemer bomo izpostavili, katere podatke je treba dodatno zajeti. Na praktičnem primeru bomo prikazali možnost zajema manjkajočih podatkov za prikaz 3D-modela nepremičnine, pri čemer smo v študijo vključili podatke cikličnega aerosnemanja Slovenije (CAS) in podatke laserskega skeniranja Slovenije (LSS), ki pokrivajo celotno ozemlje države.

2 PREGLED DOSEDANJIH RAZISKAV

Uporaba fotogrametrije v zemljiškem katastru sega v 50. leta prejšnjega stoletja (Weissmann, 1971; Dale, 1979). Tudi v Sloveniji se je fotogrametrija v tem času začela pojavljati na katastrskem področju, tako je med drugim že leta 1959 potekala aerofotogrametrična detajlna zemljiškokatastrska izmera v šestnajstih katastrskih občinah v vzhodnem delu Prekmurja (Triglav, 2015). Danes omogočajo sodobne tehnologije daljinskega zaznavanja, vključujoč satelitske sisteme in lasersko skeniranje, učinkovit zajem prostorskih podatkov v treh razsežnostih na velikih površinah. 3D-zajem stavb in prometnic se izvaja iz stereoparov letalskih in visokoločljivih satelitskih posnetkov s polavtomatskimi ali avtomatskimi postopki (Long in Zhao, 2005; Gerke in Heipke, 2008; Trinder in Sowmya, 2009; Dornaika in Hammoudi, 2010; Akca et al., 2010; Vasile et al., 2010; Shi et al., 2011; Weng, 2012) ali iz podatkov aerolaserskega skeniranja (Pfeifer et al., 2007; Kada in McKinley, 2009; Pu in Vosselman, 2009; Elberink in Vosselman, 2009; Chen et al., 2009; Tiwari et al., 2009; Wang in Sohn, 2011; Elberink in Vosselman, 2011), ki omogoča večjo točnost določitve višin kot stereofotogrametrična metoda (Vosselman in Maas, 2010). Na temelju podatkov laserskega skeniranja, ki ga obravnavamo v tem prispevku, lahko dobro opišemo podrobnosti na stavbah, prometnicah in drugih objektih, vendar ta tehnologija brez dodatne signalizacije ni primerna za določitev poteka posestnih oziroma lastniških meja (Jazayeri et al., 2014), razen pri veliki gostoti točk, ko lahko izdelamo digitalni model reliefa z velikostjo celice, manjše od 10 centimetrov. Takrat je lasersko skeniranje pri določitvi posestnih mej primerljivo s slikovnimi metodami, vendar samo, če je potek lastniških mej jasno viden (materializiran) v naravi.

V raziskavah se pogosto uporablja kombinacija različnih tehnologij zajema prostorskih podatkov z namenom izdelave 3D-modela stavb in drugih objektov, pri čemer se podatki o parcelnih mejah in notranjosti stavb običajno pridobijo iz obstoječih katastrskih in etažnih načrtov. Hammoudi et al. (2010) so združili podatke mobilnega laserskega skeniranja in obstoječega katastrskega načrta ter izdelali modele fasad objektov. Hao et al. (2011) so uporabili kombinacijo podatkov mobilnega laserskega skeniranja in fotogrametričnih podob za 3D-zajem stavb. Oblaki točk so detajlno opisovali fasade stavb, v kombinaciji s posnetki fasad pa so iz njih pridobili višino stavbe, višino etaž in prostornino stavbe ter etaž. Pristop se je izkazal kot primeren za zajem stavb in vzpostavitev 3D-katastra, razen pri stavbah iz stekla, kjer mobilno lasersko skeniranje ni bilo učinkovito zaradi večpotja laserskega žarka. Wang in Sohn (2011) sta iz podatkov terestričnega in aerolaserskega skeniranja ter etažnih načrtov predstavila pristop za izdelavo celotnega 3D-modela stavbe, ki vključuje tudi podatke o delih stavbe in podatke o notranjosti. Taneja et al. (2012) so za vzpostavitev 3D-katastra uporabili kombinacijo mobilnih snemalnih sistemov in katastrskih načrtov, in sicer so iz vozila zajeli sferične panoramske slike ter jih dopolnili s katastrskimi načrti in dobili georeferencirane stavbe na zemljiških parcelah s fotorealističnimi prikazi fasad. Tack et al. (2012) so izdelali 3D-model površja, ki je bil izdelan na podlagi stereopara satelitskih podob, pri čemer so za zajem stavb uporabljali tudi katastrski načrt. V katastru se že koristno uporabljajo tudi brezpilotni letalniki, ki poleg detajlnih modelov stavb in površja omogočajo zajem mejnih znamenj s točnostjo, ki zadošča zahtevam za kataster večine držav na svetu (Cunningham et al., 2011; Eisenbeiss, 2011; Manyoky et al., 2011; Van Hinsbergh et al., 2013). Gruen (2012) je kombiniral podatke brezpilotnih letalnih sistemov s posnetki in oblaki točk mobilnega snemanja ter izdelal podroben 3D-model stavb. Jazayeri et al. (2014) so ocenjevali ustreznost različnih tehnologij daljinskega zaznavanja za zajem katastrskih podatkov in ugotovili, da imajo dosedanje raziskave velik poudarek na zajemu zunanjega ovoja stavb, malo pa je raziskav o pridobivanju podatkov o zunanjosti in notranjosti stavbe ter o sočasnem pridobivanju podatkov o stavbah in parcelnih mejah.

Pri uvajanju trirazsežnega evidentiranja nepremičnin velja izpostaviti avstralsko zvezno deželo Queensland, kjer so 3D-nepremičninske enote del njihovega katastra že od 60. let prejšnjega stoletja, od leta 1997 pa je mogoče tako imenovane volumske parcele evidentirati z uporabo prostorskih geometrijskih modelov (Karki, 2013). 3D-nepremičninski kataster razvijajo tudi v drugih državah: v kanadski provinci Britanska Kolumbija je mogoče razdeliti zemljišče na 3D-nepremičninske enote, ki se lahko nanašajo tudi na prazen zračni prostor (Pouliot et al., 2011), medtem ko se na Norveškem (Onsrud, 2003) in Švedskem (Paulsson, 2013) lahko nanašajo le na grajene objekte (stavbe in prometnice). 3D-kataster so poskusno začeli uvajati tudi v Italiji, in sicer kot nadgradnjo katastra stavb, v Nemčiji, kot povezavo katastrskih in topografskih modelov (Lisec et al., 2015), ter na Nizozemskem (Stoter in sod., 2013). Projekti so večinoma pilotni (glej tudi Paasch et al., 2016).

3 RAZPOLOŽLJIVI DRŽAVNI PODATKI ZA VZPOSTAVITEV 3D-KATASTRA

V Sloveniji so pri Geodetski upravi Republike Slovenije, ki je med drugim pristojna za področje evidentiranja nepremičnin in topografijo, na voljo uradni podatki o nepremičninah, ki jih je mogoče, poleg katastrskih podatkov, uporabiti za vzpostavitev 3D-katastra nepremičnin. V prispevku posebej obravnavamo podatke cikličnega aerosnemanja in laserskega skeniranja ter podatke obstoječih nepremičninskih evidenc.

3.1 Topografski podatki

Glavni fotogrametrični vir za zajem državnih topografskih podatkov so stereopari cikličnega aerosnemanja Slovenije (CAS). Projekt se na slovenskem ozemlju izvaja nepretrgoma od leta 1975 (Perko, 2005; Bric et al., 2015). Z razvojem aerosnemalne tehnologije in tehnologije fotogrametričnega zajema podatkov se je posodabljal, vendar pa glavna vodila ostajajo nespremenjena – periodično ponavljanje snemanja za zagotavljanje prostorskih podatkov največjih meril na ravni vse države (Petrovič et al., 2011). Leta 2006 je bil prvič uporabljen digitalni fotoaparat, ki zajema podatke v vidnem in bližnjem infrardečem spektru elektromagnetnega valovanja. Rezultat snemanja so barvni in infrardeči letalski posnetki s pripadajočimi elementi zunanje orientacije. Prostorska ločljivost posnetkov je 25 centimetrov, njihova položajna točnost znaša 30 centimetrov, višinska pa 40 centimetrov. Radiometrična ločljivost je 24 bitov, torej po 8 bitov za rdeč, moder in zelen podatkovni sloj (Bric et al., 2015). Stereopari se uporabljajo za trirazsežni zajem topografskih podatkov, evidentiranje stanja v prostoru in kot vhodni podatek za izdelavo digitalnega modela reliefa ter ortofota, med drugim so bile iz njih zajete stavbe pri vzpostavitvi katastra stavb.

Leta 2011 se je začel projekt Lasersko skeniranje Slovenije in bil dokončan do konca leta 2015. Z njim so bili pridobljeni doslej najnatančnejši podatki o reliefu za celotno območje države. Pri snemanju je bilo državno ozemlje glede na povprečno gostoto točk laserskega skeniranja na kvadratni meter razdeljeno na območja A, B in C. Območje A, ki zajema zemeljske plazove in poplavno najbolj ogrožena območja, ima gostoto 10 točk/m^2, območje B gostoto 5 točk/m^2, kar omogoča izdelavo kakovostnih hidroloških in hidrotehničnih analiz, ter območje C, ki zajema visokogorje in gozdove, gostoto 2 točki/m^2. Rezultati aerolaserskega skeniranja so georeferenciran oblak točk reliefa, georeferenciran in klasificiran oblak točk, pri čemer so točke klasificirane na tla, stavbe, nizko, srednjo in visoko vegetacijo ter digitalni model reliefa, ki je izdelan z interpolacijo oblaka točk reliefa (Pegan Žvokelj et al., 2014). V analizi smo uporabili podatke z gostoto 5 točk/m^2.

3.2 Katastrski podatki

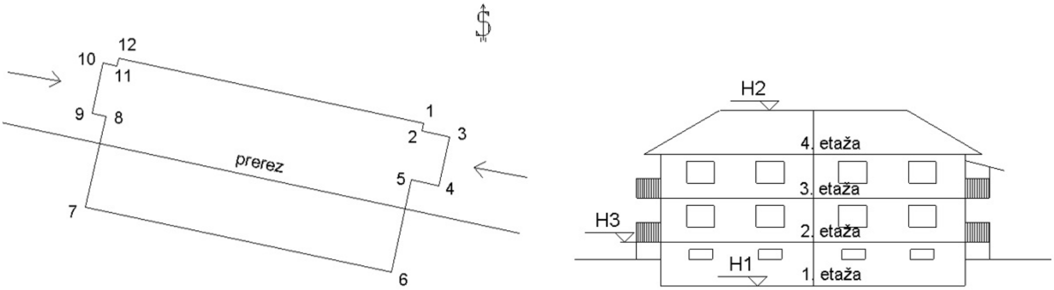
Slovenski sistem zemljiške administracije sestavljata zemljiška knjiga in kataster, ki je razdeljen na zemljiški kataster in kataster stavb. Evidentiranje nepremičnin je urejeno z Zakonom o evidentiranju nepremičnin (ZEN, Uradni list RS, št. 47/2006, v nadaljevanju: ZEN), ki v 2. členu opredeljuje nepremičnino kot »*zemljišče s pripadajočimi sestavinami*«, pri čemer je zemljišče »*zemljiška parcela, ki je evidentirana v zemljiškem katastru*«, pripadajoče sestavine pa so »*stavbe in deli stavb, ki so evidentirani v katastru stavb*«.

Zemljiški kataster je temeljna evidenca o zemljiščih z osnovno enoto zemljiško parcelo, za katero se vodijo podatki o parcelni številki, meji, površini, lastniku (privzet iz zemljiške knjige), upravljavcu, dejanski rabi, zemljišču pod stavbo in boniteti zemljišča (ZEN, 17. člen). Mejo parcele tvori »*več daljic, ki so med seboj povezane v zaključen poligon*,« pri čemer krajišča daljic predstavljajo zemljiškokatastrske točke, to so »*točke, ki imajo koordinate določene v državnem koordinatnem sistemu*« (ZEN, 19. člen).

V Pravilniku o urejanju mej ter spreminjanju in evidentiranju podatkov v zemljiškem katastru (Uradni list RS, št. 8/2007 in 26/2007) je v 28. členu določeno, da se za posamezno zemljiškokatastrsko točko določi položaj z meritvami v državnem koordinatnem sistemu, višinska koordinata pa se določi, če metoda izmere to omogoča. Koordinate se zaokrožijo na dve decimalni mesti. Pravilnik v 35. členu opredeljuje natančnost koordinat zemljiškokatastrskih točk kot »*daljšo polos standardne elipse zaupanja v koordinati točke*«. Če so koordinate zemljiškokatastrskih točk pridobljene z meritvami na terenu, mora biti daljša polos standardne elipse zaupanja koordinat zemljiškokatastrskih točk enaka ali boljša od štirih centimetrov. Natančnost višinskih koordinat ni predpisana. Pri stavbah se v zemljiškem katastru evidentira zemljišče pod stavbo, ki je »*navpična projekcija preseka stavbe z zemljiščem na ravnino*« (ZEN, 24. člen); zemljišču pod stavbo se določita površina in številka stavbe, ki se uporablja za povezavo med evidencama zemljiškega katastra in katastra stavb.

Kataster stavb je temeljna evidenca o stavbah in njihovih delih, pri čemer ima vsaka stavba najmanj en del. V Sloveniji je bil uveden z Zakonom o evidentiranju nepremičnin, državne meje in prostorskih enot (ZENDMPE, Uradni list RS, št. 52/2000), in sicer je 99. člen omogočal začasni zajem podatkov o stavbah in delih stavb. Podatki o zunanjosti stavb, in sicer tloris stavbe, najvišja točka stavbe in višina zemljišča ob stavbi (ta sicer ni jasno določena), so se ob vzpostavitvi katastra stavb zajemali fotogrametrično iz stereoparov letalskih posnetkov CAS. Geodetska uprava Republike Slovenije je projekt zajema stavb začela že leta 1998, v okviru projekta Posodobitve evidentiranja nepremičnin (PEN) pa so se med letoma 2000 in 2002 zajele vse stavbe na celotnem državnem območju, pri čemer se je zajem izvedel na črno-belih analognih posnetkih, aerotriangulacija pa je bila izvedena zgolj na podlagi oslonilnih točk. Od leta 2006 se CAS izvaja z digitalnimi fotoaparati, aerotriangulacija pa je izboljšana s približnimi vrednostmi parametrov zunanje orientacije, praviloma pridobljenimi z meritvami GNSS (angl. *global navigation satellite systems*) in INS (angl. *inertial navigation systems*). Tem stavbam so se nato v okviru projekta Izvedbe katastra stavb (LREST) v letih 2003 in 2004 pripisali opisni podatki o stavbah in delih stavb iz razpoložljivih evidenc (Grilc et al., 2003). Stavbe so se zajemale skladno z Operativnim navodilom za zajem podatkov o stavbah (2001), ki ga je pripravila Geodetska uprava Republike Slovenije, in kasnejšimi dopolnitvami navodil. Skladno z navodili naj bi se zajemale relativno trajne stavbe, običajno s stenami, pokrite s streho in zasnovane za določene namene uporabe, ki imajo večjo površino od 4 m^2 ter segajo vsaj 2 metra nad zemeljsko površje. Zahtevana položajna točnost zajema stavb je bila 50 centimetrov. Po vzpostavitvi katastra stavb je bila izvedena ocena natančnosti tlorisov stavb s pripadajočimi višinami. Dejanski ocenjeni standardni položajni odklon tlorisa katastra stavb je znašal 0,85 metra, standardni odklon višine referenčne točke stavbe pa 0,65 metra (Opredelitev natančnosti v katastru stavb, 2009).

V katastru stavb se za stavbo ali del stavbe skladno s 73. členom ZEN shranjujejo in vzdržujejo podatki o številki stavbe, lastniku (privzetem iz zemljiške knjige), upravljavcu, legi in obliki, površini, dejanski rabi ter številki stanovanja ali poslovnega prostora. ZEN v 77. členu določa lego in obliko stavbe ali njenega dela (slika 2), in sicer opredeljuje tloris stavbe kot »*navpično projekcijo zunanjih obrisov stavbe na vodoravno ravnino, opredeljeno s točkami v državnem koordinatnem sistemu*«, višino stavbe kot »*razliko med nadmorsko višino najvišje točke stavbe in nadmorsko višino najnižje točke stavbe*«. Lego in obliko dela stavbe določata številka etaže in tloris dela stavbe, ki je »*navpična projekcija zunanjih obrisov dela stavbe na vodoravno ravnino etaže*« (ZEN, 77. člen). 4. člen Pravilnika o vpisih v kataster stavb (Uradni list RS, št. 73/2012) določa, da se stavbam v katastru stavb določijo tri značilne nadmorske višine: višina najnižje točke stavbe (H_1), višina najvišje točke stavbe (H_2) in karakteristična višina stavbe (H_3), ki so določene v državnem koordinatnem sistemu in so zaokrožene na eno decimalno mesto. Višina najnižje točke stavbe je določena kot »*višina tlaka v prvi etaži*«, višina najvišje točke stavbe kot »*najvišja višina strehe ali zidanega dela stavbe*« in karakteristična višina stavbe kot »*višina terena praviloma ob vhodu v stavbo in označuje lego stavbe glede na površino zemljišča*« (Pravilnik o vpisih v kataster stavb, 4. člen). Podatki o najvišji točki stavbe in karakteristični višini, ki so bili zajeti fotogrametrično iz stereoparov letalskih posnetkov CAS ob vzpostavitvi katastra stavb, se pri katastrskih vpisih stavb nadomestijo s točnejšimi podatki, pridobljenimi z GNSS- in/ali tahimetrično izmero (Lisec et al., 2015).



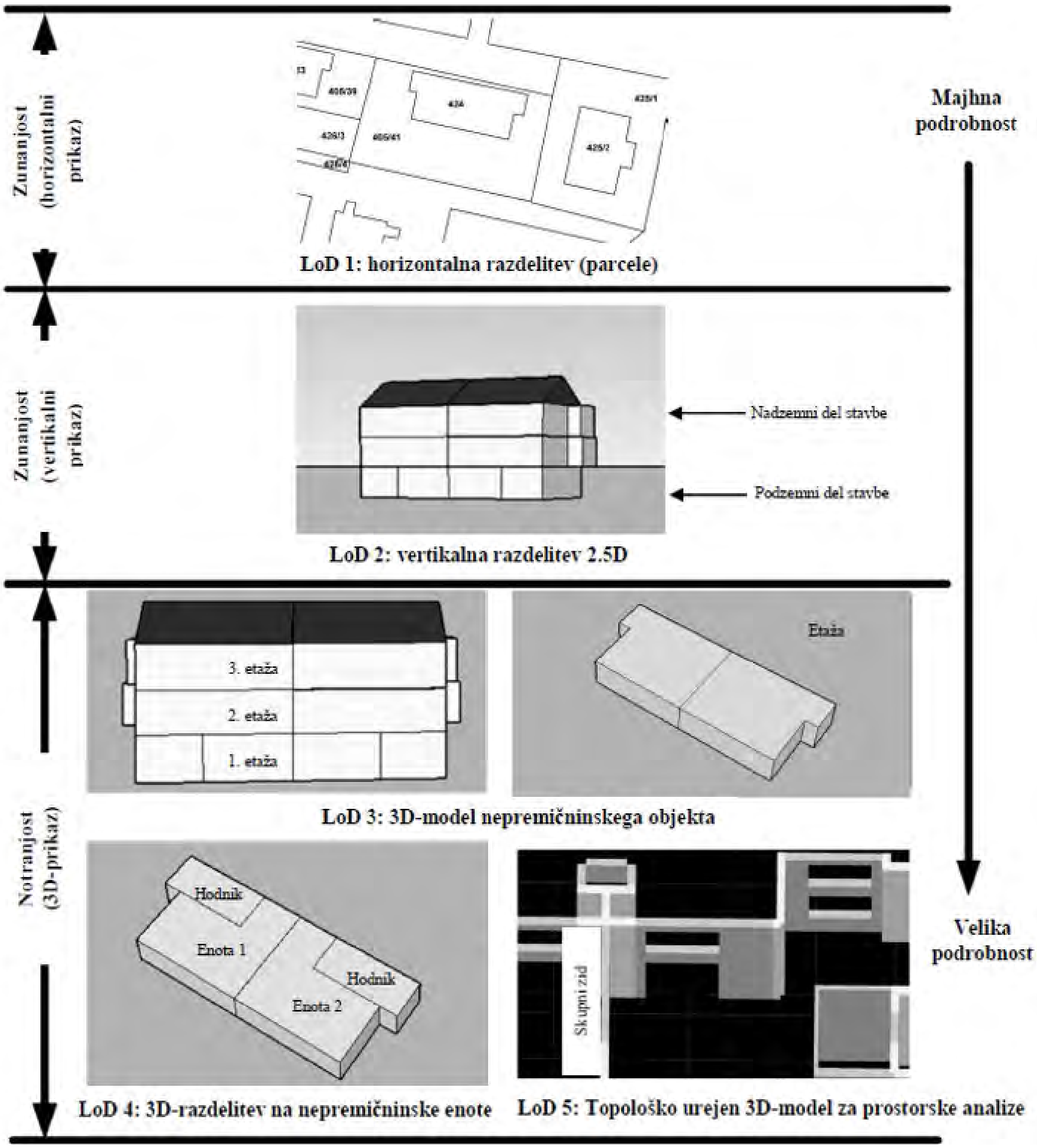
Slika 2: Obstoječe evidentiranje zunanjosti stavb v katastru stavb: tloris stavbe (levo) in prerez stavbe (desno) (Geodetska uprava Republike Slovenije).

4 PREDLOG MODELA VZPOSTAVITVE 3D-KATASTRA NEPREMIČNIN

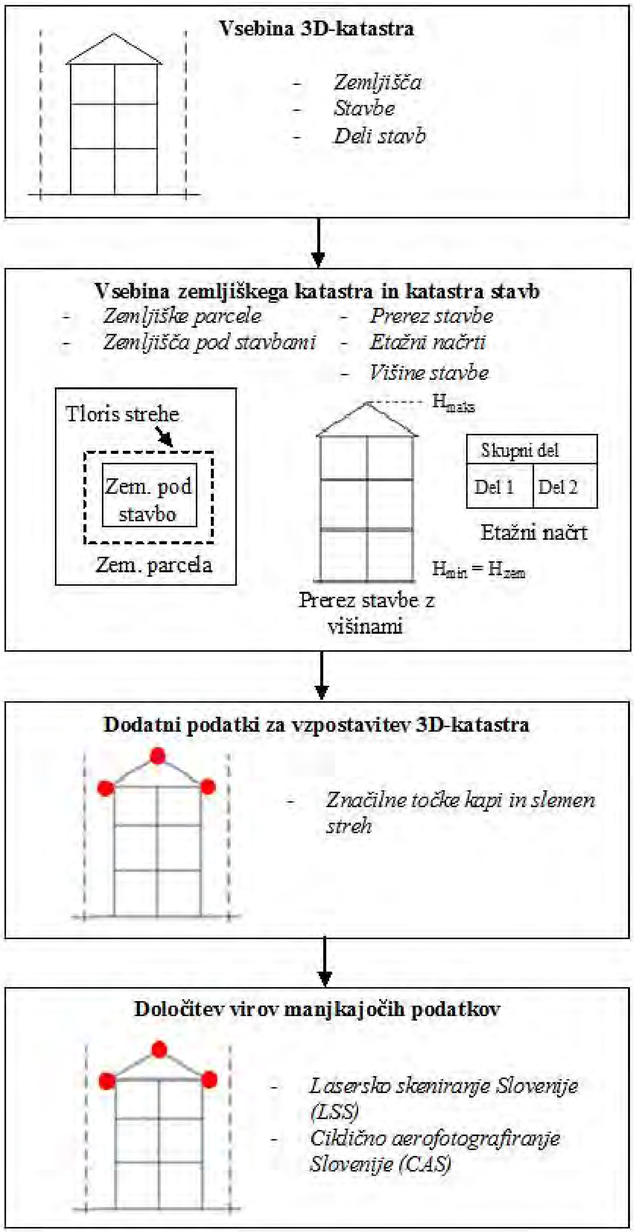
Za evidentiranje stavb in njihovih delov v nepremičninskem katastru sta Zhu in Hu (2010) po zgledu podatkovnega modela CityGML, ki ga je konzorcij OGC (angl. *Open Geospatial Consortium*) že sredi leta 2008 sprejel kot standard za topografske objekte (Kolbe, 2009; Šumrada, 2009), predlagala pet stopenj podrobnosti (LoD) (slika 3). Stopnji LoD 1 in 2 opisujeta samo zunanjost nepremičnin, stopnje LoD 3, 4 in 5 pa tudi notranjost stavb. Z LoD 1 je predstavljena horizontalna razdelitev prostora na zemljišča, kot so v Sloveniji evidentirana v zemljiškem katastru. Z LoD 2 so prikazane stavbe kot posamezne nepremičninske enote v obliki 3D-grafičnih modelov zunanje razsežnosti stavb. Stopnja LoD 3 dodatno vključuje prikaz posamezne etaže, LoD 4 modele delov stavb in LoD 5 posamezne prostore ali gradbene elemente v delu stavbe.

V predlogu nadgradnje sedanjega katastra v 3D-kataster nepremičnin se bomo omejili na raven podrobnosti LoD 2, kjer se bomo osredotočili na podatke (slika 4), ki so potrebni za trirazsežno grafično predstavitev zunanje razsežnosti stavb. Zunanji prikaz stavb v obliki trirazsežnih modelov je namreč prvi korak k vzpostavitvi 3D-katastra (Navratil in Unger, 2013; Jazayeri et al., 2014; Gruber et al., 2014). Iz stopnje LoD 2 je mogoča nadgradnja v stopnjo LoD 3, ki vključuje notranji 3D-prikaz stavb s podatki o etažah in delih stavb – države, kot je Slovenija, ki imajo vzpostavljen kataster stavb, so pri tem seveda v veliki prednosti.

Najprej določimo nepremičninske enote, ki naj bodo vključene v 3D-kataster nepremičnin. V Sloveniji so to zemljišča, stavbe in deli stavb (delov stavb posebej v tem prispevku ne obravnavamo in se omejujemo le na zunanji model stavbe), ki so že vključeni v obstoječi sistem zemljiške administracije. Te enote še niso evidentirane na način, ki bi omogočal geometrično predstavitev v 3D-okolju. V drugi fazi izhajamo iz podatkov obstoječega zemljiškega katastra in katastra stavb. V zemljiškem katastru so evidentirane zemljiške parcele na zemeljskem površju in zemljišča pod stavbami. Stavbe so v katastru stavb evidentirane na 2D-načrtih, na katerih so prikazani tloris in prerez stavbe ter tlorisi stavbe po etažah. Atributno so za vsako stavbo podane tudi najvišja in najnižja višina stavbe ter karakteristična višina zemljišča ob stavbi.

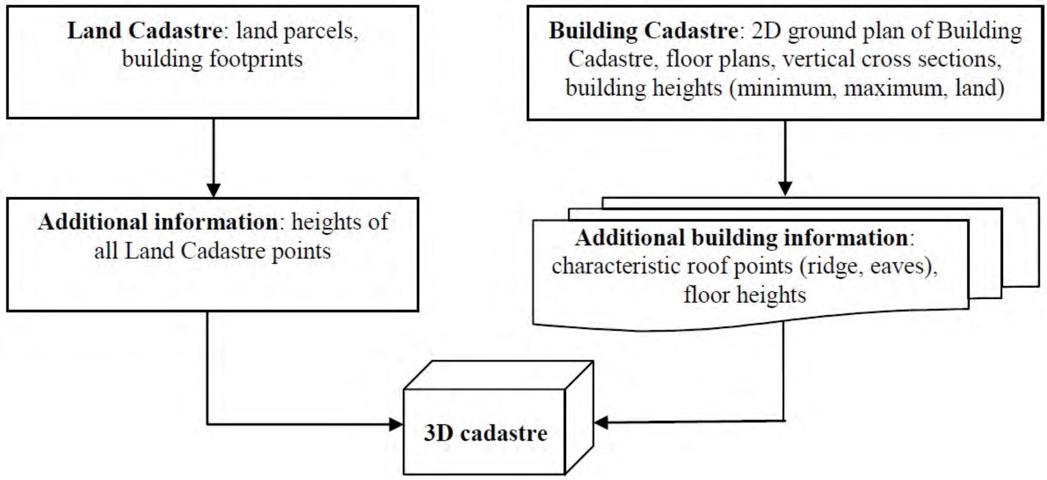


Slika 3: Pet stopenj podrobnosti (LoD) pri evidentiranju stavb in njihovih delov v katastru (povzeto po Zhu in Hu, 2010).



Slika 4: Predlog modela prehoda z obstoječega katastra na 3D-kataster nepremičnin za raven LoD 2 v Sloveniji.

V tretji fazi določimo manjkajoče podatke v sedanjem katastrskem sistemu, ki jih bomo morali za vzpostavitev 3D-katastra nepremičnin za raven LoD 2 dodatno pridobiti (slika 5). To so 3D-položaji značilnih točk strehe (kap, sleme). Kot že omenjeno, se v prispevku omejujemo na 3D-modeliranje stavbe kot celote (zunanjosti), poudariti pa velja, da so v Sloveniji podatki katastra stavb pomemben podatkovni vir za nadaljnji razvoj 3D-modelov notranjosti stavb (delov stavbe) na višjih ravneh podrobnosti, to so LoD 3, LoD 4 in LoD 5.



Slika 5: Predlog nadgradnje katastra v Sloveniji v 3D-kataster nepremičnin – za izdelavo 3D-modelov nepremičninskih enot so poleg sedanjih katastrskih podatkov potrebni dodatni podatki.

Za namen vzpostavitve 3D-katastra nepremičnin na ravni podrobnosti LoD2, kot je predlagano v tem prispevku, so za celotno ozemlje Slovenije na voljo podatki cikličnega aerosnemanja in aerolaserskega skeniranja, ki glede na že opravljene tuje raziskave omogočajo 3D-zajem podatkov o stavbah in drugih nadzemnih objektih.

5 METODE IN REZULTATI TESTNEGA PRIMERA

Teoretične izsledke smo preizkusili na praktičnem primeru, in sicer na testnem območju v okolici Osnovne šole Antona Tomaža Linharta v Radovljici, ki leži zahodno od avtoceste Ljubljana–Jesenice in na katerem stojijo del avtoceste, avtocestni priključek, lokalna cesta, nakupovalni center, osnovna šola, športni stadion in enostanovanjske hiše. Za obravnavano območje smo pridobili državne topografske podatke:

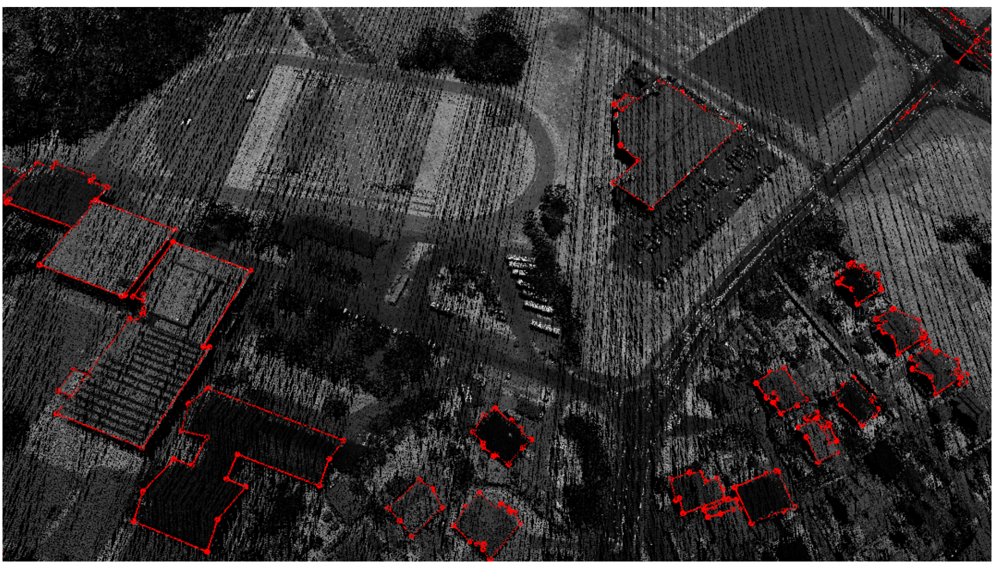
- stereopar barvnih letalskih posnetkov CAS 2011z elementi zunanje orientacije, radiometrične ločljivosti 12 bitov in povprečne prostorske ločljivosti 21 centimetrov (vir: Geodetska uprava Republike Slovenije, stereopar letalskih posnetkov Radovljica);
- georeferenciran in klasificiran oblak točk aerolaserskega skeniranja s povprečno gostoto 5 točk/m^2 (vir: spletni portal eVode, Agencija Republike Slovenije za okolje).

Podatki in meritve so podani v državnem koordinatnem sistemu D96/TM, uporabljene so elipsoidne višine.

Izvedli smo kombinacijo izmere GNSS in tahimetrične metode izmere, ki je referenčni vir. Koordinate točk geodetske mreže so bile določene z metodo RTK (angl. *real time kinematic*) GNSS-izmere v realnem času, pri čemer je bila vsaka točka mreže izmerjena dvakrat neodvisno s po 100 epohami. Značilne točke, ki jih določajo slemena in kapi streh, so bile zajete s tahimetrično izmero brez uporabe prizme pri merjenju poševnih dolžin. Točnost absolutnega položaja referenčnih vrednosti smo ocenili na 5 centimetrov.

Na testnem območju smo izbrali 30 značilnih točk streh (slika 6), od tega je bilo 11 točk na slemenih in 19 na kapeh. Glede na vrsto strehe je bilo 23 točk na dvokapnicah, 4 točke na dvokapnicah s čelnim čopom in 3 točke na ravnih strehah.

Slika 6: Značilne točke streh na testnem območju v Radovljici (Geodetska uprava Republike Slovenije).



Slika 7: Zajem streh stavb (rdeče) iz oblaka točk aerolaserskega skeniranja s povprečno gostoto 5 točk/m^2 (vir podatkov: Agencija Republike Slovenije za okolje).

3D-strehe stavb smo zajeli stereoskopsko iz stereopara letalskih posnetkov CAS v SOCET SET-u, programskem paketu za digitalno fotogrametrijo in geoprostorske analize podjetja BAE Systems. V oblaku točk aerolaserskega skeniranja smo iste strehe zajeli s programskim orodjem za upravljanje in obdelavo podatkov laserskih skenerjev RiSCAN PRO podjetja RIEGL (slika 7). Koordinate značilnih točk streh so predstavljale lomne točke (oglišča) na zajetih 3D-modelih streh stavb, ki smo jih nato primerjali z referenčnimi vrednostmi. Za izračun korena srednjega kvadratnega pogreška RMSE (angl. *root mean square error*) značilnih točk streh po posameznih koordinatnih oseh smo uporabili enačbe:

$$RMSE(e) = \sqrt{\frac{\sum \Delta e^2}{k}}, RMSE(n) = \sqrt{\frac{\sum \Delta n^2}{k}}, RMSE(H) = \sqrt{\frac{\sum \Delta H^2}{k}},$$

kjer je k število točk, e položaj točke v smeri vzhod–zahod, n položaj točke v smeri sever–jug in H elipsoidna višina točke.

V preglednici 1 so prikazana odstopanja koordinat posameznih točk streh med terensko izmerjenimi referenčnimi vrednostmi in pri zajemu s stereopara letalskih posnetkov CAS ali iz oblaka točk aerolaserskega skeniranja LSS.

Preglednica 1: Odstopanja koordinat posameznih značilnih točk streh od »referenčnih« vrednosti pri uporabi različnih virov državnih podatkov daljinskega zaznavanja

Točka	Stereopar letalskih posnetkov CAS			Aerolasersko skeniranje LSS			Značilna točka strehe	Vrsta strehe
	Δe [m]	Δn [m]	ΔH [m]	Δe [m]	Δn [m]	ΔH [m]		
1	-0,2	-0,4	-0,61	-0,52	0	0,09	kap	ravna
2	-0,16	-0,32	-0,83	-1,28	0,23	0,06	kap	ravna
3	0,34	-0,2	-0,57	0,22	-0,04	0,07	kap	ravna
4	0,36	-0,27	-0,61	0,14	0,08	-0,06	sleme	dvokapnica
5	0,01	0,02	-0,62	0,13	0,31	-0,09	sleme	dvokapnica
6	0,27	0,36	-0,13	-0,14	0,32	0,12	kap	dvokapnica
7	0,1	0,08	-0,2	0,09	0,25	-0,04	kap	dvokapnica
8	-0,45	-0,18	-0,27	-0,52	0,13	0,18	kap	dvokapnica
9	0,28	0,07	-0,77	-0,05	0,03	0,07	kap	dvokapnica
10	-0,18	-0,52	-0,8	-0,01	-0,28	0,06	kap	dvokapnica
11	0,04	-0,33	-0,72	0,17	0,27	-0,19	kap	dvokapnica (čop)
12	0,22	-0,18	-0,74	0,07	0,29	-0,02	sleme	dvokapnica (čop)
13	0,12	-0,25	-0,57	-0,13	0,3	-0,26	kap	dvokapnica (čop)
14	0,29	-0,73	-0,89	-0,05	-0,65	-0,55	sleme	dvokapnica (čop)
15	0,47	-0,35	-0,49	0,33	-0,37	0,04	kap	dvokapnica
16	0,34	-0,23	-0,16	0,3	-0,15	-0,01	sleme	dvokapnica
17	0,35	0,12	-0,76	0,17	0,47	0,35	kap	dvokapnica
18	0,08	0,19	-0,42	0,2	0,08	-0,02	sleme	dvokapnica
19	0,51	-0,04	-0,23	0,23	-0,12	0,04	kap	dvokapnica
20	0,69	-0,04	-0,69	0,24	0,13	-0,09	sleme	dvokapnica
21	0,57	-0,27	-0,43	0,32	0,37	0,13	kap	dvokapnica

Točka	Stereopar letalskih posnetkov CAS			Aerolasersko skeniranje LSS			Značilna točka strehe	Vrsta strehe
	Δe [m]	Δn [m]	ΔH [m]	Δe [m]	Δn [m]	ΔH [m]		
22	0,32	-0,14	-0,45	-0,27	0,29	-0,25	sleme	dvokapnica
23	0,32	0,22	-0,22	0,15	0,37	0,08	kap	dvokapnica
24	0,49	-0,09	-0,21	0,13	-0,23	-0,18	kap	dvokapnica
25	0,27	-0,13	-0,23	0,24	-0,72	-0,15	kap	dvokapnica
26	0,36	-0,07	-0,52	-0,65	-0,36	-0,18	sleme	dvokapnica
27	0,47	-0,07	-0,88	0,56	-0,3	-0,02	kap	dvokapnica
28	0,44	-0,23	-1,00	0,08	-0,28	-0,16	sleme	dvokapnica
29	0,49	-0,24	-0,77	0,06	0,02	0,05	sleme	dvokapnica
30	0,41	-0,09	-0,6	-0,08	-0,09	0,14	kap	dvokapnica

Preglednici 2 in 3 prikazujeta koren srednjega kvadratnega pogreška in največje odstopanje po posameznih koordinatah pri zajemu značilnih točk streh s stereopara letalskih posnetkov CAS in oblaka točk aerolaserskega skeniranja LSS.

Preglednica 2: Koren srednjega kvadratnega pogreška značilnih točk streh pri različnih virih daljinskega zaznavanja

Vir daljinskega zaznavanja	RMSE (e) [m]	RMSE (n) [m]	RMSE (H) [m]
Aerolasersko skeniranje (5 točk/m²)	0,36	0,30	0,17
Stereopar letalskih posnetkov CAS	0,36	0,26	0,61

Preglednica 3: Največje odstopanje koordinat značilnih točk streh pri različnih virih daljinskega zaznavanja

Vir daljinskega zaznavanja	Δe_{MAX} [m]	Δn_{MAX} [m]	ΔH_{MAX} [m]
Aerolasersko skeniranje (5 točk/m²)	-1,28	-0,65	-0,55
Stereopar letalskih posnetkov CAS	0,69	-0,73	-1,00

5.1 Analiza rezultatov

Iz preglednice 2, v kateri so zbrani koreni srednjih kvadratnih odstopanj RMSE koordinat značilnih točk streh od referenčnih vrednosti pri uporabi različnih virov daljinskega zaznavanja, je razvidno, da je položajna točnost pri uporabi obeh virov primerljiva, saj znaša pri zajemu iz podatkov aerolaserskega skeniranja 0,36 metra v smeri vzhod–zahod in 0,30 metra v smeri sever–jug ter pri zajemu s stereopara 0,36 metra v smeri vzhod–zahod in 0,26 metra v smeri sever–jug. Višinska točnost pa je pri podatkih aerolaserskega skeniranja precej boljša od položajne in znaša 17 centimetrov, medtem ko je višinska točnost točk, zajetih iz stereopara CAS, slabša od položajne in znaša 61 centimetrov. Kljub majhnemu vzorcu lahko ugotavljamo, da je aerolasersko skeniranje boljši vir za zajem položajnih podatkov o strehah stavb kot stereopari CAS. Iz preglednice 3, ki prikazuje največja odstopanja koordinat značilnih točk streh od »referenčnih« vrednosti, je razvidno, da je največje položajno odstopanje doseženo pri podatkih aerolaserskega skeniranja, največje višinsko odstopanje pa pri zajemu s stereopara CAS. Z aerolaserskim skeniranjem se sicer lažje zajamejo detajli, ki so značilni za strehe, pri čemer se doseže predvsem visoka višinska točnost, kar so potrdile tudi dosedanje raziskave v tujini (glej Vosselman in Maas, 2010). Pri strehah nismo ugotovili razlik glede na vrsto streh, prav tako ne glede na to, ali je posamezna točka ležala na slemenu ali na kapi. Vsekakor pa je pri zajemu streh problematična interpretacija detajlov, ki določajo značilne točke strehe, saj slemena in kapi niso opisani z ostrimi in ravnimi linijami, ampak so slemena podolgovate in okrogle oblike, kapi pa imajo zaradi oblike strešnikov in žlebov pogosto nejasno določene robove. Zaradi tega pri isti strehi težko zagotovimo, da se pri določanju njenega položaja iz dveh različnih virov zajamejo identične točke oziroma linije.

Če podatke zajema streh primerjamo s točnostjo rezultatov množičnega zajema stavb ob vzpostavitvi katastra stavb, ugotovimo, da je standardni odklon višine referenčne točke stavbe 0,65 metra (Opredelitev natančnosti v katastru stavb, 2009) primerljiv z našim rezultatom, pridobljenim z zajemom podatkov na podlagi stereopara CAS, ki znaša 0,61 metra. Dosežena položajna natančnost 0,36 metra v smeri vzhod–zahod in 0,26 metra v smeri sever–jug pa je precej boljša od množičnega zajema pred več kot desetletjem, ko je znašala 0,85 metra (Opredelitev natančnosti v katastru stavb, 2009). Pomembno pa je dodati, da je bilo v oceni kakovosti množičnega zajema pri položajni natančnosti v vzorec vključenih 118 točk na kapeh streh in pri višinski natančnosti 21 točk na slemenih streh (Opredelitev natančnosti v katastru stavb, 2009), naš vzorec pa je vključeval le 30 točk. Druga razlika je v tem, da smo pri oceni natančnosti uporabili en stereopar, v oceno natančnosti množičnega zajema pa je bilo vključenih 35 stavb na območju celotne Slovenije (Opredelitev natančnosti v katastru stavb, 2009). Prav tako je bila pri množičnem zajemu stavb uporabljena druga tehnologija (analogne črno-bele fotografije, aerotriangulacija opravljena na podlagi oslonilnih točk). Zaradi različnih vzorcev in uporabe druge tehnologije so dobljena odstopanja med množičnim zajemom in današnjimi rezultati pričakovana.

Glede na dosežene rezultate in obstoječe podatke množičnega zajema lahko ugotovimo, da višinska točnost aerolaserskega skeniranja, ki je ocenjena na 17 centimetrov, zadošča za množičen zajem streh stavb, ki so manjkajoči podatki za izdelavo 3D-modleov stavb na ravni podrobnosti LoD 2. Točnejše rezultate je mogoče doseči s terensko izmero GNSS in tahimetrično izmero, ki lahko v okviru rednih katastrskih postopkov nadomestijo podatke, pridobljene z množičnim zajemom z uporabo virov daljinskega zaznavanja. Opozoriti velja, da je pri zajemu podatkov o položajih značilnih točk in linij streh zaradi večpotja laserskega žarka in slabe vidljivosti s tal včasih nezanesljiva tudi tahimetrična izmera.

6 SKLEPNE UGOTOVITVE

V prispevku smo obravnavali tehnologije daljinskega zaznavanja kot mogoč vir za vzpostavitev 3D-katastra nepremičnin, pri čemer smo se omejili na državne uradne podatke daljinskega zaznavanja. Ugotovili smo, da so v Sloveniji že na voljo državni topografski podatki, poleg katastrskih podatkov, ki pokrivajo celotno območje države in so ključni za vzpostavitev 3D-katastra nepremičnin. Ob pregledu obstoječih podatkov zemljiškega katastra in katastra stavb smo ugotovili, da za izdelavo 3D-modelov stavb za raven podrobnosti LoD 2 dodatno potrebujemo položaje značilnih točk streh v prostoru, za zajem katerih so med razpoložljivimi uradnimi podatki najustreznejši podatki aerolaserskega skeniranja (že s povprečno ločljivostjo 5 točk/m^2), ob pogoju, da se redno posodabljajo. Prednost aerolaserskega skeniranja je tudi, da omogoča zajem objektov na zaraščenih območjih. Dodaten vir podatkov daljinskega zaznavanja bi bil lahko zajem podatkov z brezpilotnimi letalniki. Podatki daljinskega zaznavanja so pomembni tudi za zajem drugih manjkajočih podatkov v katastrskem sistemu – zaradi zgodovine nastanka katastra na primer veliko zemljiškokatastrskih točk nima določenih položaja in višine v referenčnem državnem koordinatnem sistemu, ampak imajo položaj podan v lokalnih koordinatnih sistemih. Vsekakor pa je uporabnost tehnologij daljinskega zaznavanja iz zraka v katastru omejena na zunanjost objektov in na odprta območja brez ovir, zato je pri geometrijskih ovirah priporočljiva uporaba drugih tehnologij geodetske izmere.

Uveljavitev predlaganega modela 3D-katastra nepremičnin na ravni podrobnosti LoD 2 bi bila pomembna tako z vidika topografije kot nepremičninskih evidenc, zato toliko bolj izpostavljamo pomen vzpostavitve 3D-katastra nepremičnin vsaj na tej ravni podrobnosti. Pomemben izziv je zagotovo nadaljnji razvoj 3D-modelov nepremičnin na višji ravni podrobnosti (LoD 3, LoD 4 in LoD 5), kjer v Sloveniji prav tako že imamo pomembne podatke (kataster stavb), kar je precejšnja prednost v primerjavi z državami v regiji. Tu velja poudariti, da je v slovenskem sistemu zemljiške administracije evidentiranje nepremičnin sedaj omejeno le na zemeljsko površje in stavbe (ter dele stavb), ni pa še pravne podlage za evidentiranje drugih gradbeno-inženirskih objektov, ki niso stavbe in ležijo nad ali pod zemeljskim površjem, kot so na primer prometnice, podzemne vode, zaloge rudnin itd.

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