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APPLICATION OF TERRESTRIAL LASER SCANNING AND UAV-BASED PHOTOGRAMMETRY IN THE BUILDING FACADE INSPECTION PROCESS

Abstract: In the modern practice of facade inspection, there are several technologies of data acquisition and processing in order to optimize the process itself: to obtain the best possible knowledge about the degree of facade's deterioration and damage, with minimal time consuming. With the development of modern instruments and sensors, as well as the rapid growth of data processing capabilities in various software solutions, the approach to the realization of facade inspection projects has changed. This lecture will review two modern technologies that are used in the facade inspection process – terrestrial laser scanning and UAV-based photogrammetry. The focus is given on how data is collected and processed and advantages and disadvantages of both methods.

Key words: Engineering survey, Laser scanning, Photogrammetry, UAV

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1. INTRODUCTION

Roads, bridges, buildings, towers, dams and similar structures over time lose their performance due to the action of various external and internal forces. Changes in the mechanical properties of structural elements due to aging; natural disasters such as earthquakes, landslides and floods; climate change - the influence of wind, changes in temperature and groundwater levels; as well as dynamic and static loads of the structure have the most common impact on deformation occurrence. The effects of these forces on structure result in: bending, slope, torsion and distortion [1]. One of the most common and most obvious indicators of the effects of adverse impacts on a building is the appearance of cracks on the façade.

Like many other disciplines, imperatives in job include quality, cost-effectiveness, efficiency, minimal time consumption and automatization. With the development of modern surveying technologies, a precondition for fulfilling these requirements in the field of assessment of the technical condition of the facade has been created. Namely, the traditional approach to this process entailed visual inspection, which is expensive, time consuming and leads to data redundancy. Modern laser scanning and photogrammetry technologies are faster, more reliable, objective, accurate and, accordingly, their use is fully justified. The importance of inspecting the building's facade is confirmed by the fact that operational phase of a building is the main contributor to the building lifecycle cost [2].

2. UNMANNED AIRCRAFT VEHICLE (UAV)

In order to overcome the challenges related to the traditional building facades assessment approach, new assessment methods based on UAV data acquisition technologies have been developed. UAV, also known as drone, represents an unmanned aircraft vehicle controlled by a ground operator or computer located within the vehicle. UAV is a part of UAS (*Unmanned Aerial System*) that usually consists of an aircraft platform mounted with one or more sensors combined with a ground-based control station from where it is operated.

The sensor typically comprises an inexpensive, nonmetric, consumer-grade digital camera, from which small-format overlapping images are acquired for photogrammetric purposes [3]. A variety of UAV system has been developed and some of them includes the fixed-wing aircraft, chopper, multi-copter, motor parachute and glider, congregating ready-made parts and commercialized UAV (Figure 1).

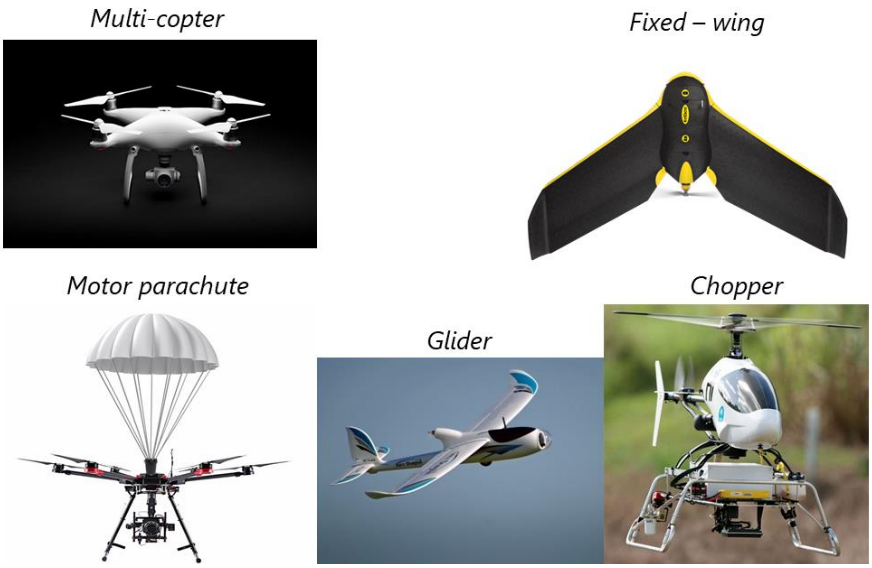

Figure 1 – Types of UAVs

Based on landing, they can be divided into *Horizontal Takeoff and Landing* (HTOL) and *Vertical Takeoff and Landing* (VTOL) [4].

Within data acquisition, the object must be captured from a minimum of two camera positions in order to obtain information about the three spatial coordinates. The created imagery represents a stereo pair that allows creation of object’s 3D model that provides information about its real dimensions (shape, position, size). Based on the analysis and measurement of UAV-collected two-dimensional images, automated digital photogrammetric method, Structure from Motion (SfM), is used for reconstruction of physical objects (Figure 2).

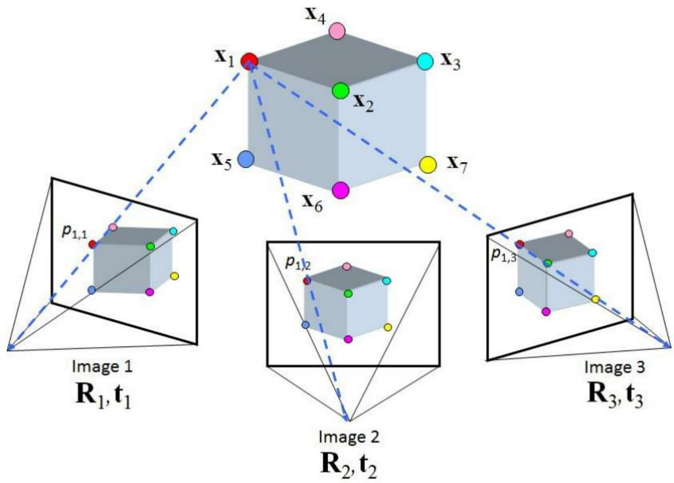

Figure 2 – Structure from Motion [5]

The result of SfM image processing, beside 3D model, could be also a digital terrain model, point cloud, orthophoto image or orthophoto map. Quality and usability of images acquired by UAV depends on the number of parameters that should be defined within the mission planning phase. These parameters should be defined in relation to the mission goal.

Human vision also works on the principles of stereo visualization since human can create a spatial image of the environment by seeing it with two eyes. Information reaching the brain is automatically recognized as a three-dimensional space. The computer works in a slightly different way as automatism has been replaced by complex mathematical models that make it possible to determine the exact position of an object in any coordinate system [6].

2.1. UAV photogrammetric workflow

[7] gave the general workflow for UAV data acquisition and image processing (Figure 3). Green fields represent input parameters, while single workflow steps are shown in the yellow fields.

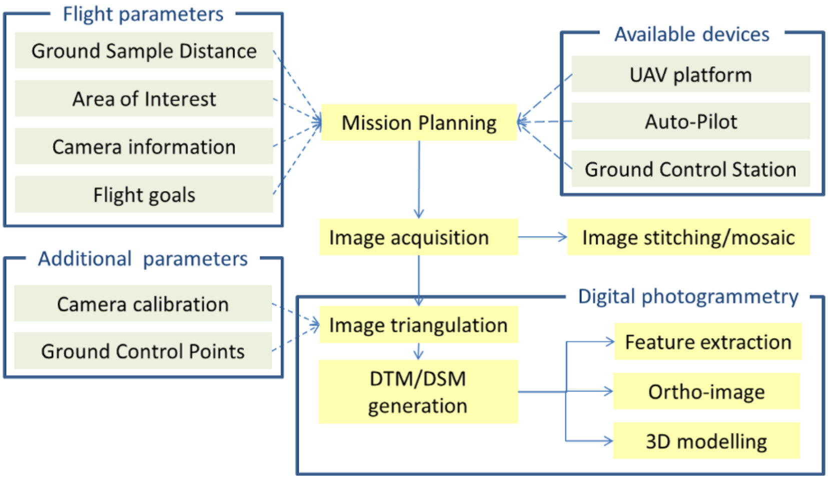

Figure 3 – General workflow for acquisition and processing of UAV images [7]

Presented workflow is divided into three phases: mission planning, image acquisition and data processing.

Mission plan should be established based on the area of interest, the acquired GSD and camera specification (Figure 4). Parameters that should be defined in this stage are flight mode, path, speed, image overlaps, camera angle, flight altitude and distance from the target surface. The selection of optimal flight parameters depends on the mission goals, as well as on the available devices. Factors that should also be considered in the process of flight planning are limitations related to UAV battery life, legal regulations and weather conditions.

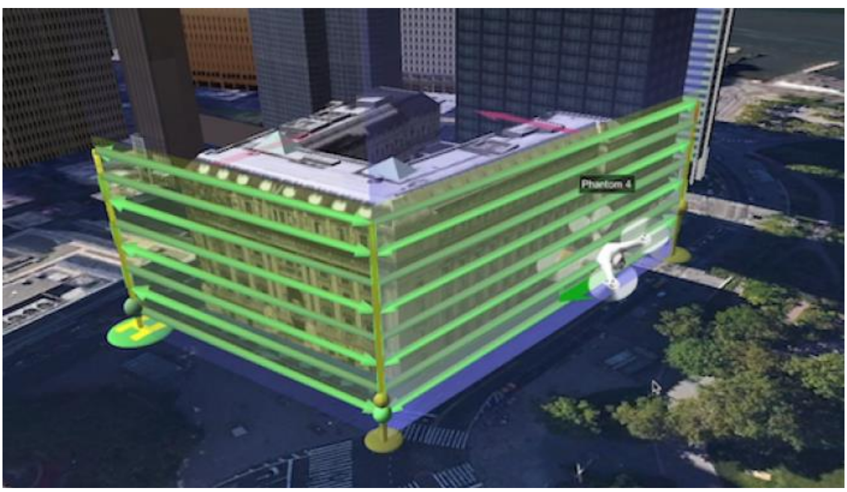

Figure 4 – Mission plan [8]

Within the *image acquisition* phase, flight is usually performed in manual or autonomous mode, based on the performances of available devices (platform, auto-pilot and GCS - *Ground Control Station*) affecting the quality of the collected data (Figure 5). In autonomous mode the flight path is set based on GNSS/INS (*Inertial Navigation System*) waypoints which UAV will follow using navigation system (auto-pilot). In this case, GCS observes UAV platform providing insight into real-time flight data such as drone position, flight speed, attitude and distances, battery level, etc. In manual mode, platform is remotely controlled by operator from the ground station and image acquisition process usually results with irregular image overlap and acquisition geometry. During the fully automated flight, limitations in GPS (*Global Positioning System*) positioning and relevant communication between drones and remote operating systems, obstacle interference with UAS and possible crashing, signal acquisition risks are some of the challenges that needs to be addressed [9].

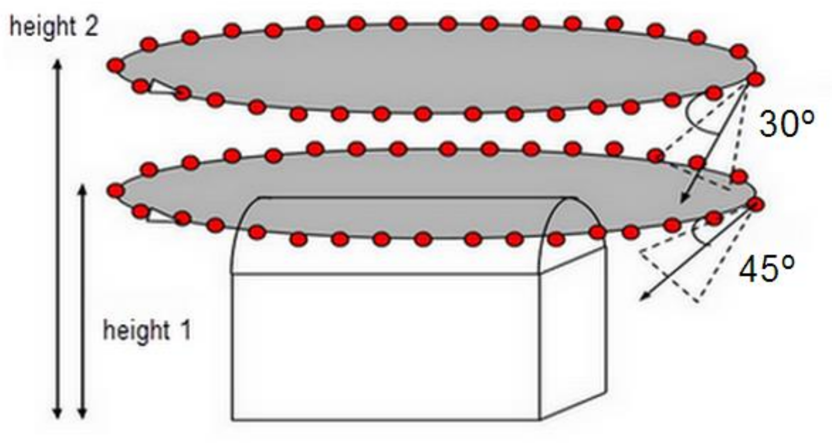

Figure 5 – Image acquisition [10]

An additional step to the image acquisition process is placing and measuring of GCPs on site for scaling and geo-referencing purposes (Figure 6). This is done though a traditional surveying method of using a total station or GNSS positioning method.

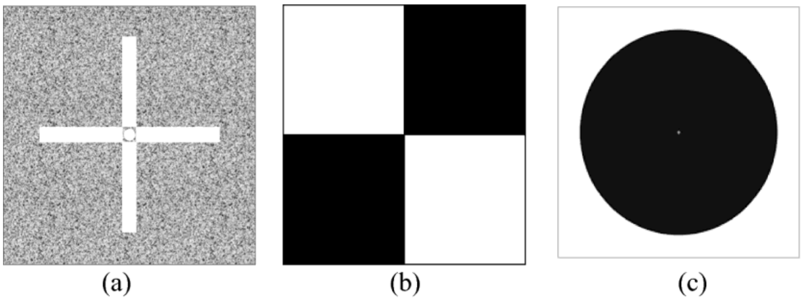

Figure 6 – Types of GCPs [11]

The final phase represents processing of UAV acquired images. In order to successively generate a *Digital Surface Model* (DSM) or *Digital Terrain Model* (DTM) camera calibration and image triangulation should be initially performed. DSM and DTM can be finally used for the production of 3D models, ortho-images or for the extraction of further metric information.

3. TERRESTRIAL LASER SCANNING (TLS)

TLS technology is a relatively new technique for quickly collecting three-dimensional spatial information. TLS can be used to obtain three-dimensional (3D) location information for a structural member or an entire building without being restricted to a particular location on the structure or affected significantly by the environmental conditions. It was hailed as another technological revolution in the field of surveying and mapping after GPS technology which accurately reconstructs the scanned objects and builds high-fidelity, high-precision 3D point clouds (Figure 7) [12].

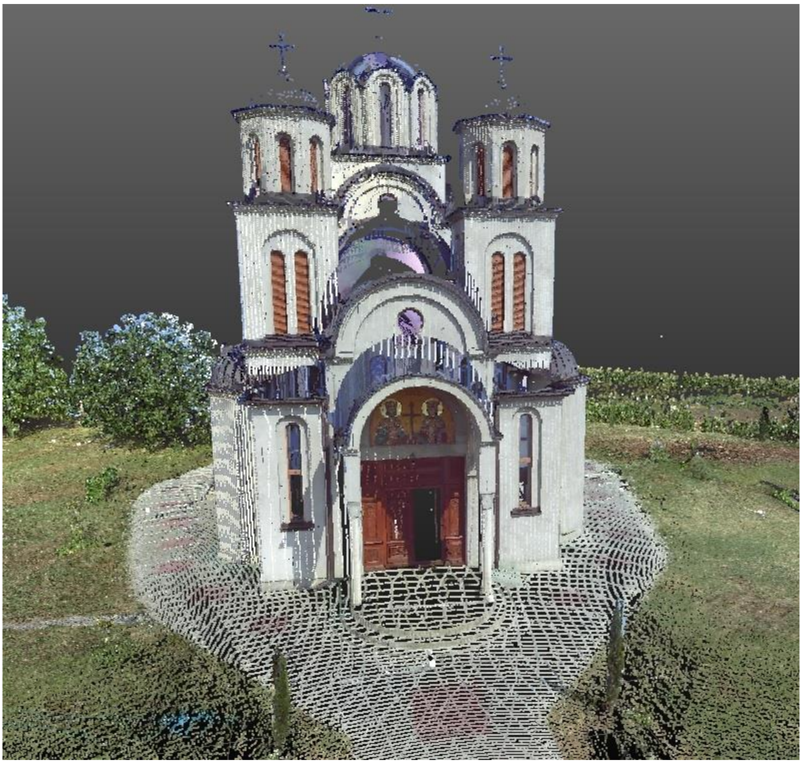

Figure 7 – Point cloud generated using TLS technology

TLS helps sample complex objects easily using 3D point clouds. The product of TLS measurements is a three-dimensional (XYZ) point cloud acquired with high-density and high-accuracy. This geometric dataset allows one to build 3D models, as well as detect building defects. However, the TLS can also receive the power of the laser beam backscattered from the observed object, which is called “intensity”.

In contrast to camera-based vision systems, using such laser signals to obtain 3D coordinate data does not require the additional computation for coordinate information upon image acquisition.

Modern TLS instruments measure target objects by observing either (a) TOF (*Time Of Flight*) or (b) change in phase of a reflected laser signal [13]. The principle of 3D coordinate extraction using TLS is based on measuring the time it takes for the laser pulse to travel from its source to an object and return, and computing the distance based on the travel speed of the pulse (the same as the speed of the light) (Figure 8).

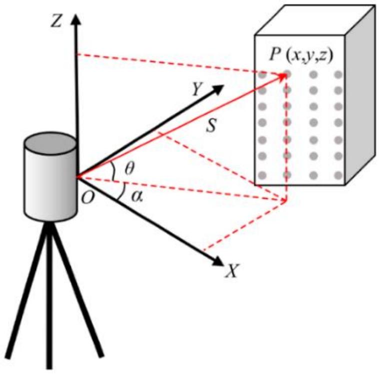

Figure 8 – Measuring principle of the terrestrial laser scanning [14]

TLS is able to record dense point-clouds over an extremely short period of time by using the distance and laser pulse angle data at rates of tens of thousands per second. Moreover, the TLS can also record the intensity of the reflected pulsed laser and RGB color data of the target object (Figure 9). The intensity information can be very useful for façade inspection and detection of cracks.

Figure 9 – Different types of point cloud styles [15]

TOF can measure over very large distances (e.g., 300 m) but is slower and less accurate than phase-based observations. Conversely, phase-based observations are rapid and accurate but presently limited to shorter ranges. Hybrid phase-pulse laser scanners combine the range and low noise sensitivity of the TOF technique, with the high accuracy at short range of phase shift technology [16].

TLS point clouds provide the benefit that each point is registered in the instruments reference frame upon measurement. This reference frame can be either arbitrary or a known coordinate system. As a result, dimensions can be extracted directly from the point cloud. The acquired information can be integrated into CAD systems for measurements or change detection studies. TLS technique, as a non-invasive surveying technique, can allow continuous monitoring without coming into physical contact with the interested object (especially useful in unreachable places).

For the purpose of health monitoring of structures accuracies in the order of 1 mm or less is required. Accuracy of spatial coordinates ranges from 2 mm to 3 mm from stationary measurements [17].

The use of *Terrestrial Laser Scanner* (TLS) technology as an inspection tool has been the subject of a number of recent studies. At present, TLS is used in multiple civil engineering applications, such as dam monitoring, landslide monitoring, bridge monitoring, motorway and tunnel monitoring, façade deformation analysis, assessing architectural heritage and other unusual fields like forestry inventory, environmental monitoring and crime scene reconstruction.

4. CASE STUDIES

4.1. Case study – UAV

Subject: Residential building in Novi Sad, Serbia, Crack detection

Used aircraft: Anafi Parrot

Table 1- Aircraft specifications

Take-off weight	320 g
Dimensions	175x239x63.5 mm
Max flight time	25 min (no wind)
Operating temperature range	0 – 40°C
Maximum work range	4 km
Satellite Positioning System	GPS/GLONASS

Table 2- Camera specifications

Sensor format	6.194 x 4.646 mm
Sensor	1/2.4" CMOS
Lens	FOV 180°
ISO range	100-3200
Image resolution	4608 px X 3456 px
Pixel Size	1.12 µm
Focal length	4 mm
Diagonal crop factor	7.487

Table 3- Flight plan parameters

Flying distance from the façade	6 m
Pilot mode	Manual
Ground Sample Distance (GSD)	2.1 mm
Area covered by a single image	9 m x 7 m
Overlap	
End lap (along flight lines)	Side lap
89%	89%

Figure 10 – Residential building – cracks and damages

4.2. Case study – TLS

Subject: Hotel in Indjija, Serbia, Reconstruction

Used TLS: Trimble FX

Table 4- Trimble FX – Specifications

Typical scan time	5 minutes (single pass)
Position accuracy	0.4 mm @11m; 0.8 mm @21m; 2mm @50 m
Angle uncertainty	<30 arc second (1.6mm @11 m; 3mm @21 m; 8 mm @50 m)
Angular resolution	8 sec
Beam diameter	2.3 mm @ 5 m; 16 mm @ 46m
Range uncertainty	1 mm @ 15 m single pass (on 90% reflectivity)

Distance accuracy (std dev.)	0.6 mm @ 11 m; 0.8 mm @ 21 m; 2.4 mm @ 50 m; (on 90% reflect.)

Figure 11 – Point cloud of the front facade of the Hotel

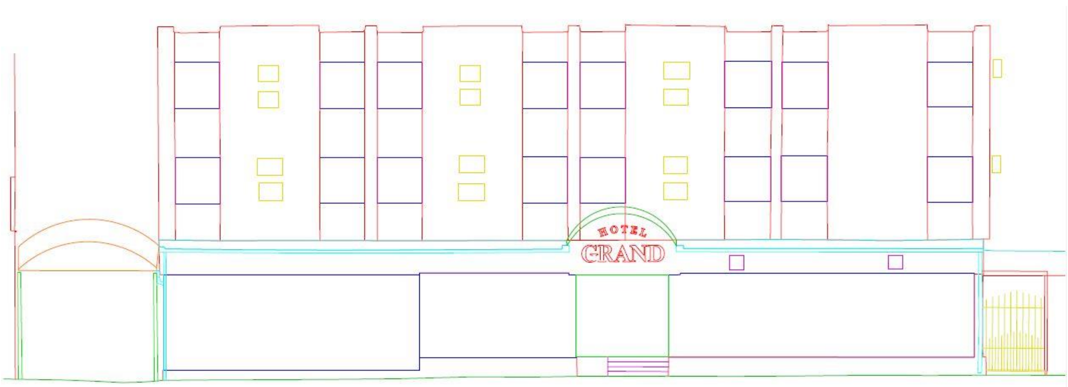

Figure 12 – Detailed 2D .dwg drawing of the front facade of the Hotel

5. DISCUSSION

A major advantage of using TLS is that it can provide rapid and very dense measurements in inaccessible regions. However, there are also some limitations, which may preclude its use in certain applications. For example, TLS use is weather dependent and expensive. Further, the accuracy of the measured point clouds degrades with distance (the most accurate measurements are acquired at close distances), and the equipment and software can be expensive. Surveying the exterior of tall objects is especially problematic because of the need for large distance from the object. In this case, it is even more of a problem if such a facility is located in the narrow streets of urban areas. The object properties are also an influencing factor on which the user has very little or no control -

specular surfaces such as objects made of glass or mirror-like metal negatively affect reflection's diffusion when scanning with TLS. TLS is also limited by the location of the acquisition point of view and the subsequent results are generally affected by lacks and non-homogeneous data.

Optical techniques such as close-range photogrammetry, is a cheaper option (relative to TLS) and can provide very accurate measurements at specified locations (e.g., control points and targets). However, this technique requires more careful setup of control points and coordinate space to ensure sufficient network geometry and datum definition. In contrast, using TLS, the coordinate system can be defined in the instrument axis. Close-range photogrammetry also requires much closer proximity to the target area for precise observations. Other laser technologies, such as laser displacement sensors, can also provide extremely precise distance and displacement/ deformation observations, but lack the spatial coverage of TLS. TLS allows measuring the 3D displacement of any particular point in a structure as well as the static deformed shape of the structure. However, in cases of small and medium objects it is possible to apply UAV technique without external framework or high-performance camera and obtain results comparable with the TLS corresponding ones, both in terms of accuracy and density. However, the architectonic or urban scale still requires the integration with a topographic survey and cannot always reach the same quality level of laser scanning results [18].

Advantages of using TLS in assessing facade condition are (1) no in situ instrumentation of sensors, (2) no difficulties to reach structures or structural members, (3) independence of natural light sources, and (4) no wiring costs. On the other hand, the main advantage of the photogrammetry stays is that images contain all the information required for 3D reconstruction of the scene as well as the photo-realistic documentation.

6. CONCLUSION

Both methods presented in this lecture - TLS and UAV have their advantages and disadvantages and one cannot generally tell which method is better and more applicable. It is always necessary to look at the requirements of the project - what is the subject of the surveying, what is the required accuracy, what level of detail is required and, of course, at what time interval it is necessary to collect the data and deliver product. Once these answers are defined, the choice of surveying method and the data collection process can begin. However, as in other areas, a more comprehensive approach is needed to obtain the best data and of highest quality. Based on what is presented in the lecture, as a recommendation in documenting the condition of the facades, the integration of two modern methods - UAV and TLS can be adopted as the best solution. To obtain complete data coverage, TLS technology must be used, while UAV can be used to capture facades that are not in the scanner's field of view due to various obstacles in order to obtain complete data coverage.

7. QUESTIONS

1. What are the causes of facade damage?
2. What types of UAVs exist depending on the construction and on the mode of take-off and landing?
3. What are the output data of the mapping by using UAV?
4. Which are the main phases of UAV mapping?
5. What are the results of mapping using UAV?

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