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Establishing the utility charges spatial database using digital twin technology

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Abstract - **Digital twin technology is getting more attention when it comes to smart city management. Digital twins or 3D models of cities are created by utilizing 3D laser scanning, unmanned airborne vehicles (UAV) and mobile mapping systems. Photogrammetry based UAVs are increasingly used for land surveying and infrastructure mapping. In comparison to other techniques, photogrammetry can be used to collect large amount of geospatial data in relatively short time. Current techniques used to maintain and manage utility charges database often relies on long lasting field measurements and manual data collection. Such approach may result in incorrect, unreliable and outdated information about building area and floor count, which significantly affect the utility charge amount. This paper presents a methodology of establishing geospatial database by utilizing digital twin technology, photogrammetry and a fixed wing UAV with precise GNSS (Global Navigation Satellite System) also called GPS (Global Positioning System) receiver. Mentioned UAV has the ability of taking oblique images of terrain, buildings and infrastructure, which are then used to reconstruct 3D model (digital twin) of the city. It is presented how data extracted from 3D model is used to establish digital geospatial database containing building layouts, floor count and area. These information were compared to official data, which showed all the benefits of digital twin technology, but also all the issues of current utility charge system. Finally, the focus is turned to other applications of digital twin technology and its involvement in Industry 4.0, together with autonomous vehicles, 5G networks and IoT.**

Key words – digital twin technology, utility charges, UAV, 3D city model, GIS, geospatial database

I. Introduction

Nowadays, with the rapid technological development, local governments are starting to rely on modern technologies in order to run the city infrastructure more efficiently. That technology allows not only to lower costs through optimization of managing different processes, but it can also expand the functionalities of current systems. One example of that technology is digital twin, which allows creation of up to scale 3D virtual clone of buildings and infrastructure that can also be upgraded by adding attributes to each individual object. By using detailed replica of the city, it is possible to digitize and optimize different processes like traffic or spatial planning, and emergency services like fire department or police. Also, upgrading the digital twin model with data from different sensors and IoT devices would result in creating a smart clone of the city. That clone can not only monitor current state of the city, but if we would feed historical and current data into a machine learning software, it would be possible to model the behavior of the city and simulate what would happen in different emergency situations. Furthermore, the twin could be used for 5G network infrastructure planning. Since the 5G technology performance is limited by obstructions, and it requires line of sight between the antenna and the device for optimal performance, 3D data from digital twin would make it easy to create visibility maps and plan the best positions for antennas. In addition, by utilizing advanced neural networks, it would be possible to optimize the city traffic and predict the effect of future infrastructural and transportation projects, and by doing so, reduce traffic jams and speed up the public transportation.

Although there are a lot of different use cases for this technology and its benefits are obvious, the implementation process can be challenging. That is the reason why in this paper we decided to use the digital twin for a simple, yet effective method of creating spatial database for utility charges. It is a great example because such registers depend on spatial information like building areas and location. Moreover, the reliability of such data is often questionable since there are cases where current system is not up to date. Unfortunately, Croatian local governments quite frequently use nothing more than a simple Excel based table system, from which it is not possible to determine where the buildings are placed, what is their shape and size, what is in their neighborhood and has anything changed with the building (for example has it been expanded or demolished). It is not possible to know how the building area was defined or how many floors does it have from a simple table. What is more, there are some cases where payers themselves are the ones who reported the building areas, so it is doubtful if reported areas can be trusted. Despite that, those registers are used as official area and position information for utility charges calculation. All of this shows there is a need for upgrade, and digital twin technology may be the way to go. All the necessary data for the spatial database can be extracted precisely because it is high resolution, up to scale and visually representative model of reality.

A. Utility charges

According to the law of utility management, utility charges is a financial public charge used for maintenance of utility infrastructure [1]. Utility charges resources are meant to be used for: maintaining of public surfaces, maintenance of unclassified roads, public lighting, maintenance of cleanliness, drainage, maintenance of cemeteries and crematoriums, and the rest utility activities of the local significance [2]. Utility charge is a monthly fee that the real estate owner or user is required to pay. Monthly fee depends on three parameters [1]:

1. Zone coefficient (Kz)
2. Usage coefficient (Kn)
3. Utility charge point value (B)

Zone coefficient (Kz) has a different value based on a location (zone) of the building. Different zones are determined by the level of development of utility infrastructure [1]. For the first zone the coefficient value has the highest value of 1.00. Usage coefficient (Kn) depends on the type of real estate and what it is used for. For the residential and garage area the value is 1.00. Utility charge point value (B) is determined in Croatian kunas (HRK) by the square meter (m^2) of net usable residental area in the first zone [1]. Utility charge point value can vary, and its amount is set by the local government. The value of utility charge is defined with the formula (1)

$$K(kn) = Kz \times Kn \times B \quad (1)$$

The most important parameter in Utility charge point value is net usable area of residential area. Net usable area defined by law as gross residential area reduced by the thickness of the walls [3].

Also, the net usable area does not include basement, attic, staircase and balcony areas which are not equipped enough to be used as residential or office spaces. Those areas and elements are multiplied by defined coefficient before adding to the net usable area. When everything is taken into consideration, net usable area will always be smaller than gross area. Lisjak [4] estimates this difference to be around 15%. One of the problem is that there is no regulation how the area is measured and calculated, or what register can be used as an official source for net usable building area. It is quite often the case to use the area reported in building permit, land registry or cadaster. In some cases, local government relies on the net usable areas and floor count reported by the payers themselves. The last system is used mostly in areas where the record is old, outdated or even nonexistent. Besides that, some local governments keep their record in a form of simple table. It makes it difficult to simply and unambiguously determine which building is the record referring to, where the real estate is located and how the building area is defined. For previously mentioned reasons those utility charge records are quite often based on inaccurate data. In these situations, benefits of the new technologies for mass spatial data collection like photogrammetry come to play.

II. Data acquisition and digital twin reconstruction

Photogrammetry is a science and technology of acquiring reliable data of Earth, its surroundings and other physical objects by using imagery, without direct contact with objects [5]. Although it is a very useful technique, its usage was not widely spread because the process required a specialized, expensive equipment and a lot of manual labor. Development of modern photogrammetric software and high-performance CPU-s and GPU-s vastly contributed photogrammetry as a technique to gain popularity, and is

Figure 1. Test area of city of Čakovec (17 ha)

now one of few key methods for mass spatial data collection. [6][7]. One of the biggest advantages is the ability to reconstruct 3D models (digital twins) of any object using nothing more than digital photos. This ability makes it really useful in different industries like construction, agriculture, precise engineering, movie and gaming industries etc.

The development of unmanned aerial vehicles caused a revolution in acquiring spatial data for large areas. UAVs are designed to perform flights without any pilot on board, therefore they are controlled with remote control, by preprogrammed flight plan or autonomously by autopilot [8]. By mounting imaging sensor like photographic camera, GNSS receiver and inertial measurement unit (IMU) on UAV, it can be converted into photogrammetric mobile mapping unit that can acquire large amount of data necessary for reconstruction of spatial information in short time. It is systems like this that enable utilization of full potentials that modern photogrammetric algorithms provide.

In order to create digital twin model of the city and establish spatial database for calculation of utility charge amount, photogrammetric mobile mapping unit was used. As a test polygon we chose north part of the city of Čakovec, Croatia, with area of 17 ha (Figure 1). On our request, Local utility management department provided us official area information used for certain amount of residential buildings. That areas should represent net usable areas of the buildings, so we are expecting a mismatch between them and gross buildings area (which will be derived from digital twin of the city). Regardless, the mismatch should be quite small. If not, we can assume there is an error in one of compared areas.

A. Equipment used

The photogrammetric measurements were done on 10^{th} of July 2019. Data acquisition was made with Topcon (Intel) Sirius Pro UAV (Figure 2). It is a fixed wing type of UAV with quite small weight relative to its size (2.7 kg including camera) and flight autonomy of 50 min on a single battery [9]. What distinguishes this UAV from all the other drones is integrated GNSS RTK (*Real Time Kinematics*) module, which enables centimeter grade positioning accuracy of every taken photo in the moment of exposition. In other words, Sirius Pro UAV allows us to collect the data needed for rendering 3D model with high positional accuracy without using ground control points (GCP). One of the most important aspects of any UAV used

Figure 2. Topcon Sirius Pro UAV

Figure 3. GeoSLAM mobile scanner

for accurate 3D reconstruction is the camera it can carry and use. For purposes of this paper Sony Alpha 6300 was used. It is equipped with 24 MP sensor, and it supports usage of so called "City mapping" module. The "City mapping" module allows capture of images in such way that not only the rooftops are visible, but also walls of the buildings. The module is a key component of the system since images taken with regular cameras can only reconstruct the rooftops and the ground.

Data for specified area was acquired in one 20 min automated flight. In order to create flight plan necessary for automated flight, we used MaVinci Desktop software. Flight altitude was set to 60m and the GSD (Ground sampling distance) which defines the final resolution of the digital twin was set at 3cm. Front and side overlaps were set at 80% to ensure good coverage and high reliability of photogrammetric reconstruction, which also ensured high accuracy of 3D city model.

B. Digital twin rendering

After successful flight, data post processing and 3D reconstruction was made. First step was the process of aerotriangulation, where images are aligned and exact positions and orientations of the images sensor in the moment of expositions are determined. It is followed by 3D reconstruction process, where software automatically renders 3D mesh and then transfers the texture/color from corresponding images onto the mesh (Figure 4). With all that, the creation process of digital twin model is done. For the purposes of this paper Topcon ContexCapture photogrammetric software was used.

C. Digital twin accuracy

In order to analyze positional accuracy of the created model, eight points were marked on the different parts of the test area. Position of the points was determined using high precision GNSS (GPS) receiver and RTK method of positioning. Measured coordinates were compared with the

Figure 4. Digital twin of the city

ones determined from the 3D model. Comparison was made separately along each coordinate axis. In addition, minimal error, maximal error, range, mean error and RMS (*Root Mean Square*) were calculated (table 1). The data shows high accuracy and consistency of position determined with RTK module. RMS values of only 2 cm and error range bellow 7 cm along each axis indicate that high accuracy was achieved.

TABLE 1. DIGITAL TWIN POSITION ACCURACY

	Easting	**Northing**	**Height**
Min [m]	-0,030	-0,022	-0,031
Max [m]	0,033	0,047	0,013
Range [m]	0,063	0,069	0,043
Mean error [m]	0,013	0,015	0,011
RMS [m]	0,019	0,020	0,019

In addition, it was decided to measure part of the test area by using mobile 3D laser scanner GeoSLAM ZEB-Horizon (Figure 3). The scanner technology is based on SLAM (Simultaneous Localization and Mapping) algorithm. Since the accuracy of GeoSLAM system is proved to be within 1 to 3 cm [8][10] and can be used to cover large areas in short time span, the system is ideal for photogrammetric data and building gross area quality control. In both datasets the gross area is derived from outer building boundaries at the height of 1.4 m from the ground. By doing so, consistency was assured for the comparison between two datasets. The results are presented in table 2. The data shows minimal mismatch that can be attributed to human error in determining break points used in area measurements. It is worth mentioning that it wasn't possible to enter the backyards in order to scan the back of the buildings. When everything is taken into consideration, it is possible to conclude that the accuracy of the areas measured on digital twin model is adequate for determining the utility charge amount.

III. CREATION OF SPATIAL DATABASE

Since the created digital twin model is a representative and up to scale recreation of the real-life city, it is fairly easy to extract geometrical or spatial information like position, shape, area, volume etc. for any object. In order to make a database with consisted data, all of the building layouts were based on a section of the digital twin done at exactly 1.4 m above the ground. The height of 1.4 m was determined empirically by trying to eliminate all objects that are not buildings, like cars, fences and vegetation. In other words, the digital twin model was sliced at constant distance from the ground by taking in consideration the irregularities of the ground surface (Figure 5a). On created cross section, edges of the buildings were well defined, so to add buildings in the spatial database it was just the matter of vectorizing the boundaries in CAD software. (Figure 5b).

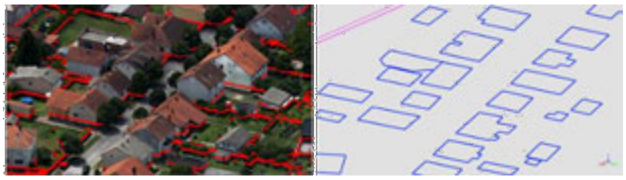

Figure 5. (a) Cross section at the constant height from the ground; (b) Vectorized building boundaries

TABLE 2. COMPARISON OF PHOTOGRAMMETRY AND LASER SCANNER DERIVED AREAS

Building ID	Area (digital twin) [m^2]	Area (Laser scanner) [m^2]	Difference [m^2]
1	62	488	692
2	211	275	30
3	207	273	32
4	101	443	340
5	-	83	-
6	-	186	-
7	134	312	132
8	129	386	200
9	62	332	435
10	194	351	81
11	146	346	138
12	86	210	145
13	136	301	121
14	158	286	80
15	477	1095	130
16	144	265	84

TABLE 3. COMPARISON BETWEEN SOME OF OFFICIAL AND PHOTOGRAMMETY DERIVED AREAS

Object ID	Official area [m^2]	Digital twin area [m^2]	Percentage of deviation [%]
1	62	488	692
2	211	275	30
3	207	273	32
4	101	443	340
5	-	83	-
6	-	186	-
7	134	312	132
9	62	332	435
17	214	223	4
23	227	256	13
24	158	256	62
25	205	422	106
26	216	238	10
27	195	224	15
35	483	510	6

Vectorized building layouts are then imported into GIS software (QGIS) as polygon shapefile layers, where each building became separate database object with its ID as a primary key. In that way we have created spatial database where each object is defined by its position, shape and attributes placed in the attribute table. Since the goal of this paper was to create a spatial database for billing utility charges, columns for floor count, building area, zone coefficient, usage coefficient, and calculated utility charge amount were added to the attribute table. Every building was connected with corresponding database object in original (official) utility charges database in order to cross reference the data and analyze the differences.

The floor count had to be input manually for every building, but thanks to the high-resolution digital twin, the process was pretty straightforward. Number of floors was counted on a twin by counting only those undoubtedly functional and in use. If it wasn't possible to determine whether building had a basement or functional attic, those floors were not taken into account. Usage coefficient was also manually input with the use of digital twin, where the operator would visually determine how the building was used (residential, office, garage or undeveloped area). The usage coefficient was also compared to the one registered in the official utility charges database. The Zone coefficient is defined by utility charge directive which defines the boundaries of the zones. Those boundaries were acquired in a form of a shapefile polygon, and the zones were simply transferred by visual inspection in GIS software. It the end, the building gross area was calculated using built in algorithm for polygonal area calculation. Final utility charge amount was calculated for each building using the official equation (1). Of course, it is always possible to expand the database by adding any additional attributes to the buildings, like house number, street name, municipality etc.

IV. Results, Discussion and Other Implementations

Data extracted from digital twin were compared to official data provided by Local utility management department. Due to the fact that official data should represent net area values, while those calculated by using digital twin should represent gross area values, it was expected to see some differences between compared areas. Comparison is shown in table 3. It was decided to express the differences with percentages, with intention to show the proportion of deviations. By examining the results, it is obvious that there is a problem with current system of utility charges. Not only did we discover two objects which were not listed in official database, but the average percentage of deviation between official and digital twin data shows significant value of 122%. Potential reasons for such results could be found when inspecting the 3D city model. Many properties have garages which seem to be unregistered. Furthermore, many adaptations in form of terraces were found. On the other hand, areas calculated for newer buildings correspond to official data, which shows that such areas were calculated and recorded correctly. Such examples show all the benefits and efficiency of proposed methodology.

Nowadays, digital twin technology is much more than interesting news. It can be argued that it is highly efficient and advanced concept which could lead to some significant time and cost reduction in many industries. One example is telecommunication industry, where this technology can be implemented to create 3D models of telecommunication towers. Such models could be used for inspection purposes, which would reduce time and risk, since it is still mainly done manually by climbing the tower. Moreover, digital twin could be used to extract important measurements like azimuth and tilt angles of antennas mounted on the top of the towers. Such approach provides detailed and more accurate results, while significantly reducing tower's down-time, even up to 5x [11]. Another example is inspection and monitoring of objects like bridges, dams or power plants. Digital twin technology could be used to detect potential threats and damaged parts. Thermal and RGB imagery provide added value to such inspection. Finally, it is possible to detect geometrical deformations, which could be critical due to the fact that such deformations could potentially cause the object to collapse.

V. Conclusion

Primary aim of this paper was to show how geospatial database can aid utility charges and make the complete system more efficient and functional. It was done by utilizing digital twin technology and photogrammetry based mobile mapping system. Proposed methodology turned out to deliver results of high accuracy and could easily reduce time and cost of creating and maintaining traditional utility charges database. Such approach can help to quickly determine area and floor count of every building, that can be used to identify objects with inaccurate data or no data at all. Although the sample size for this research was relatively small (35 buildings), the results seem to show some significant issues in current utility charges system. Such issues definitely have major financial impact on local government. Based on data derived from this research, we roughly estimated that, due to inefficient and outdated utility charges system, local governments experience losses counted in millions of Croatia kunas (HRK). This paper showed that these problems could potentially be solved by implementing digital twin technology.

An example we presented here is not the only way of utilizing 3D city models. This technology has wide application and we can expect to see its further expansion over next few years. It can be argued that many industries require high-resolution, up to scale and representative digital copy of real-life objects. Digital twin technology plays significant role in asset and infrastructure digitization with purpose to optimize resource management in smart cities. It can act as a geospatial foundation for autonomous vehicles since it can be used to derive 2D and 3D maps for navigation and positioning purposes. Furthermore, digital twins can be used for advanced and highly effective 5G networks planning, which are key aspect of IoT implementation. By connecting digital twin technology and IoT sensor data, it is possible to recreate the lifecycle of city in real time and, based on collected data, perform simulations that could optimize traffic and spatial planning. To sum up, it is undoubtedly true that digital twin technology will have major impact on many Industry 4.0 technologies. It will aid their successful implementation, which will consequently improve the overall life quality in cities.

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