Challenges of Using Drones and Software Solutions for Smart Cities

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Abstract

The fast urbanization that we are witnessing today worldwide has led to the fact that more than half of the world's population lives in cities. Relying on broad and rapid technological progress, the concept of smart cities was developed. This concept brings together information and communication technology with various physical devices connected to the network to optimize the efficiency of city services. Smart cities require large amounts of collected data to plan new and improve existing infrastructure. The use of UAVs can improve the realization of this new concept of smart cities and creates the conditions for quick and efficient collection of large amounts of necessary data over a large area. With the obtained data, it is possible to create different basis for the development of a smart city. Today, there are numerous software solutions for processing data collected from UAV that contain automated algorithms and procedures for obtaining products that can be used for various analyses and purposes. In this paper, analyses, and comparison of the obtained products of UAV imaging in the municipality of Bedekovčina (Republic of Croatia) was carried out through three different software: SiteScan, Drone2Map and Context Capture Master. The results show what each software offer for users. Based on the analysis and the obtained products; assessment was made on the best software solution for specific needs.

1. Introduction

The fast urbanization that we are witnessing today around the world has led to the fact that more than half of the world's population lives in cities (UN, 2014). Because of this, the existing metropolises are increasingly densely populated, and the management of such megalopolises has begun to pose an increasing challenge. Relying on broad and rapid technological progress, the concept of smart cities was developed, which began to be realized at the beginning of the 21st century (OECD, 2020).

The concept of a smart city brings together information and communication technology (ICT) and various physical devices connected to the network to optimize the efficiency of different city services and to improve sharing information with the public (Nevistić and Bačić, 2022). This allows city authorities to see how the city is developing and introduce possible changes to the system in the future. This leads to an improvement in the quality of life in cities and a reduction in costs. Also, various smart applications are being developed to manage city affairs and enable real-time reactions so that authorities are better prepared to respond to numerous challenges.

Smart cities require large amounts of collected data to plan new and improve existing infrastructure. The classical (terrestrial) data collection methods could not meet these needs. Although the emergence of unmanned aerial vehicles (UAV) is primarily related to military use, it has been seen that there are great benefits for the use of UAVs for commercial purposes as well as for the realization of this new concept of smart cities (Nader et all, 2022). The use of UAVs creates the conditions for quick and efficient collection of large amounts of necessary data over large area.

With the obtained data, it is possible to create different basis for the development of a smart city. Some of the possibilities of using UAVs in smart cities are for the inspection of buildings, monitoring and surveillance of traffic, monitoring of air pollution, fires, etc. In addition to monitoring the current situation in the city, UAVs can also serve as a tool for creating the basis for spatial planning and resource management in real time so that every area of the city can be used as best as possible (Brešić, 2022). However, processing of these large amount of data is also a big challenge. Today, there are numerous software solutions for processing data collected from UAV that contain automated algorithms and procedures for obtaining products that can be used for various analyses and purposes.

In this paper, analyses, and comparison of the obtained products of UAV imaging in the municipality of Bedekovčina (Republic of Croatia) was carried out through three different software: SiteScan (SS), Drone2Map (D2M) and Context Capture Master (CCM). The main purpose was to create the basic products necessary for the application of the smart city concept. Various products such as ortho-mosaics, slopes, digital surface models, point clouds, 3D models and others were produced in each software. The results show what each software offer for users and based on the analysis and the obtained products; final assessment was made on the best software solution for specific needs. Also, the problems that arise when processing this large amount of data that is collected for the purposes of establishing the concept of smart cities where also described.

2. UAVs for Smart Cities

There is no generally accepted definition of a smart city, and the term has different meanings for different groups of people and varies from city to city and state to state depending on the level of development, readiness for change and reforms, resources, and aspirations of the population. A smart city would have a different connotation in Africa than in Europe, and even within one country, there is no single definition (Nevistić and Bačić, 2022). According to International Telecommunication Union, smart sustainable city is an innovative city that uses ICT and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations concerning economic, social, and environmental aspects (ITU-T, 2014). Smart cities can create efficient and smart services available to the public and authorities using sensor technology and platforms that will allow the sharing, storage, and management of collected data.

The successful implementation of this concept is closely related to the Internet of Things (IoT) and Big data concepts. The Internet of Things is a dynamic global network infrastructure in which physical and virtual "things" of all types communicate and are invisibly integrated. The development of new network technologies, such as 5G technology, creates conditions for faster communication and faster development of the IoT (Henke, 2020). The Big data concept refers to a collection of large and complex datasets that, with classical databases and tools, are difficult to analyze and manage. One definition describes this concept as "any data set that does not fit into Excel spreadsheets" (Batty, 2014). The IoT, Big Data Concept and Smart Cities are closely interconnected. Data in smart cities is generated through a large collection of sensors, databases, emails, websites, and social media. The challenges of the Big Data concept include their visualization, mining, analysis, storage, recording, searching, and sharing, so they require new approaches of processing to enable better decision making, search, optimization, and insight into the process itself (Nevistić and Bačić, 2022).

Classic terrestrial data collection methods often do not meet the needs of the smart city concept, where it is necessary to collect a large amount of data on a relatively large area in the shortest possible time. Therefore, UAVs are one of the emerging technologies for fast and efficient data collection in this concept. UAVs have a wide range of applications in many fields like environmental hazards monitoring, traffic management and pollution monitoring, all of which contributes greatly to the development of any smart city. Also, UAVs can be used for many geo-spatial and surveying activities, for civil security control, traffic and crowd management, agriculture and environmental management, health emergencies, inspection of buildings and others (Mohammed et all., 2014). The use of UAVs enables production of various products such as ortho-mosaics, slopes, digital surface models, point clouds, 3D models and others. These products enable different spatial analyzes for the purpose of improving city management and providing more efficient services to citizens. One example of using UAVs for smart cities is the city of Jeonju (South Korea). UAVs are used to create a 3D model of the terrain, and then the resulting 3D model is connected to GIS and BIM, and based on these combinations, a detailed representation of the city (digital twin) is created in real time (Brešić, 2022).

But in addition to numerous advantages, there are also some limitations to the use of UAVs. They primarily refer to legal and regulatory restrictions on flying, which differ from country to country, and to software and hardware requirements on data processing and collection. Today, there are numerous software with automated algorithms for flight planning and data collection, as well as software with automated algorithms for different product generating based on the collected data. Because of a large amount of data, certain minimum hardware requirements must be met for processing and creating different products. Below are described and analyzed three different software for processing a large amount of data collected by UAV for the purpose of creating spatial bases and products for the needs of a smart city.

3. Data collection and software

The municipality of Bedekovčina (Republic of Croatia) was chosen as a test area for data collection due to the variety of natural and built terrain features in a relatively small area. The covered area is approximately 2.7 km^2 and consists of the city area, industry, the railway, agricultural land, six smaller lakes and the Krapina river.

Data collection was carried out using two different UAVs, the Phantom 4 Pro V 2.0 from DJI and the eBee X drone from SensFly. The data collection was divided into three parts. The first two parts covered the lakes, industry, city area and agricultural area in a single flight using single grid method for agricultural area and lakes, and double grid method for city area and industry with the Phantom 4 Pro V 2.0. Third part is recording with the eBee X, which covers the entire area in single flight. To obtain georeferenced products, it was necessary to set ground control points (GCP). The area covered by each flight and the GCPs are shown in Figure 1.

In total, nine flight plans were created in the Site Scan software and one in the eMotion software for the eBee X. Each software allows simple automated flight definition with the selection of flight parameters depending on the purpose. For example, for the creation of ortho mosaics and other 2D products, the method of a single grind over the same area at a height of 60 m was chosen, while for the needs of creating 3D models of terrain and buildings, the method of a double grid with increased overlap with the same flight height was used.

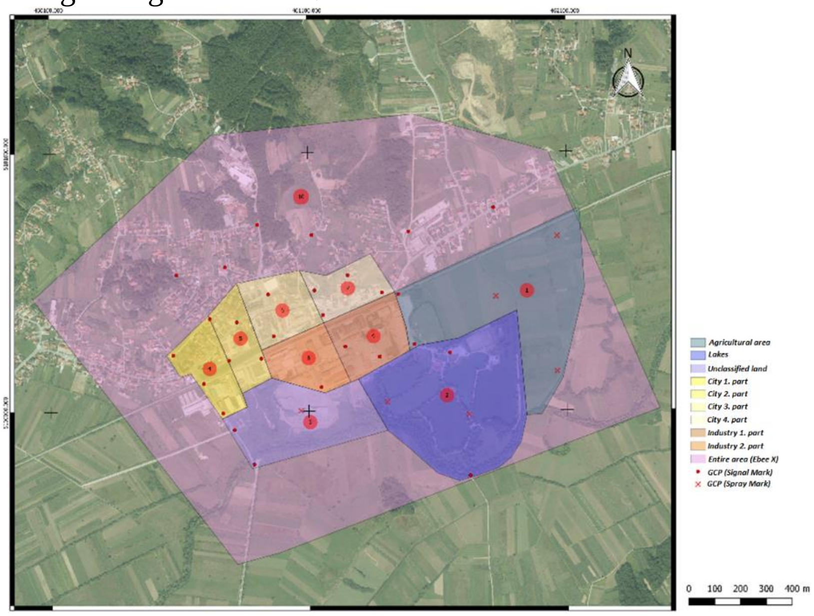

Figure 1. Test area and coverage of flight plans with GCPs

Three different software were used to process the data. The first software used is Site Scan (SS) for ArcGIS which is an end-to-end UAV mapping software designed for image collection, processing and analysis. It is used for image processing in cloud environment to enable the creation of high-quality 2D and 3D image products that can be quickly shared on any device. With SS, UAV operators can plan and execute flights and manage flight data and metadata to support project requirements, manage a fleet of UAVs to conduct safe and efficient UAVs operations, perform 2D and 3D mapping and generate products for analytics and publish products to ArcGIS Online, ArcGIS Enterprise, and Autodesk BIM 360. The software is divided into two applications. The first, Site Scan, is for planning and controlling flights for UAV operators, which works on iOS (iPad) platform only. The application is integrated with the ArcGIS platform and allows users to plan automated flights in 2D or 3D and allows the user to control the UAV in flight. The second application, Site Scan Manager, is a web application for processing, managing, and performing analysis on collected images. The generation of all products is automated, and all processing is done in the cloud, and apart from an Internet connection, there are no hardware requirements for users to successfully use the capabilities that the software provides (Windahl and Johnson, 2020).

Drone2Map (D2M) is an application developed by the ESRI for the purpose of creating various

2D and 3D products such as ortho mosaic, point cloud, 3D model, slopes, DTM (digital terrain model) and others. Products can be used for several purposes such as: environmental monitoring, volume calculation, monitoring of changes, creation of geodetic bases and various others. D2M is a desktop application, and the successful processing and analysis of collected data must meet several hardware requirements. The operating system must be Windows 7 or higher with a 64-bit processor that is 6-core or 8-core. It is recommended to use an Intel i7 or Xnenon processor. It is necessary to have at least any graphics card compatible with the OpenGL 3.2 interface and with a minimum of 2GB of RAM. Random Access Memory must be at least 4 GB depending on the amount of input data, and it is necessary to have an HDD storage disk whose size depends on the input data. Table 1 shows the minimum and recommended requirements for the successful use of the D2M software depending on the amount (number of images) of collected data (ESRI 2022).

Table 1. Minimum and recommended requirement for Drone2Map depending on input data

Number of images	**Minimal hardware specifications**		**Recommended hardware specifications**	
	RAM	**HDD (GB)**	**RAM**	**SSD (GB)**
0-100	4	10	8	15
100-500	8	20	16	30
500-2000	16	40	32	60
>2000	16	80	32	120

The third software used is Context Capture Master (CCM) which is a reality modelling software that can create 3D models of existing objects for all infrastructure projects, derived from photographs or point clouds collected by a UAV. Software is made by Bentley Systems, and it is used for the civil geospatial market, mostly in the fields of engineering, architecture, geodesy, and similar branches. Software is mostly used for 3D models of bridges, buildings, roads, utility networks, industries, and other. CCM is only one of many Bentleys network software, and it is mostly used when creating a 3D model. Resulting product can be analyzed and shared with other Bentley software. The software creates products using images taken with any digital camera, from cameras on mobile devices to UAV cameras. The resulting product is called a reality mesh and includes photorealistic details. The software consists of a main module and an engine module. The main module provides a graphical user interface for defining input data, processing settings and tasks, monitoring progress and visualizing results. The engine module runs on the computer in the background, without user interaction, and performs computationally intensive algorithms. The software contains automated procedures for creating different products, and certain hardware requirements (Table 2), must be met to use, depending on the input images (Bentley 2021).

Table 2. ContextCapture software hardware specifications

	Minimum requirements	**Optimal requirements for <500 images**	**Optimal requirements for 500 - 2000 images**	**Optimal requirements for >2000 images**

CPU	Intel/AMD processor 1.0 GHz	Intel Core i7-4770	Intel Core i9-9900k	Intel Core i9-9900k
GPU	Any graphics compatible with 3.2 OpenGL	Nvidia GeForce 2060	Nvidia GeForce RTX 2080/2080Ti	Nvidia Titan RTX
RAM	8 GB	32 GB	32 GB	64 GB
Space	2 GB SATA disk	500 GB SATA disk	2 TB SATA disk for storage and 128 GB SSD for software	10 TB SSD
OS	Windows 8.1	Windows 10	Windows 10	Windows 10

All used software are commercial, and a computer with the following specifications was used for data processing: CPU: Intel(R) Core (TM) i3-9100F CPU @ 3.60 GHz, Ram: 16 GB, GPU: nVidia GeForce GTX 1660S.

4. Processing and image analysis

Due to the large amount of collected data and hardware requirements, the processing was divided into three parts. The first part of processing includes the city and industry area, while the second and third parts include lakes, agricultural parcels, and the river. The creation of products from the UAV data in all used software can be divided into five basic steps: creating project settings, uploading images, processing, joining GCPs with redefining settings, and reprocessing. The first three steps are common to all software, the fourth and fifth steps are mandatory in SS and D2M. In these steps it is necessary to join the GCP points to obtain a georeferenced model and to change the project settings if first results were not satisfied. In CCM, GCP are defined in first step, and last two steps are only necessary if we want to change initial settings and perform reprocessing to improve the product.

Also, one of the key differences between the software is that in SS the processing is done in cloud, and the computer does not have to meet any minimum hardware requirements, but its limitation is that the number of input images cannot be more than 3000. Therefore, the data collected using eBee X UAV are not processed in SS.

After the products are obtained and before their analysis and reaching some conclusion, it is necessary to analyse the processing report in which processing details are presented. The generated reports are almost identical in all three software, and what is included in these reports is partially shown in Figures 2 and 3, which show parts of the report obtained by the SS software. The report shows information on quality, camera parameters, absolute camera precision, control point accuracy, camera correlation data, data on the number of connection points, data on absolute and relative geolocation parameters, and data on initial processing. Quality control is the best evaluation for displaying the results, because it is possible to easily determine whether the result is favourable for further analysis. The quality results are satisfactory for all performed processing in all software, and Figure 2 shows the quality result for the area of the city and industry in SS.

Quality Check

Images	median of 51477 keypoints per image	✓
Dataset	2153 out of 2153 images calibrated (100%), all images enabled	✓
Camera Optimization	0.84% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 15702.8 matches per calibrated image	✓
Georeferencing	yes, 10 GCPs (10 3D), mean RMS error = 0.011 m	✓

Figure 2. Processing quality check in SiteScan

After a successful quality check, it is necessary to review the rest of the report in more detail, and check georeferencing quality. Figure 3 shows GCP errors from the processing report in SS. One of the GCP was taken for verification, and from given results this GCP (no. 33) has an error of 10 cm along the X axis, 5 cm along the Y axis and 5 cm along the Z axis. Considering that the GCP is marked on 3 different images and is located at the very edge of the processed area, and that this error decreases as it approaches the centre, it can be concluded that the processing result is satisfactory. Georeferencing of the model was successfully performed in all software.

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
gcp10 (3D)	0.020/ 0.020	0.010	0.023	0.005	0.481	5 / 5
gcp11 (3D)	0.020/ 0.020	0.000	0.001	-0.001	0.224	5 / 5
gcp12 (3D)	0.020/ 0.020	-0.010	-0.008	0.013	0.230	5 / 5
gcp13 (3D)	0.020/ 0.020	0.005	-0.002	0.003	0.331	5 / 5
gcp14 (3D)	0.020/ 0.020	-0.021	-0.021	-0.036	0.477	3 / 3
gcp21 (3D)	0.020/ 0.020	0.013	0.009	0.013	0.335	5 / 5
gcp23 (3D)	0.020/ 0.020	-0.004	-0.006	-0.010	0.294	5 / 5
gcp29 (3D)	0.020/ 0.020	0.003	-0.002	0.005	0.421	5 / 5
gcp30 (3D)	0.020/ 0.020	0.013	0.002	0.004	0.674	5 / 5
gcp32 (3D)	0.020/ 0.020	-0.011	0.004	-0.001	0.358	5 / 5
Mean [m]		-0.000169	-0.000101	-0.000579		
Sigma [m]		0.010702	0.010874	0.013489		
RMS Error [m]		0.010703	0.010874	0.013501		

0 out of 1 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
gcp33		-0.1019	0.0473	0.0549	0.2025	3 / 3

Figure 3. GCP quality check

To compare the obtained results, an ortho mosaic of the entire area, a point cloud and a 3D model were created in all three software. From the obtained products, it can be seen how different software, which contain different data processing algorithms, generate the same products based on the same input data (recordings). Figures 4 and 5 show the resulting ortho mosaics. It can be visually concluded that all software has different algorithms, which is seen from different colours display of the reality. The most realistic 2D ortho mosaic of the entire area was obtained in SS, but with enlarging the scale, the resolution of the model is significantly reduced. On the other hand, CCM visually appears "dotted" when presenting the entire area, but by increasing the scale, this software gives the most reliable results.

Figure 4. Ortho mosaic in SiteScan (left) and Drone2Map (right)

Figure 5. Ortho mosaic in ContextCapture

The point clouds are shown in Figures 6 and 7, it is noticeable that the smoothest and most realistic point cloud is obtained in CCM, while D2M and SS are very similar and give „pixelated“ views with unclear details.

Figure 6. Point cloud in SiteScan (left) and Drone2Map (right)

Figure 7. Point cloud in ContextCapture

Figures 8 and 9 show parts of the 3D model. Here is also noticeable a great similarity between SS and D2M. 3D models in this two software, although sufficiently precise for certain analyses, are "dispersed" in some parts, while in CCM, the 3D model is the most realistic with the least “sketchy” details. It is important to note that data processing in CCM took 50 hours, and in D2M and SS about 20 hours. From these, it can be concluded that CCM has the most complex algorithm, but because of that it has the most reliable results.

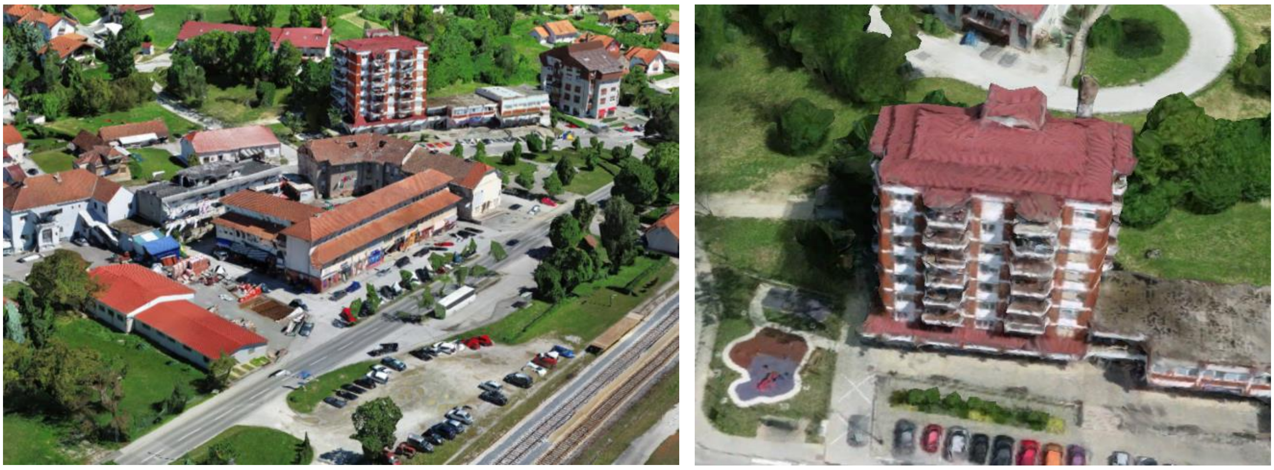

Figure 8. 3D model in SiteScan (left) and Drone2Map (right)

Figure 9. 3D model in ContextCapture

5. Software analysis

To provide a comparison of the software used, data on technical processing are given for each individual software, which is shown in Table 3. The technical processing parameters that were compared show the number of images used, the size of the created product, the achieved positional accuracy, the total processing time, and ground sample distance (GSD).

Table 3. Tehnical processing parameters

	Site Scan		Drone2Map		ContextCapture	
	P1	**P2**	**P1**	**P2**	**P1**	**P2**
Number of used images	2151 (2151)	1576 (1638)	2151 (2151)	1534 (1638)	2151 (2151)	1493 (1638)
Size of model (GB)	14	20	8,5	5,3	400	170
Positional accuracy (3D)	< 10 cm	< 10 cm	< 10 cm	< 10 cm	< 10 cm	< 10 cm
GSD	2.38	1.75	2.33	1.75	2,1	1.74
Processing time (hh:min)	~20:00	~ 18	19:40	10:00	~50:00	~ 35

All three software used all input images to create products, and the products were created using the same input parameters. The size of the generated product with CCM takes 13 times more memory than the other two software combined. This indicates that this software uses the most complex processing algorithm, which relates to the obtained level of detail on the model shown in the previous chapter. However, this entails certain shortcomings because the processing takes more than twice long, takes too much memory on the disk, and requires the highest hardware requirements for the processing to be possible. These shortcomings limit the frequent use of this software considering the given requirements and shortcomings. The achieved positional accuracy of all software for products is below 10 cm, which is taken as the limit value for the highest achieved model accuracy. The next comparison parameter is the GSD, which represents the distance between the two centres of a pixel. GSD is especially important for ortho mosaic and digital terrain model resolution. Given the same input data, the best GSD value is achieved in CCM.

The choice of the ideal software depends on several factors: price, software complexity, processing time, quality, and quantity of obtained data. Each of the three used software has advantages and disadvantages in a particular segment of use. The biggest advantages of SS software are the time of data processing, ease of use and data processing in the cloud. Also, SS provided the best and most realistic ortho mosaic for the entire coverage area. The products obtained by SS are burdened with small deformations, which we can conclude are negligible considering the used camera parameters and the flight height. With further analysis, if we consider only the processing results without technical parameters of processing, it can be concluded that the best results are given by the CCM, where the level of detail of the product is the highest, especially in 3D model and the point cloud. In addition, this software provides the best technical processing results such as positional accuracy and GSD. The main disadvantage of using this software is the processing time, required memory and hardware requirements. D2M gives worse results in almost all segments of the comparison, but it is characterized by ease of use and a user-friendly interface. Considering all elements of comparison, CCM gives the best and highest quality processing results, but, depending on the purpose of the products, the other two software also give high-quality results in less time and with less hardware requirements.

The obtained products can be used for many segments of the establishment of a smart city concept. One of the most important things is that using UAVs the necessary data is obtained in real time. By using data in real time, the actual state of the terrain is obtained, which is the basis for all types of engineering works and management. One of the examples of the use of the obtained products is the creation of geodetic bases for designing buildings and other city objects. Obtained 3D models can serve to better visualize the object in the real world, which forms the basis of urban planning and development. The products can also be used by city services for a quick insight into the problems of the city, such as waste disposal, solving traffic jams, monitoring the condition of the roads, monitoring communal fees, etc. These data can also be used for various inspection tasks, such as the inspection of buildings, bridges, electrical networks, railways, and all other natural and man-made objects, which reduces the risk of injury to people, and saves time and money. Also, the products can serve as the basis for many GIS applications in which the data can be overlapped with other sources (e.g., Copernicus data) to get detailed analysis for the purpose of better planning, development of the city, and providing better services to citizens.

6. Conclusion

One of the challenges in development of smart cities is the collection of a large amount of data, which is necessary to provide improved services to citizens, and to enable simpler and more efficient decision-making by city authorities. With the advancement of technologies, UAVs are emerging as one of the main data collection tools for the smart city concept, as they enable quick and easy collection of a large amount of data over a relatively large area. However, their use also faces numerous challenges. On the one hand, there are regulatory and legal restrictions for flying within the city, while on the other hand, it is a challenge to process such a large amount of data. Today, there are numerous software with automated algorithms for processing UAV data and creating different products for different purposes. The software, although easy to use, requires certain prior knowledge as well as hardware requirements that must be met for successful use. In this paper, three software for processing data collected by a UAV are compared: SiteScan, Drone2Map, and ContextCapture. By analysing the obtained products, the two tested software emerge as the best solution for these needs. SiteScan, although it gives weaker results in terms of details of the products, gives sufficiently accurate and acceptable results that can serve the purpose of planning and implementing a smart city initiative. Its biggest advantage is data processing in the cloud, which does not require meeting the hardware requirements that a used computer must meet. On the other hand, ContextCapture gives the best results in terms of accuracy, precision, and level of detail of the products, and the products obtained with it can best be used for further analysis and development. Its main disadvantage is the long processing time and the need for investment in the infrastructure, because for successful processing it is necessary to meet high hardware requirements. The selection of adequate software depends on several factors, and the main factors that influence the choice are the price, the complexity of the software, the time of processing, the quality and quantity of the obtained data. Users must decide which software is the best to choose, depending on the purpose for which it will be used. However, all the used software provides satisfactory results for the creation of products that can serve as the basis for the development of a smart city, and by using them, city services and management can be improved in various segments, from communal work to building inspection, traffic control, new GIS services and many others.

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