APPLICATION OF UAV DATA IN CITYGML DEVELOPMENT

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Abstract

Aero photogrammetric images acquired with the unmanned aerial system senseFly eBee were used for point cloud creation of the inhabited part of the Silba Island. The automatic point cloud classification that relies on machine learning was processed in the Pix4D program. DSM, orthomosaic and CityGML were created from the classified point cloud. Apart from classified point cloud as a basis for buildings heights, topographic map created from high-resolution orthomosaic of the area was used as a basis for buildings boundaries. CityGML was created using 3dfier software for detail level 1 (LoD1), encompassing all external surfaces of objects. A unique identification, along with house number, floor area, height and volume attributes were assigned to the buildings. The realistic preview of the recorded area in 3D was achieved inside Pix4D Cloud platform. Information and analytical preview of objects was achieved by loading and stylizing CityGML inside QGIS 3.0. Information preview holds buildings outline with house numbers, while stylizing buildings according to the attributes of height, floor area, accomplished the analytical preview and volume attributes. The information preview of the objects provides insight into the basic attributes of buildings and along with the realistic and the analytical preview creates a base for complete modern 3D buildings inventory.

Key words: 3D buildings, UAS, CityGML, DSM, point cloud

Introduction

The purpose of every model is to represent reality in as much as possible credible way. Modeling large-scale data like cities brings attention to model’s substantiality and heterogeneity. A key feature of every 3D city model is representation of georeferenced urban spatial data (DÖLLNER et al., 2006). Such georeferenced spatial data consists of terrain elevation, buildings, land use, vegetation and roads (IÑAKI et al., 2014), among others that are necessary to govern cities sustainably. After being used mainly for 3D visualization in last decades, 3D city models became matter of necessity for wide range of tasks like area population estimation, solar-radiation models, building models, visibility analysis, urban planning, and potential assessment (BILJECKI et al., 2015a).

Croatian cadaster is in great rate originated in 19th and 20th century (ROIĆ et al., 1999) which causes topological incompatibilities with reality, due to various datums and precisions of surveys. Condition of not implementing changes and their registration in cadaster during the second half of 20th century (IVKOVIĆ, VLAŠIĆ, 2006) caused large number of unregistered objects and changes on registered ones, along with unregistered changes in position and shape of parcels. The result of this is unusable cadaster as topological basis for 3D objects creation, except 10% of cadastral municipalities generated in new surveys (KLEKOVIĆ et. al., 2014).

Nowadays, the core data for 3D city models generation is point cloud generated from LIDAR of SAR (ZHU, SHAHZAD, 2014) data. Our exordial data for 3D buildings model in this work is also point cloud but generated from aerial images acquired with UAS. We decided to rely our 3D buildings model on aerial photogrammetry point cloud in order to enhance geospatial data registration rate and positional accuracy, and at the same time deploying model as rich as possible.

Material and methods

For showcasing 3D buildings generation we have chosen the Island of Silba located in the southern part of the northern Adriatic sea. The Island of Silba is almost 15 km^2 large and has constant population of around 300 people. Populated part of Silba covers about 2 km^2 which holds 512 objects on the southern part, as we have mapped in this work, and even so much on the northern part as divided by the line connecting a eastern and western dock. Silba is one of 6761 Croatia's settlements (BUDIMIR et al., 2015), thus settlements present considerable challenge to local governments and authorities in reconstruction and regular maintenance of building registries, in order to provide accurate assessments.
As told in the introduction majority of cadastral municipalities' data is not accurate enough to be paired with up to date technologies or outdated with missing key data for 3D buildings development. Cadastral municipality of Silba is also one of these municipalities unusable as topological basis for 3D buildings creation. Inaccurate and missing buildings data is shown on Croatian official orthophoto from year 2011 in Fig. 1.

Fig. 1. Part of Cadastral municipality of Silba on Geoportal.
Source: (http://geoportal.dgu.hr/#/).

For creating input data used for modern buildings registry which can also be used for cadastral parcels enhancement and GIS development we have chosen aerial photogrammetry method with data acquired with unmanned aerial system (UAV). We have set up geodetic basis of 12 ground control points (GCPs) and 14 control points (CPs) all over the populated part of the island for purpose of aerial photogrammetry. GCPs were used for referencing the model and CPs were used for accuracy control of the model. Geodetic basis was set up with Global Navigation Satellite System (GNSS) Real-time Kinematics (RTK) and very precise positioning service (VPPS) on network of GNSS reference stations - Croatian Positional System (CROPOS). Survey has been proceeded in HTRS96/TM datum. We have used senseFly eBee UAV for aerial images acquisition. We have acquired images with 80% lateral overlap and 75% longitudinal overlap at approximate 148 m altitude. Images acquisition was proceeded in 4 UAV flights and total of 1140 georeferenced images was acquired.

Images were processed both in Pix4Dmapper desktop and in Pix4D cloud. Main desktop outputs are automatically classified point cloud in LAS format, which is relied on machine learning in processing progress (BECKER et al., 2017). Machine learning algorithms consider both geometry and color information from point cloud. Automatically classified point cloud was used for digital terrain model (DTM) generation, considering only points classified as ground and road surfaces. Cloud processing provided the same outputs as desktop processing and enables online preview of orthomosaic and digital surface model (DSM) in 2D georeferenced on satellite base map. Average ground sampling distance (GSD) of outputs is 4.03 cm, except DTM with five times smoother GSD of 20 cm. Georeferencing the model in processing equaled mean RMS error of 0,015 m in all three dimensions. Georeferencing details for GCPs is shown in Table 1 and for CPs in Table 2. Table 1 shows very accurate model georeferencing in absolute aspect according to GCPs surveyed in Croatian official datum (HTRS96/TM) with nominal accuracy of 0.02m horizontally and 0.03m vertically for VPPS. Table 2 shows very accurate model georeferencing in aspect relative to GCPs.

Table1. GCPs georeferencing details.

GCP Name	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]
gcp1	-0.018	0.046	-0.007	0.443
gcp3	-0.009	0.000	0.016	0.546
gcp5	-0.006	0.002	0.013	0.409
gcp7	0.005	0.020	-0.030	0.589
gcp10	0.026	-0.003	-0.003	0.493
gcp13	0.001	0.002	-0.002	0.444
gcp16	0.019	-0.024	0.022	0.720
gcp18	-0.007	-0.017	0.017	0.442
gcp20	0.004	-0.005	0.000	0.421

Source: Own study based on own data.

Table 2. CPs georeferencing details.

Check Point Name	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]
gcp2	-0.010	0.013	0.035	0.426
gcp4	-0.051	0.020	0.230	0.894
gcp6	-0.007	-0.019	0.098	0.642
gcp8	0.036	-0.008	-0.144	0.601
gcp9	-0.019	0.022	0.048	0.293
gcp11	-0.010	-0.029	-0.092	0.425
gcp12	0.038	-0.021	0.165	0.336
gcp14	0.029	0.027	0.095	0.628
gcp15	0.016	0.032	-0.170	0.358
gcp17	-0.054	-0.003	0.035	1.127
gcp19	-0.069	0.001	-0.112	1.189
gcp22	-0.060	-0.012	0.031	0.684
gcp24	-0.038	-0.010	0.002	0.647
gcp26	-0.043	0.070	0.287	0.544

Source: Own study based on own data.

After generation of centimeter precision orthomosaic, which can be used for cadaster enhancement, we have used it as a basis for buildings topography layer. Topography layer was created in Spatial lite format containing a basic buildings features as house number and building type. Buildings topography included all outer buildings borders along with all their constructive parts like outer stairways, balconies and terraces on floors. Buildings with such defined topography can be used for CityGML generation of Level of detail (LOD) 1.2 or higher as shown in Fig. 2.

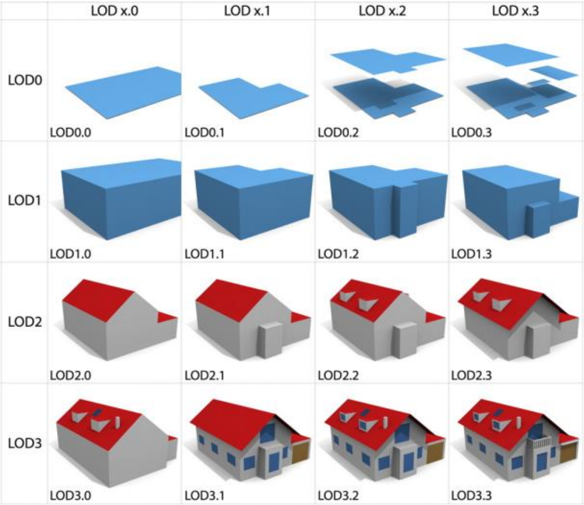

Fig. 2. Refined series of 16 LODs.
Source: (Biljecki et al., 2016).

After completing the building topography main inputs for CityGML were ready. CityGML LOD1 generation was proceeded in 3dfier, an open-source software (source: https://github.com/tudelft3d/3dfier). 3dfier uses 2D topography data, in our case only the buildings, and point cloud data in LAS format, in our case an aerial photogrammetry point cloud. While defining CityGML lifting options in 3dfier we have set up percentiles for buildings height and roof read from the LAS files. 90th percentile of all point heights in buildings footprint was used for the roofs in LOD1, thus filtering outliers and roof features like chimneys. 10th percentile of all point heights in buildings footprint was used for floor height. For input elevation options we have set up omitting point cloud (LAS) classes 1, 3, 4 and 5, representing respectively unclassified, low vegetation, medium vegetation and high vegetation points according to ASPRS Standard LIDAR Point Classes (ASPRS, 2011). Omitting unclassified and vegetation points from classified point cloud prevented false roof and floor height definition in LOD1 generation. 3D buildings were generated in CityGML and OBJ format (Fig. 3).

Fig. 3. CityGML 3D preview in QGIS 3.0.
Source: Own work.

Results and discussion

Pix4D cloud processing enabled basic 2D preview of orthomosaic and DSM on the base map, thus placing project area on world’s map. Except the 2D preview, Pix4D cloud provides 3D preview for 3D model (mesh model) and point cloud with project coordinates, although not placing them on the globe. Both previews are available on URL1.

CityGML provided main buildings data as floor and roof height, which conceal absolute and relative building heights, and buildings area as defined in buildings topology. Both area and relative height include outward buildings volume into attribute data.

Fig. 4 shows buildings heights emphasizing lowest buildings, which are actually bedrocks for future buildings with heights of 0,98 m and taller, and highest building, local church with height 15,20 m.

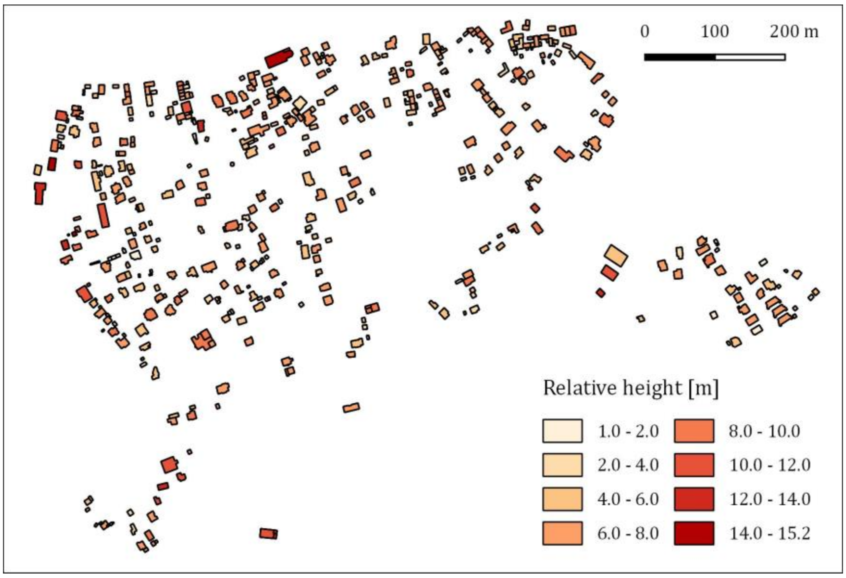

Fig. 4. CityGML heights.
Source: Own work.

Comparing relative heights with point cloud data, difference of 20 cm has been measured on the highest building. This indicated good trail for analyzing relative heights data but also involved oversized volume data, as expected in the simplified LOD1 data. Area, 2D buildings data created digitizing aerial photogrammetry orthomosaic can be used for enhancing and reconstructing cadaster data (Fig. 5).

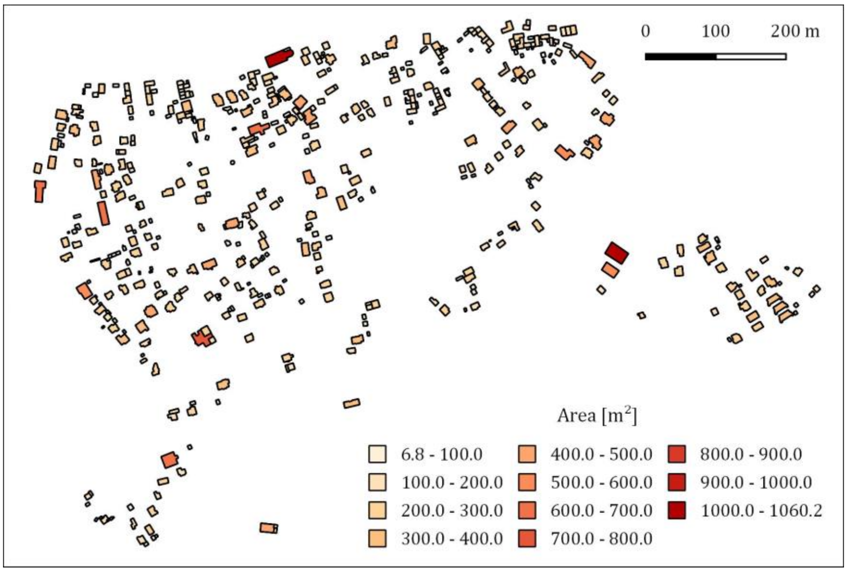

Fig. 5. CityGML area.
Source: Own work.

Enhancing cadaster data in the dimension aspect is the core value of CityGML as volume (height) data significantly enriches building information inside the Registry. Volumes calculated using area and relative height data is shown in Fig. 6.

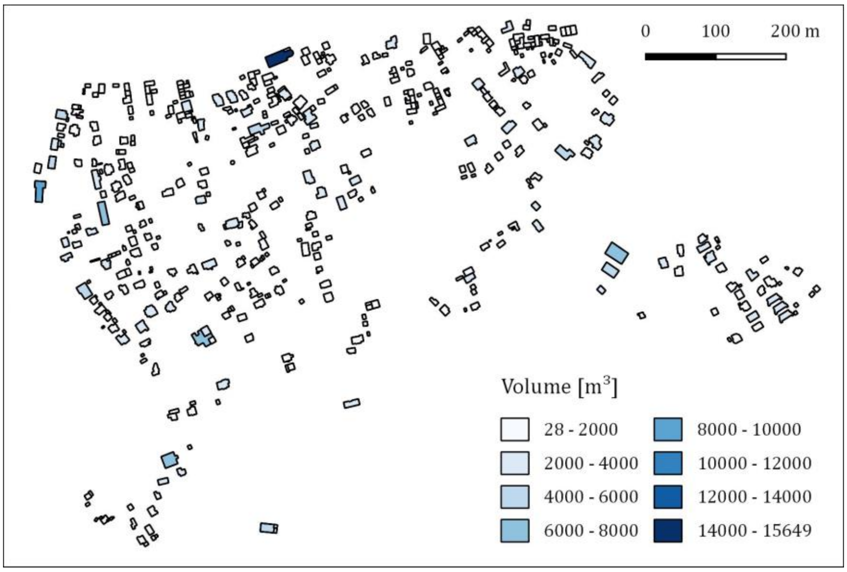

Fig. 6. CityGML volumes.
Source: Own work.

CityGML holds attributes form the spatial units Registry, in this case only house numbers, but normally it holds and streets nomenclature. CityGML should also be enriched with basic buildings attributes from cadaster, indicating building type. We have used only two basic building types, residential buildings and auxiliary buildings. Separating buildings by type enables analyzing their use in the target area and which helps in future urban planning and regulation definitions. Buildings should be enriched with as many attributes as possible, thus compellingly heading towards a multipurpose land administration system (MLAS) (Roić et al., 2017).

Multipurpose of land administration is highly contained in 3D buildings data, as it's briefly shown in Fig. 4 and Fig. 6. Previewing both of them together, i.e. in 3D, gives us insight into building trend in this area and helps creating assessments in future resources needs. Analyzing Fig. 6 we get to conclusion that building with highest volume is sacral building, and other building gravitate around 2000 m^3 as their main use is for tourists' accommodation. Analyzing the absolute building heights can result in enactment of zones or areas with maximum buildings height, in order to preserve sea view in objects further from the sea. Similar analyses exists in building shadows analyses, visibility analyses (BILJECKI et al., 2015a) and solar irradiation analyses (BILJECKI et al., 2015b).

Conclusions

Today's cadaster in Republic of Croatia still falls behind modern 3D cadasters, while still in great need for enhancement and registration of 2D data. On the other hand growing abilities of modern surveying technologies and software advancement gives great deal of time saving and accurate methods for not only quality but also structure uplift providing 3D data for high-end interference. Aligning on growing UAV industry, which we use in surveying more with every day, we have created inputs accurate and rich enough to recreate 2D and create 3D buildings using 3dfier. Richness is mainly contained in point cloud classified in machine learning algorithm. Creating LOD1.3 CityGML gave fast solution for 3dfieing Croatia's large number of settlements that do not require grater details than contained in stated LOD. On the other hand cities with large number of buildings and growing population surely need 3D buildings in LOD2 or higher. Once 3dfied buildings provide insights and possibilities like shadow analyses, solar irradiation analyses and visibility analyses. Last two could find great application in Adriatic region. Solar irradiation analyses can provide insight in possibilities of solar panel implementation and thus improve competitiveness in tourism sector, while visibility analyses can provide enactment of maximum buildings height zones in order to preserve sea view line of sight in desired locations.

References

THE AMERICAN SOCIETY FOR PHOTOGRAMMETRY & REMOTE SENSING 2011. *LAS specification version 1.4 – R6*. USA, 2011.

BECKER, C., HÄNI, N., ROSINSKAYA, E., D'ANGELO, E., STRECHA, C. 2017. *Classification of aerial photogrammetric 3D point clouds*. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-1/W1. ISPRS Hannover Workshop: HRIGI 17 – CMRT 17 – ISA 17 – EuroCOW 17, 6–9 June 2017, Hannover, Germany.

BILJECKI, F., LEDOUX, H., STOTER, L. 2016. *An improved LOD specification for 3D building models*. Computers, Environment and Urban Systems, Vol. 59, p. 25-37.

BILJECKI, F., STOTER, J., LEDOUX, H., ZLATANOVA, S., ÇÖLTEKIN, A. 2015a. *Applications of 3D City Models: State of the Art Review*. ISPRS International Journal of Geo-Information, 4: 2842–2889.

BILJECKI, F., HEUVELINK, G. B. M., LEDOUX, H., STOTER, J. 2015b. *Propagation of positional error in 3D GIS: estimation of the solar irradiation of building roofs*. International Journal of Geographical Information Science, 29(12): 2269-2294.

BUDIMIR, I., GRGIĆ, I., ŠUSTIĆ, A. 2015. *Evidencija naselja i katastarskih općina u Registru prostornih jedinica (Record of Settlement and Cadastral Districts in the Register of Territorial Units)*. Geodetski list 2015, 3:207-220.

DÖLLNER, J., KOLBE, T., H., LIECKE, F., SGOUROS, T., TEICHMANN, K. 2006. *The virtual 3D city model of Berlin - managing, integrating and communicating complex urban information*. 25th International Symposium on Urban Data Management UDMS.

IÑAKI, P., IZKARA, J. L., DELGADO, F. J. 2014. *From point cloud to web 3D through CityGML*. Proceedings of the 18th International Conference on Virtual Systems and Multimedia, VSMM 2012: Virtual Systems in the Information Society. https://www.researchgate.net/publication/235635196_From_point_cloud_to_web_3D_through_CityGML (access 25.04.2018).

IVKOVIĆ, M., VLAŠIĆ, I. 2006. *Usporedba površina katastarskih čestica stare i nove izmjere (Comparison of Cadastral Parcel Areas in the Old and New Surveys)*. Geodetski list, 4: 285-294.

KLEKOVIĆ, B., LIPOVŠČAK, G., PAJ, R., SMOLJAN., Z. 2014. *Poboljšanje modela katastarskih izmjera (Improvement of cadastral survey models)*. Croatian Chamber of Charted Geodesy Engineers, Zagreb.

ROIĆ, M., VRANIĆ, S., KLIMENT, T., STANČIĆ, B., TOMIĆ, H. 2017. *Development of Multipurpose Land Administration Warehouse*. FIG Working Week 2017, Surveying the world of tomorrow – From digitalization to augmented reality, Helsinki, Finland, May 29 – June 2, 2017.

ROIĆ, M., FANTON, I., MEDIĆ, V. 1999. *Katastar zemljišta i zemljišno knjižni registry (Land Cadaster and Land Registry)*. Zagreb.

ZHU, X., X., SHAHZAD, M. 2014. *Facade Reconstruction Using Multiview Spaceborne TomoSAR Point Clouds*, IEEE Transactions on Geoscience and Remote Sensing, 52(6): 3541-3552.

URL 1: https://cloud.pix4d.com/pro/project/280470/map?shareToken=b1ab314b22384b0aa6d38f38b970c7b2 (access 25.04.2018).