TERRESTRIAL PHOTOGRAMMETRY AND APPLICATION TO MODELING ARCHITECTURAL OBJECTS

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Abstract. *In this paper terrestrial photogrammetry is analyzed and its applications in architecture presented. Photogrammetry is a technique of representing and measuring 3D objects using data stored on 2D photographs and it has many advantages over traditional methods. We give theoretical background for the methods used in creating 3D models from photographs and then, using the appropriate software, we apply these methods to create 3D models of architectural objects. Using the described photogrammetric methods we constructed detailed 3D models of over 100 sacral objects in Vojvodina built from 18th until the first half of the 20th century. Many of these objects were seriously damaged, some in a critical condition and it was the last moment to record their present state.*

Key words: *terrestrial photogrammetry, calibration, central projection, modeling, architectural objects.*

1. INTRODUCTION

A photograph is an image made by projecting every point of an object on film plain (or sensor, which is the equivalent of film for digital cameras) in direction of lines through camera's lens optical center. As any other single projection, a photograph also does not contain enough information to give complete view of implied space because every light ray contains infinite number of points, hence the three dimensional space by taking its photograph is reduced to two dimensions [2].

Photogrammetry is a technique of representing and measuring 3D objects using data stored on 2D photographs, which are the base for rectification. At least two projections are necessary to obtain information about three space coordinates, that is, from two photographs of the same object its true size can be determined and 3D model constructed (Fig. 1) [8,12,13,3].

Human sight is based on the principles of stereo visualization, and one can get the entire impression of his surroundings by observing it with two eyes. Based on experience,

the information coming to the brain is automatically recognized as three dimensional space [11].

A computer performs in a different way, where automatism is replaced with complex mathematical models which are then used to determine the exact location of objects in an arbitrary coordinate system. Recent progress in software development makes it possible to achieve high accuracy of generated 3D models, thus providing a background for using such a model instead of a real object for various investigations. Traditional method of architectural design and construction relies heavily on construction documentation, but in many cases such documentation does not exist. Whether this documentation is available or not, such methods are costly, time consuming and require many people and hours to gather the data in useful form. Photogrammetric methods can save an abundance of time and energy and they can create not only two dimensional data, but also three dimensional information which can provide all necessary documentation.

Fig. 1. Minimum two photographs are basis for terrestrial photogrammetry

2. TERRESTRIAL PHOTOGRAMMETRY

Depending on the properties of an object which has to be modeled, different types of photogrammetry are used. Primary classification is made on the basis whether the photographs are taken from the air or from the ground. If satellite or airplane images show terrain, photogrammetry is aerial [1, 10]. Terrestrial photogrammetry use images made from a spot close to the ground, and generally do not represent terrain, but smaller natural or artificial objects.

Which coordinate system will be chosen mainly depends on the size of an object which has to be modeled. GPS systems and global coordinate systems are practical to use only for huge objects and where high level of hardware equipment is available. For modeling architectural objects a local coordinate system is used, which is chosen according to the building which is to be modeled [3, 4, 16].

2.1. Calibration

Prerequisite for using photogrammetric modeling is that cameras and images must be calibrated. To calibrate means to determine the exact positions and distances of camera and object in a coordinate system. Cameras can have special equipment, which can measure positions and distances during shooting in assumed coordinate system. However, if

the analysis is based on usage of minimal equipment, it is not possible to precisely determine positions and rotations of the camera during sequence of shots.

To compensate for that, software for subsequent image calibration were created. This type of calibration became possible with the development of computer systems. Calculation of exact coordinates of the lens optical center in the moment of taking shots and its rotation in all three coordinate plains, is determined by identification of connecting points on all used images. A connecting point is the point which exists on both images and it is determined by the user. Focal length of the lens is also known. The minimal number of connecting points required for calculation is determined by the software. Using higher number of connecting points, right angles and straight lines, increases quality of calibration. The precision of the obtained model depends on the precision of marking and choice of the connecting points, that is, on the quality of calibration [6, 9].

As focal length of the lens gets shorter, distortions of images are increased. This can be alleviated using various software processing. Distortions decrease model accuracy, which emphasize the need for precise calibration.
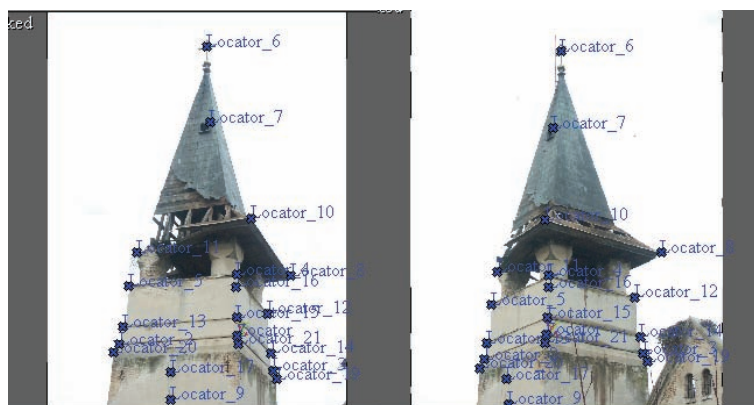

Fig. 2. Calibrated images with connecting points

Subsequent calibration is also very economical because there is no need to make a sitting plan. This is very important when architectural objects have to be modeled, because the elements of the surrounding are usually randomly situated, and it is impossible to calculate camera position in relation to the ground or object, because vegetation and other obstacles are often placed between the main object and the camera. This indicates great advantage of subsequent calibration, as camera position and rotation can be freely chosen on site [15].

Figure 2 shows two images of Banostor's church tower which we calibrated. It is completely inapproachable due to structure damages and overgrown vegetation. In the tower, which originally had three stories, there are no stairs. The only reasonable method we had for modeling the tower was to implement photogrammetric method and so we obtained all dimensions which otherwise would be impossible to measure. Thanks to precise calibration, it was sufficient to measure only one dimension on the ground, all other dimensions are automatically obtained from the model.

2.2. Modeling

2.2.1. *Point coordinates restitution*

To explain usage of terrestrial photogrammetry where measuring is done in local co-ordinate systems, it is useful to introduce epipolar planes – ε, that is, find epipolar traces. This procedure applies to already calibrated images, its main purpose is to make marking of connecting points easier and more precise.

The **epipolar plane** is the plane (ε) which contains both optical centers (Z_1 and Z_2) from which photographs were taken and the point (A) on the object, the coordinates of which are searched for. It intersects planes of both photographs (2 and 3) in lines which can be defined as epipolar traces (ε_2 and ε_3). Perspective images of every point on photographs must belong to the corresponding epipolar traces, consequently they belong to the epipolar plane (Fig. 3).
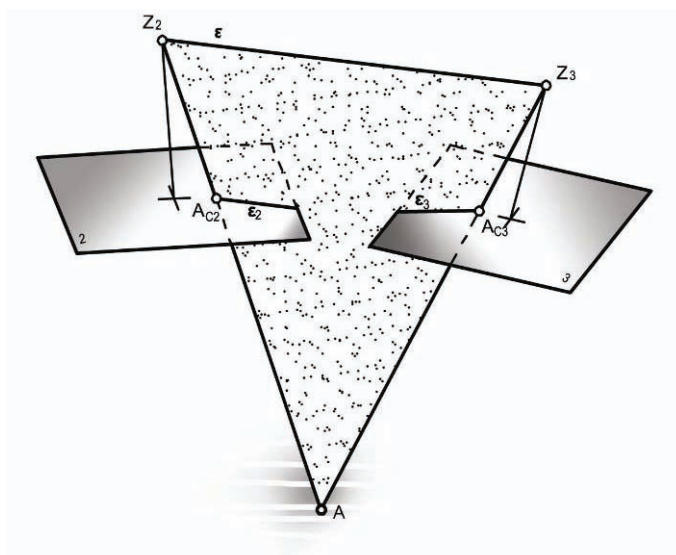

Fig. 3. Epipolar plane

This means that if we know the image of a point on one photograph, it is possible to find the epipolar trace on the other photograph, since the epipolar plane is defined by three known points (two optical centers and one image of the point) and the exact position of the image plane in space is known. If we can find that point also on the other photo-graph, then its coordinates in arbitrary system are known.

Terrestrial modeling software contains tools for detecting epipolar traces, and after de-fining new connecting point, calibration is iteratively upgraded for every imported point or angle. If the user defines a connecting point too far from epipolar trace, that point will not be used for calibration and the point will be marked as potentially wrong.

Figure 4 shows a model of bell tower in Apatin in Donje groblje. In the left part of picture we defined a connecting point, and in the right part the detected epipolar trace on model can be viewed.

Fig. 4. Epipolar trace on model of bell tower in Apatin in Donje groblje.

For easier explanation of this procedure it is useful that the planes with photographs, plane 2 and plane 3, which have arbitrary positions in space, are observed in the direction of their intersecting line. That line will be seen as point 2'∩3', and both photographs will be seen as lines (Fig. 5). Since the coordinate system in which we search exact dimensions is arbitrary, it is convenient to put one coordinate axis on this intersecting line. The plane of one photograph (for example, 2) can then coincide with a coordinate plane (for example, frontal plane). Let the plane of the other photograph be plane 3 which is rotated into horizontal coordinate plane 1.
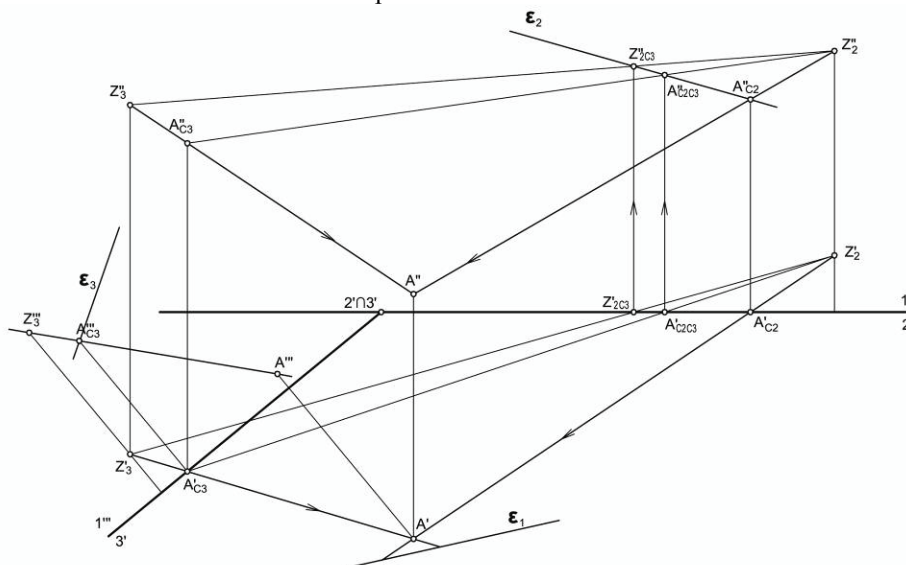

Fig. 5. Point coordinates restitution

Since the position of photographs in space is known, projections of optical centers onto planes 2 and 3 ca be determined easily, because they are always in the center of the photograph. Also, we can easily find first projections of optical centers, since image edge projection and focal length are known.

Central projections of point A – A_{C3} and A_{C2} on both planes 2 and 3 are also known.

Recapitulated, we know four points which belong to epipolar plane ε. Three points (two optical centers and one central projection of point A, for example onto plane 3 -

A_{C3}), exactly define epipolar plane ε. We find fourth point (central projection of point A onto plain 3- A_{C3}) because it must belong to the intersection line of plane 2 and plane ε, which is second trace of plane ε. In this procedure we use central projection of the image 3 (A_{C3}) on the image 2 (A_{C2C3}). By this procedure we control calibration accuracy.

If known central projection of point A (A_{C2}) is also considered, it is possible to find all coordinates of point A (A',A''), which belongs to the intersection of lines which contain optical center and corresponding central projection (Z_2A_{C2} and Z_3A_{C3}).

2.2.2. *Angle*

The precision of calibrated images can be also increased by considering right angles. This is very practical for modeling architectural objects, which usually contain many such elements.

Such procedure can be explained similarly to previously described method (Fig. 6). We assume that one photograph contains two points which lie on one ray of right angle, A_{C3} and B_{C3}. Point B is the vertex of the angle. Using the same described method it is possible to find epipolar traces on plane 2, and determine projections A_{C2} and B_{C2} on it. This enables us to obtain exact coordinates of point A (A',A'') and B (B',B'') in local coordinate system.

After that, we introduce plane β which contains point B and is perpendicular to line AB. This right angle is shown by transforming segment AB, so it's real size is seen (Fig 6). Any ray in plane β would contain one point C belonging to intersection of plane β and plane 2, β_2.
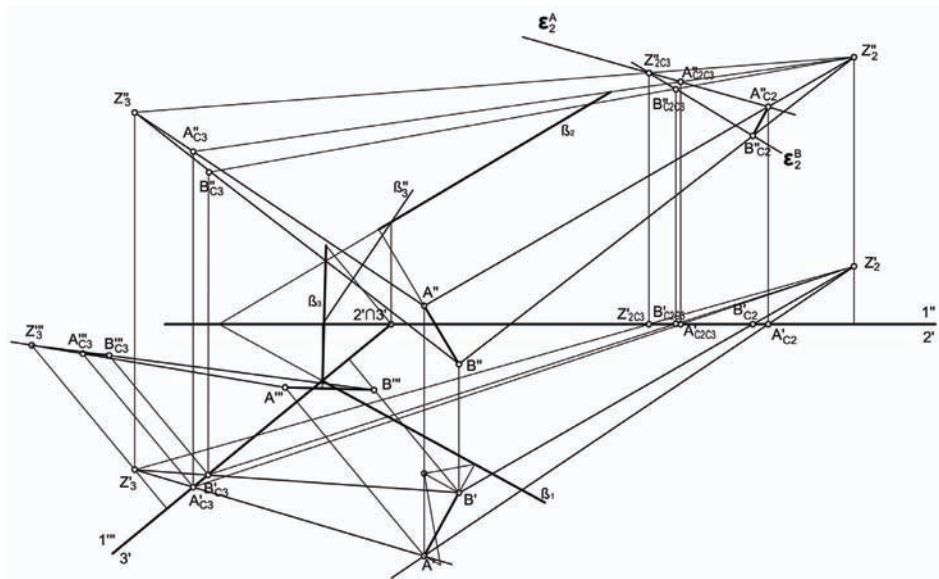

Fig. 6. Implementation of right angle

Further, if central projection of point C is detected on plane 3 - C_{C3}, it is possible to find its epipolar trace on plane 2 and second trace of plane β which enables to find exact coordinates of point C ($C_{C2}= \varepsilon_2 \cap \beta_2$), without its location on image 2. This proves that detecting right angle on the image also improves calibration.

2.2.3. *Objects*

This procedure can be repeated for other points or/and angles, which gives the general view of the object. In Figure 7 using the previously described procedure we obtain the true size of a cube from two photographs. The cube has been shown in three orthogonal projections, but two of them are translated to other height, to improve the clarity of presentation. Because of its complexity photogrammetry is not a method which can be used for manual drawing, without software processing.
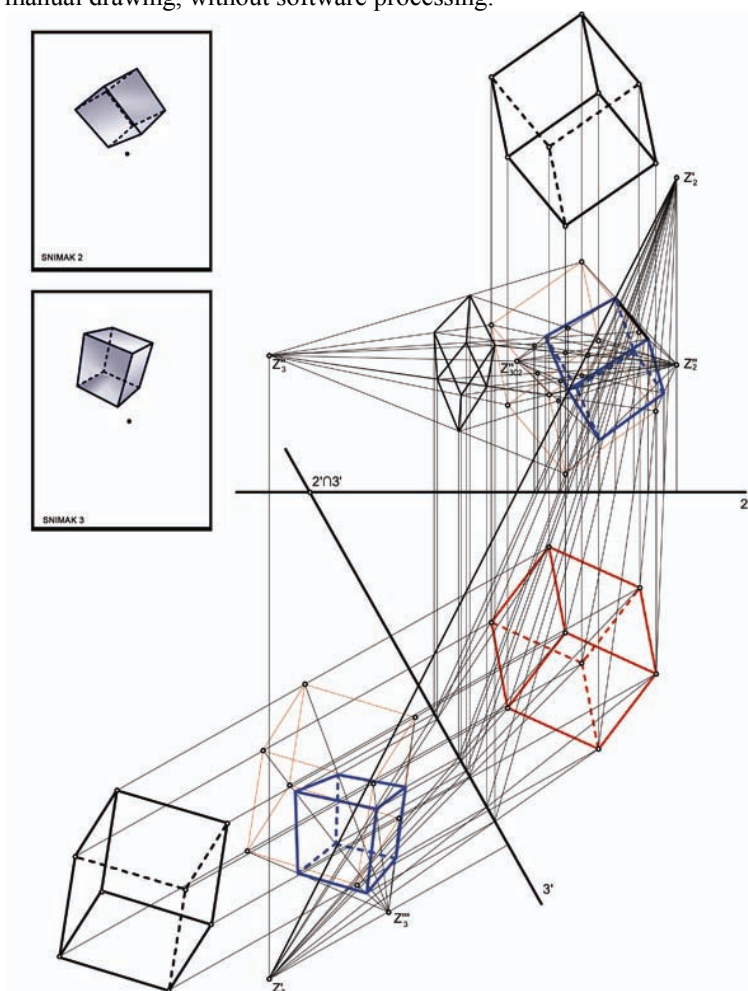

Fig. 7. True size of a cube determined from two calibrated photographs using manual drawing

Of course, software modeling is much more practical. After calibration is done, it is posible to add any amount of connecting points and angles, which will increase accuracy and reduce deviations.

Software for terrestrial modeling have large amount of various tools for creating and editing regular geometric bodies and simple mesh surfaces, and other shapes which exist on objects which can be photographed from ground [4].

Figures 8, 9 and 10 show Apatin's church portal (church Presvetog srca Isusovog), church of Saint Rudolf in Banoštor and Stockl chapel in Kljajićevo. All these models we generated from images using the described photogrammetric method.
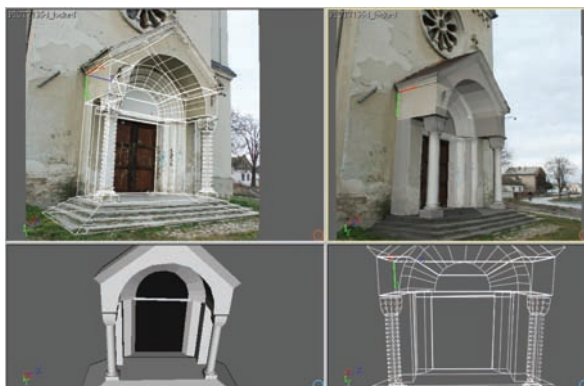

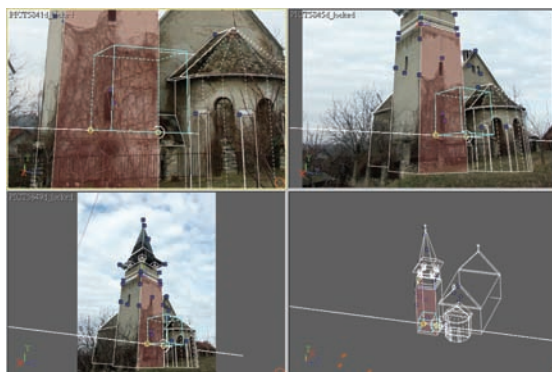Fig. 8. Modeling process of Apatin's church portal

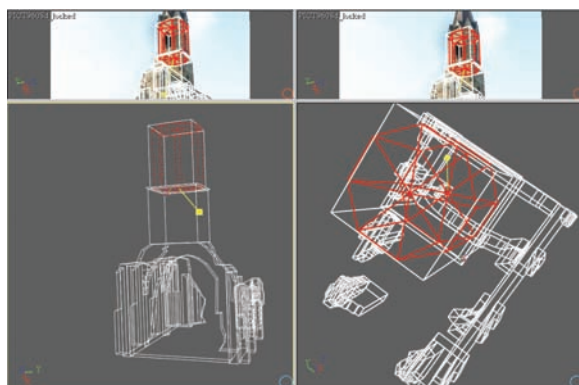Fig. 9. Modeling process of church of Saint Rudolf in Banoštor

Fig. 10. Modeling process of Stockl chapel in Kljajićevo

When modeling is finished, scale between model size and real object size should be determined. Since in subsequent calibration the position of the optical center in a local coordinate system is not measured, it is not possible to determine scale in advance. The most practical solution is to implement one known dimension into model. After that implementation, it is possible to measure any length or angle in the model (Fig. 11).

Important tool set for this kind of software is the tool that enables implementation of textures. Such tools allow attaching parts of photographs on model surfaces. This is important because it adds new significant information about architectural and other objects which cannot be obtained using traditional methods. We illustrate this on Fig. 12 which shows model of church Presvetog srca Isusovog in Apatin. Attaching texture from photographs we obtained additional information about all details on the surface of the object – architectural and areas which are seriously damaged because of ravaged influence of moisture. These damaged areas could not be exactly registered by manual measuring and drawing.
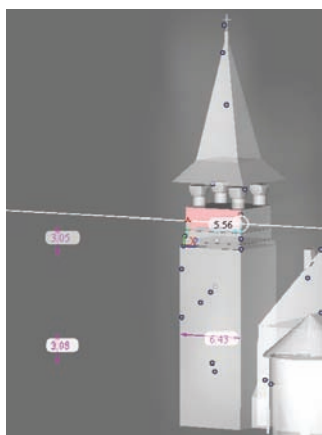

Fig.11. Implementing scale and measuring

Fig. 12. Model of church Presvetog srca Isusovog in Apatin

In Figure 13 we show model of Saint Ana's church in Bačko Novo Selo, which was built in 1826 and it represents a typical example of the sacral architecture in Vojvodna at the beginning of the 19th century. In Figures 14 and 15 3D model of the remains of Kalvarien chapel in Kljajićevo is presented. This chapel, built in 1889 is detected as the most critical object in the analysed area. It is the only object for which it's original form can not be determined based on the remains. The object represents an interesting example of neogothic character, typical for the transition from 19th to 20th century having details unusual for that period and area. Figure 16 shows 3D model of Stockl chapel in Kljajićevo, built in 1927 in neogothic style, alleviated with the influence of calm facades of moderna. Figure 17 shows model of Josef Dah's chapel in Ratkovo, built in 1925, a typical example of late neogothic.
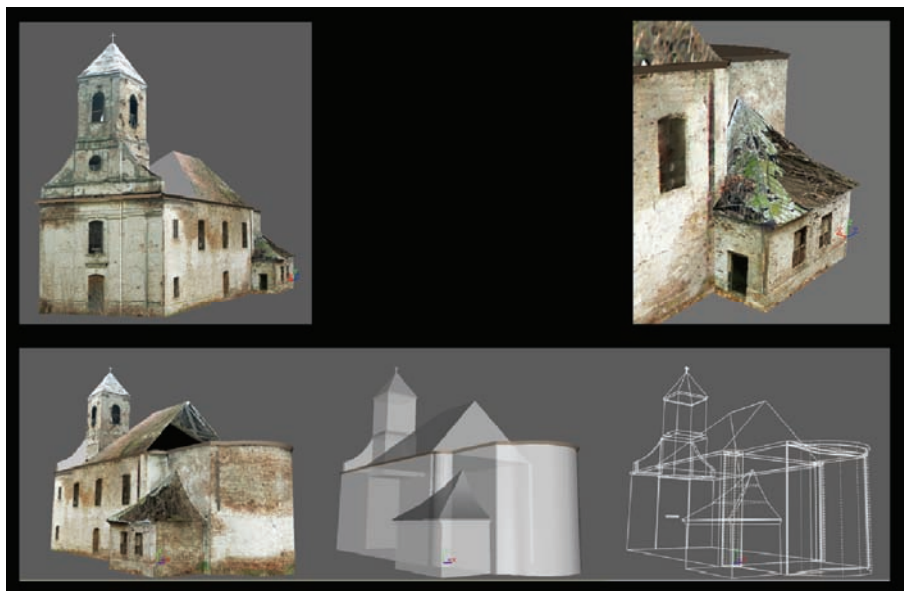
Fig. 13. Model of Saint Ana's church in Bačko Novo Selo

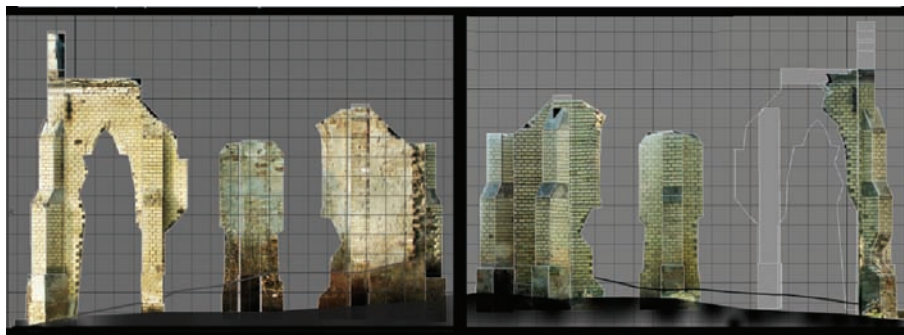Fig. 14. Model of Kalvarien chapel in Kljajićevo

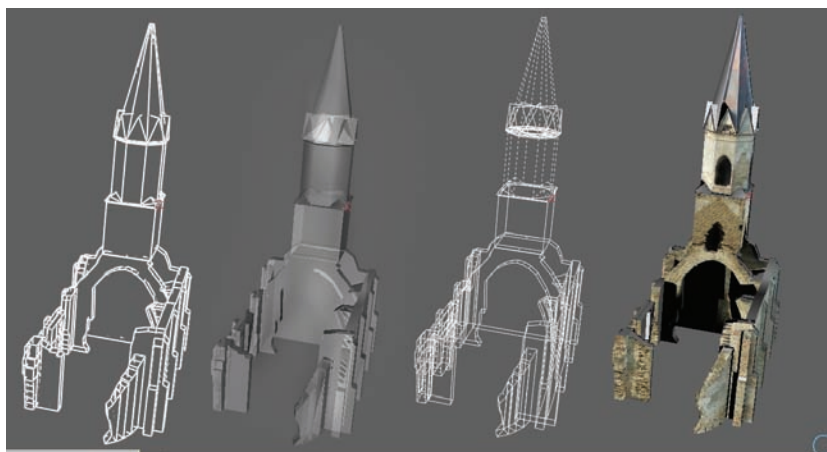Fig. 15. Model of Kalvarien chapel in Kljajićevo - facades

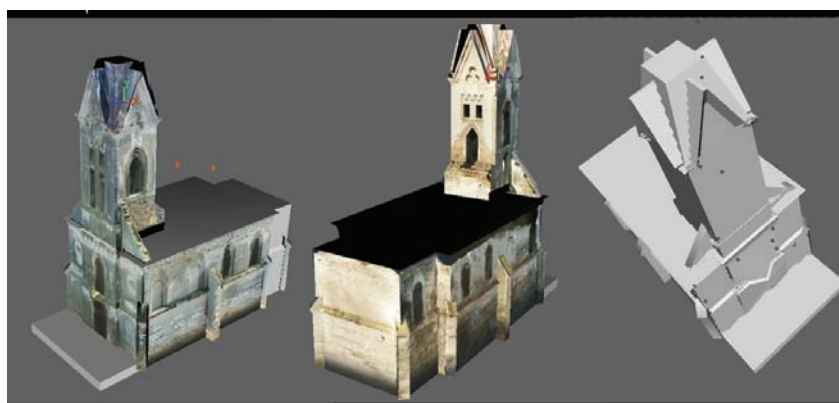
Fig. 16. Model of Stockl chapel in Kljajićevo

Fig. 17. Model of Josef Dah's chapel in Ratkovo

3. CONCLUSION – ADVANTAGES OF PHOTOGRAMMETRY COMPARED TO THE TRADITIONAL METHOD OF MEASURING OBJECTS

Main advantage of photogrammetric modeling is the economy of procedure. The terrain work is much shorter compared to on site measuring dimensions. Time needed for modeling is about the same as time needed for drawing object.

Greater quantity of information is obtained using 3D modeling then on drawings in 2D. When 3D model is finished, it is possible to generate any orthogonal or central object projection. Model can be exported in other modeling or animation software which allows further treatment (element editing, adding lighting, creating dynamic view, etc.).

Depending on the software quality, accuracy and precision of model can be higher. Software is under constant development which brings many improvements.

Important advantage of photogrammetric modeling is obtaining information about inapproachable structures or some of its elements. This is essential for architectural objects which are located on rough terrain, or structure elements having high and inapproachable facades.

In contrast to traditional drawings of architectural objects which contain only dimensions, model also contains detailed information about used materials. This is especially important if damaged parts of structure appear, which are then dimensioned altogether with model.

Using the described photogrammetric method we recorded in detail over 100 sacral objects in Danube area in Vojvodina which were built in 18th, 19th and first half of the 20th century. Based on these recordings, 3D models were constructed and we detected 12 objects which are in a critical condition and this was the last moment to record their present state, because huge damages cause quick lost of shape and details data.

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TERESTRIJALNA FOTOGRAMETRIJA I PRIMENA NA MODELOVANJE ARHITEKTONSKIH OBJEKATA

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U ovom radu analizirana je terestrijalna fotogrametrija i njene primene u domenu arhitekture. Fotogrametrija je metoda kojom se predstavljaju i dimenzioniraju 3D objekti koristeći podatke sa 2D fotografija i ona ima mnoge prednosti u odnosu na tradicionalne postupke. Date su teorijske osnove metoda koji su korišćeni u kreiranju 3D modela na osnovu fotografija a onda, koristeći odgovarajući softver, ti metodi su primenjeni na kreiranje 3D modela arhitektonskih objekata. Koristeći opisane fotogrametrijske metode konstruisali smo detaljne 3D modele preko 100 sakralnih objekata u Vojvodini izgrađenih od 18. do prve polovine 20. Veka. Mnogi od tih objekata su bili veoma oštećeni, neki od njih u kritičnom stanju, i ovo je bio poslednji trenutak da se zabeleži nihovo sadašnje stanje.