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# Comparing Quality of Aerial Photogrammetry and 3D Laser Scanning Methods for Creating 3D Models of Objects

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**Abstract.** Latest technologies are modern and productive, therefore they are increasingly becoming integral part of any engineering work. Information about real-world objects are collected very quickly and accurately using either spatial data of a terrestrial 3D laser scanners or photographic material obtained from unmanned aircraft vehicle (UAV). After processing data with special software three-dimensional spatial data of objects are obtained, which use is extensive. These data are needed for building facades measurements and inventory, construction, environmental studies, mining, archeology, civil engineering works and for building infrastructure modeling (BIM) systems that are currently being integrated in Lithuania. The result should ensure a high level of accuracy and quality. The article examines 3D modeling using different methods of the selected object. Systems characteristics, quality analysis of 3D models, recommendations and conclusions has been made.

**Keywords:** laser scanning, 3D modelling, unmanned aerial vehicle, photogrammetry.

**Conference topic:** Technologies of Geodesy and Cadastre.

## Introduction

Urban planning, building inventory, and other engineering needs requires for digital data type. Three-dimensional x, y, z – spatial data of objects being collected using modeling technologies, which is by using photogrammetry or laser scanning methods. Both of these methods can have a high accuracy of any objects Digital Surface Model (DSM), which is formed by a point cloud. Based on DSM three-dimensional model of an object or ortophotographic image is generated. DSM differs from site terrain model in that it applies all types of structures (homes, chimneys, bridges, overpasses, etc.), surface of vegetation and natural terrain specific features (Aktaruzzaman, Schmitt 2017). The application of the laser scanning method, to have a digital surface model with texture, requires capturing photos of the object (Moussa *et al.* 2012). That requires expensive and complex equipment. Less expensive method – photogrammetric. It is enough to have a digital camera (sometimes works well with the camera in your phone) when working from the ground or unmanned aerial vehicle (UAV) with a integrated camera to work from the air. The UAV may be of various size, shapes and structures (Tang *et al.* 2013; Xu *et al.* 2014); and they are qualified by characteristics of their camera sensor (Austin 2010). This is a new, rapidly emerging technology, which makes it possible very quickly to have accurate 3D models of objects. In the article both methods has been studied, experimental work has been carried out and quality of made 3D object evaluated.

## Method of laser scanning

Laser scanning method, also known as LiDAR (Light Detection and Ranging), the most popular spatial (3D) data collection method is used for topography of large areas or capturing terrestrial objects by laser and photographs. 3D laser scanner scans the surface by sending laser beam to the obstacle, then, resolving the distance to the object by time, needed for laser beam to reach the object and reflect back. If we mark interval of time – $\Delta t$, and average path of the laser beam from the sensor to the subject – $c_G$, then traveled distance of the laser beam $r$ can be calculated using this formula (Pfeifer, Briese 2007):

$$r = c_G * t / 2. \quad (1)$$

Currently, laser scanners from the air can measure up to 1.33 million points per second (the pulse repetition rate PRR), this is the PRR up to 2 MHz, while systems with terrestrial scanners – PRR = 300 kHz and can measure up to

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222 thousand points per second (or in some cases even 1 MHz, 976 thousand points per second), the measurement accuracy of the short distances have been striving to millimeters (*RIEGL* VQ-1560i 2017; *RIEGL* VZ-6000 2017).

In many systems, the relationship between the distance traveled by the beam and the number of points can be expressed as – $c_G/(2PRR)$. During one scan various 3D information about the object being collected – the object being scanned consists of so-called point cloud, each point is expressed as X, Y and Z coordinates. Scanning takes place from more than one scan station, using special targets. Point clouds captured from several stations are transformed into one point cloud and/ or into a common coordinate system. When scanning from the air and the ground scanner algorithms applied are slightly different for transformation of data into a common coordinate system, because of differences in equipment being used. The airborne equipment for direct georeferencing is a combination of the GNSS (global navigation satellite system) receiver and an inertial measurement unit (IMU), together composing the POS (position and orientation system). Typically, a GPS antenna is mounted on top of the aircraft and the IMU is rigidly mounted to the sensor platform. The vector from the GPS antenna phase center to the laser emitting point, or more precisely to the point of reflection at the mirror, is called the GPS offset or level arm (Pfeifer, Briese 2007). The mathematical model, relating to the primary measurements of the laser scanner, i.e. range *r* and scan angle α, with the time-dependent exterior orientation of the sensor system, expressed by the position of the antenna phase center ( $x_0, y_0, z_0$ ) and the sensor attitude angles ω, φ, and κ, to the ground point (*x*, *y*, *z*) is:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix} + R_{,,} \left( t + R_m \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos & \sin \\ 0 & -\sin & \cos \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ -r \end{pmatrix} \right), \tag{2}$$

where *t* – the GPS antenna offset; $R_m$ – the IMU misalignment. The rotation angles are summarized in the matrix $R_{,,}$ accounting for the rotation of the body frame to the global frame. All measurements acquired by the multi sensor system have to be synchronized, which is possible with the GPS time signal.

In the terrestrial laser scanning, when the object is scanned from few stand points three observations are made, namely the range *r* and two angles α, the horizontal angle and β, the angle in vertical. In the sensor coordinate system the coordinates (*x*, *y*, *z*) of the point are obtained by a conversion from the spherical to the Cartesian coordinate system by formula:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = r \begin{pmatrix} \cos\cos \\ \sin\cos \\ \sin \end{pmatrix}. \tag{3}$$

Most scanners has an integrated camera, the purpose of which – to capture the site after scanning and to assign the smallest points (pixels) color (RGB) value for each scanned point on the 3D image. Collinear algorithm for calculation of point coordinates is applied, in which appears – integrated camera lens focal length *c* and the elements $r_{ij}$ of the rotation matrix *R* (Forstner, Wrobel 2016; Moussa *et al.* 2012):

$$x = -c\frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)}; \tag{4}$$

$$y = -c\frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)}, \tag{5}$$

where (*x*, *y*) – the unknown image coordinates – (*X*, *Y*, *Z*) – the corresponding known object coordinates in the laser point cloud; $(X_0, Y_0, Z_0, r_{ij})$ – the known exterior orientation parameters since we assume that the camera is placed in the same position as the laser scanner.

The generated images from laser point clouds and camera images indicate differences related to image resolution, radiometry, direction of illumination and viewing direction. As a consequence, the identification of corresponding points between generated and camera images requires a robust feature matching algorithm, which is insensitive to illumination and scale differences and employs region descriptors instead of edge detectors (Fassi *et al.* 2013; Moussa *et al.* 2012).

Depending on the maximum distance that can be measured, 3D laser scanners are categorized into: long range (150 to 6,000 m), medium (50–150 m) and short range (0–50 m) terrestrial laser scanners or by the measuring principle: laser rangefinder scanners (Time-of-flight), phase scanners and scanners that operating by optical triangulation principle (Fröhlich, Mettenleiter 2004). Depending on the size of the object, to scan the object takes from several hours to several days, and the data processing can take almost four times or even more. Data processing time also depends on the desired end result. If only object orientated 3D point cloud sufficient, then the process takes significantly less time, but if the final 3D object model drawing is needed, then more time is spent.

To manage 3D scanners and to process data acquired most manufacturers have developed their software. Some manufacturers offer even the entire software package, which consists of a scanner control, "point cloud" registration, up to a further processing, such as creating a 3D surface model of the object, and integrating various details into the 3D "point cloud", creation of cutting planes or producing 2D drawings of facades.

The software can be divided into two groups: manufacturers of terrestrial laser scanners have developed software which functionality is limited to pre-processing, such as a "point cloud" orientation (referencing), analyzing and minimal adjustment of data; software for creating deliverables, such software consists also of various 3D modeling tools for achieving the desired result. Engineer chooses which software would be convenient to work with, depending on the type of work and the desired result. Options are modelling platforms such as PointSense Plant (Autodesk "AutoCAD" plug-in toolbox), LFM, RealWorks, EdgeWise and others, which has integrated library (catalogues) of various structural steel, pipelines and joints standards, with specifications and dimensions for recognition integrated. While working with software – inserting or fitting geometry into "point cloud" is simple, for successful modeling, it is a must to plan scanning station locations, from where object will be scanned, because overall accuracy of finished model will depend on it. After scanning the object or entire system of objects (e.g.: group of pipes), density of points covering an object, has to be sufficient. Otherwise, the object will not be reproduced accurately and with appropriate parameters added to point cloud.

As a final result modeled 3D plant can be obtained or part of pipeline visually, with all the attribute information – pipes, valves or other type of elements, dimensions and other additional parameters. With help of laser scanner various plants have an option from scanned data to create entire databases with all information about objects inside. When having scanned data and planning any changes or reconstructions, it is possible at any time to analyze the situation and quickly design new objects, knowing current location of existing elements in the factory environment.

If buildings or structural elements of buildings are to be modeled, then there is a choice of advanced engineering design software, like "MicroStation" (Bentley), "Tekla" (Trimble), "Revit" (Autodesk). Various manufacturers of laser scanners offers their software plug-ins for Revit, which allows smoother and easier modeling and creation of objects directly on the loaded point cloud". e.g.: PointSense for Revit (FARO), Cloudworx for Revit (Leica), etc. While working with these tools a detailed drawing of the building in 3D is being created, with 3D visualization, (detailed) attribute information of elements, accurate measurements, which can be used for any kind of analysis and simulation. Having scanned data allows planning any changes or alterations, at any time to analyze the situation and quickly design new objects. These capabilities enable the collection, analysis and early warning of a variety deformations of objects, buildings and documentation of the current situation.

### 3D modeling from UAVs images

For modeling 3D objects required data also collected using unmanned aircraft that are rapidly gaining popularity, which replaces the traditional photogrammetry for their autonomy and versatility. There are different types of unmanned aircrafts: fixed-wing, copters, and multi-copters. Different aircraft types used for different jobs. For example a fixed-wing unmanned aircraft used in generation of orthophoto terrain models and 3D surface models, their working time depends on the battery capacity and ranging from 30 minutes to approximately 3.5 hours. Multicopters commonly used to photograph buildings, although it may also be used for creating orthophoto terrain models and battery operating time usually ranges from 15 minutes–45 minutes. In certain areas UAV system competes not only with photogrammetry, but also with terrestrial laser scanners, such as for modeling building facades. The unmanned aircraft vehicles have the ability to become airborne, thus pictures of building elements (roof, facade elements) are taken from all angles and at different heights.

When taking images of buildings with unmanned aircrafts, it can be quick and effective way to capture even the most complex construction of buildings, tall buildings or hardly noticeable from the ground architectural components in high accuracy. Unmanned aircraft with integrated digital camera can take pictures of an object in a densely built-up areas where with other surveying instruments to do this would be difficult or even impossible. Processing time of photographic material depends on the size of the subject being photographed, images resolution and amount. Number of software which offers a fast and convenient automated data processing of unmanned aircraft data, such Agisoft PhotoScan, Pix4D Mapper, Trimble's UAS Master, etc. is growing constantly. Sophisticated photogrammetric software is replaced by the user-friendly automated software (for particular applications) where a variety of image processing, orientation and network triangulation development steps are hidden under a few software buttons. This allows you to quickly and easily process the data and prepare them for later use. User is required to check the results for each step individually, to review and assess the quality of data and taking into account the results, if necessary, adjust the parameters of automatically generated template for processing. When drawing buildings, photogrammetric algorithms are used, which during preprocessing generates, not only geometric information about the object, but also whole model of object with existing texture, on which, in later stages, various complex details of configuration may be may be drawn directly on the 3D image.

**Comparison of quality of 3D objects generated by laser scanning and photogrammetric methods**

The object of research – building façade of Vilnius Gediminas Technical University Faculty of Environmental Engineering was scanned using Leica ScanStation C10 terrestrial laser scanner. Data was scanned at 50,000 points per second rate. Scanner has integrated video / photo camera allows to take pictures of scanned area and for each pixel RGB value to be assigned. In total in the object was 6 scan stations (Fig. 1). Scan data preprocessed using Leica "Cyclone" software.

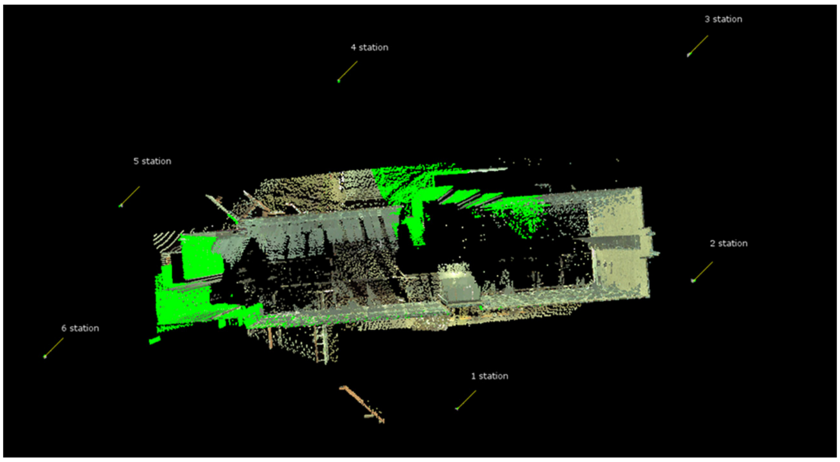


Fig. 1. Scan stations of a building

In each station after scanning same covered territory was captured with in Leica ScanStation C10 laser scanner integrated photo camera. In order to be able to register all the point clouds scanned from different stations into a single common system, at least 3 beforehand marked targets had to be visible in each scanning station, which were arranged at various distances and angles within scan area. In total 22 tie points was chosen in that area. At least four tie points were visible from the adjacent scanning stations. Stations were selected so as to ensure visibility of features on object from at least two stations. Using Leica "Cyclone" software scanned data was transformed into a single common coordinate system (Fig. 2, 3).

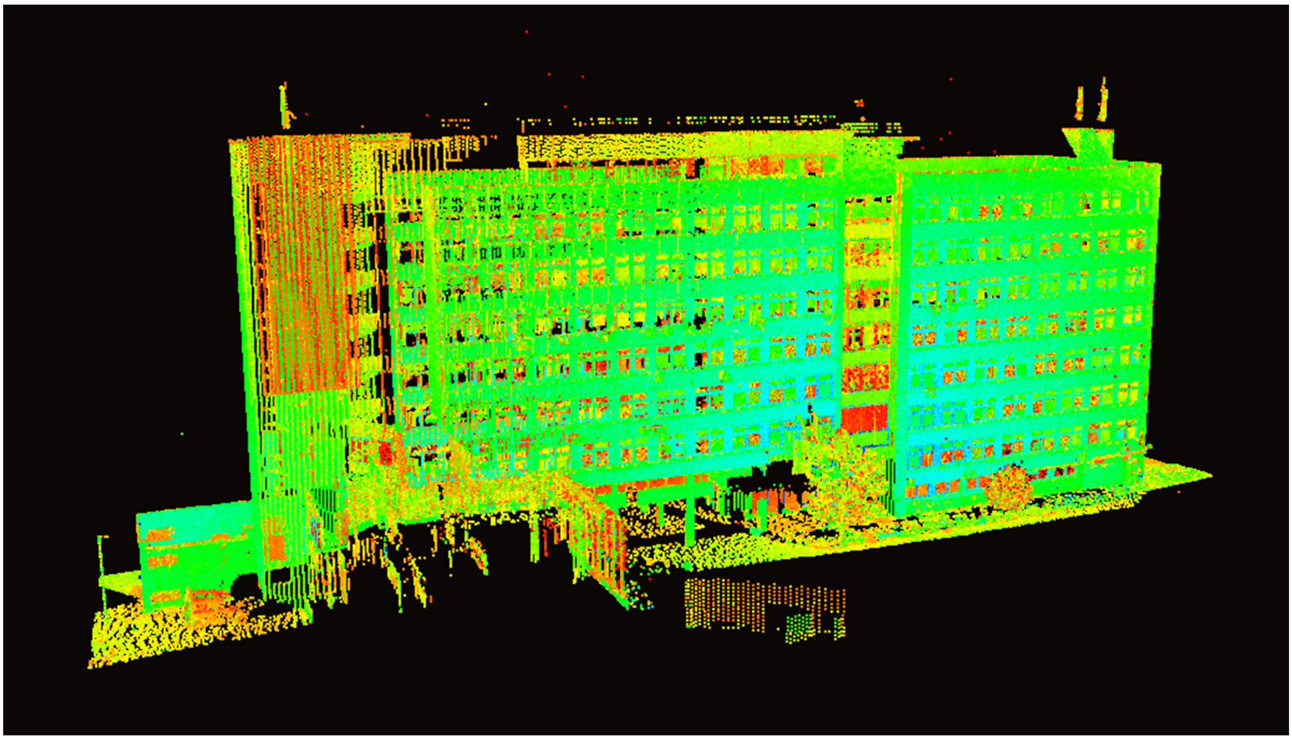

Fig. 2. Point cloud representing building of Vilnius Gediminas Technical University Faculty of Environmental Engineering acquired using Leica ScanStation C10 laser scanner

Fig. 3. RGB colored point cloud representing building of Vilnius Gediminas Technical University Faculty of Environmental Engineering

While analyzing scan data it is observed that in areas where edges are clearly visible (corner of a building, overhang of the roof, etc.) "Scatter" of a point cloud is noticeable, which makes up a large part of the so-called point cloud "noise" (redundant points). Also data is lacking information about objects that are on the roof and rooftop itself, because that part of a building is not visible from the ground. Since terrestrial scanners laser measures the distance only until the first obstacle, what remains in the "shadows" is not recorded in the scanners memory. Therefore, the places where façade elements are concealed by the parts of the building, and if they are not scanned from another station – that data will not appear in the final orientated "point cloud" (Fig. 4).

Fig. 4. The lack of data in shadowed places

While scanning, laser beam passes through window glass, thereby by scanning the buildings from the scan station partial information is collected – about objects inside the building, such as walls and ceilings, which can be seen from the scanning position (Fig. 5). With such data, façade drawings may be supplemented with additional information about floor ceilings. It is very valuable data.

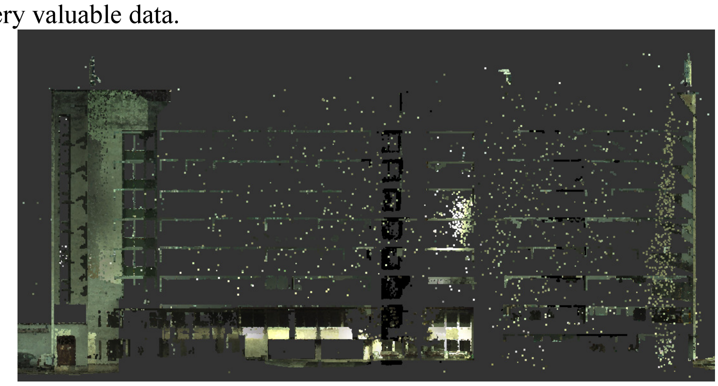

Fig. 5. Visible information, acquired by scanning through windows

For use in 3D modelling of buildings or preparing 2D drawings of facades technology of terrestrial laser scanning allows extremely precise surveying of geometry of the façade, also to assess deformations of the building structure. When preparing building for reconstruction or renovation such data also allows extremely thorough examination of the current condition of the building. When working with the previously listed software, data on the various elements of the building facade and the features of building itself are stored in attribute tables with all parameters of measurements that allows highly detailed analysis of drawings or models.

Facade of the building was also captured using DJI Phantom 3 model of unmanned aircraft. 3D modeling done using 69 images processed in Context Capture software developed by Bentley Company. After combining images into a single coordinate system and model, and after calculating aerial triangulation determined, that RMS of re-projection error is 0.75 pixel and RMS of distances to rays 0.031 m. Image of 3D model prepared presented in Fig. 6.

Fig. 6. 3D model generated from DJI Phantom 3 images

After comparing 3D model resulting from photographic material with results obtained from the laser scanning noticed, that the model practically has no "noise", and even if noise exists it can be accurately identified, for example, that point belongs to the trees. The roof, details of rooftop surface, attic is well identifiable in the model. According to the 3D model generated on the ortophotographic view, it is well shown (Fig. 7). Internal objects of building that are visible from the scan data, in the photographic images are not visible, it would additionally require taking pictures inside.

Fig. 7. Rooftop and objects in detail. Ortophotographic view

Quality of each step of the modeling process technology depends on the devices systematic or human errors that affect the final result. The following Table 1 summarizes accuracy and reliability indicators of the instruments used.

The information in the Table 1 additionally corresponds that low cost UAV photogrammetry systems are an alternative solution to the high-priced surveying systems. UAV photogrammetry is much more efficient method than the laser scanning which had a workload of more than 7 hours for the experimental object. The scientist from Germany just published article with the same conclutions, where the authors investigated three different systems and methods for DSM generation and compare the results (Lindstaedt *et al.* 2017).

Table 1. Quality indicators of system used

| Leica ScanStation C10 System | | |
|---|---|---|
| Components | Accuracy of single measurements in the specification | Results in the experimental object |
| System performance | Position at 1 m–6 mm;<br>Distance at 1 m–4 mm;<br>Angle (horizontals/vertical) – 12´´/12´´<br>Precision of modeled surfaces – 2 mm | Accordance specification |
| Laser beam | Centering accuracy – 1.5 mm–1.5 m<br>Laser dot diameter – 2.5 mm<br>Scanning optics – Smart- X Mirror lens system (factory calibrated) | Accordance specification |
| Integrated camera | Size of images – 1920×1920 pixels<br>Maximum number of images from one station – 260<br>4 mega pixel sensor | In total 531 images from all scan stations |
| Geo referencing | Georeferenced mean value from all stations: | Standart dev. X = 0.0015m; Y = 0.001 m; Z = 0.0055 m |
| Data acquisition | Time of measurements in experimental object<br>Time of acquisition of experimental object | About 7 hours<br>About 2 hours |
| Prices | All equipment | 47 400 € |
| **UAV System** | | |
| DJI Phantom 3 | Automatic Flight Assistant Built-in GPS<br>Fly time – up for 25 minutes<br>Price | Yes<br>About 30 minutes<br>600 € |
| Integrated SONY NEX-7 camera | Size of images – 6000 × 4000 pixels (1 pixel is 0.035 m)<br>Maximum number of images – no limited<br>24.3-megapixel sensor<br>Price | 4000×3000<br><br>69<br>Yes<br>800 € |
| Geo referencing | Integrated GPS system | Yes |
| Image acquisition | Commercial program Context Capture<br>Time of acquisition<br>RMS of re-projection error<br>RMS of distances to rays | Yes<br>1 hour<br>0.75 pixel<br>0.031 m |

## Conclusions

When modeling buildings or preparing façade drawings, technologies of terrestrial laser scanner and unmanned aircraft systems very accurately investigates geometry of the building facade and evaluates deviations of building structure. While modeling Vilnius Gediminas Technical University Faculty of Environmental Engineering building in 3D was observed that:

1. For modeling of the building unmanned aircraft DJI Phantom 3 system with a built-in digital camera SONY NEX-7 was used, which is almost 34 times cheaper than the laser scanning system Leica ScanStation C10.
2. Using a laser scanning method results in a point cloud of a building surface and images, which are necessary for each scanned 3D point to assign from the image color (RGB) value of the smallest point, to form the final 3D model of the object. Additional photographs increases the amount of initial data. While using UAV photogrammetry technology initial data consists of only photo material of object. Surface of the point cloud, if needed, can be generated during the processing of images.
3. To scan and capture images of object using technology of terrestrial laser scanner takes more time, than capturing images using UAV photogrammetric system. To scan experimental object took about 7 hours, when the unmanned aircraft took about 30 minutes.
4. The laser scanning technology is based on emitting laser beam to the object and receiving reflected signal, if along path of the beam there are some elements that are concealed by the facade of the building (e.g.: attic, objects in the shadow, etc.), and if they are not scanned from another scan station – these elements will not appear in the final orientated point cloud. However, the laser beam successfully passes through glass in the windows, thus partial information about inside objects of the buildings being collected, such as walls and ceilings, which can be seen from the scanning position. With such information, façade drawings may be supplemented with additional information on the floor ceilings. It is very valuable data.

5. UAS photogrammetry technology generates a 3D model with all visible details of the building, that are lost during scanning from the ground, information about the roof is lost in this case. In experimental object accurate roof geometry and coating results from UAV photogrammetry data.

6. The quality of 3D modeling is determined by the tie points between the images (UAVs method) or between the laser scanning stations registration results. In case of UAVs photogrammetric method, calculated matching root mean square error of binding points (RMS of re-projection error) is 0.75 pixels and RMS of distances to rays is 0.03 mm.

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