Novi Sad J. Math.
Vol. 38, No. 3, 2008, 65-72

3D MODELING BASED ON PHOTOGRAPHIC DATA [1]

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Abstract. Photography is a 2-dimensional medium which represents 3-dimensional space, as a central projection on a plane. As it is possible to represent 3D space by a photograph, it is also possible, using mathematical methods, to obtain data about 3-dimensional structures from the data registered on photographs. We used two methods to obtain spatial data from photographs: restitution of perspective image and photogrammetry. For the restitution of an object one photograph is sufficient and that is why this method is used for modeling of objects which do not exist. For the photogrammetry several photographs of the same object are needed and this method is used for existing objects. For 3D modeling of architectural objects which are not accessible or parts of which are ruined restitution and photogrammetry are indispensable methods. Using combination of these two methods we created 3D models of devastated sacral objects in Vojvodina representing their remains and their original form.

AMS Mathematics Subject Classification (2000): 00A69

Key words and phrases: 3D modeling, photogrammetry, photo restitution, architectural objects

1. Introduction

Three-dimensional objects and structures can be represented in different ways using 2-dimensional media. In order to represent such structure as realistic as possible it is necessary to create a model whose properties are analogous to the properties of the structure. Digital 3D models are very flexible, enabling different representations depending on the user needs.

A 2-dimensional medium which can be effectively used in creating 3D models is photograph. If we have only one photograph of an object, then we use photo restitution to generate its true dimensions. Having more than one photograph of an object we use photogrammetry. Both methods can be implemented by geometric constructions or by using software.

In this paper we give methods for creating 3D models of devastated architectural objects in which geometry and appearance of these objects are recovered. Classical techniques of converting architectural plans or survey data to CAD models are labor intensive, time consuming, expensive, and do not have facade material data, which is especially important if the facade is damaged. Methods

[1]This paper was partially supported by the organizers of the 12th Serbian Mathematical Congress

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based on using photographs make the process of modeling architectural objects fast, photorealistic and can be used even when the objects are unapproachable.

We create 3D virtual reconstructions of devastated sacral objects in Vojvodina using combination of photogrammetry and photo restitution, based on today's remains and old photographs of these objects. Both methods are implemented by geometric constructions and use of software.

2. Modeling based on two or more photographs - Photogrammetry

Photogrammetry is a technique of representing and measuring 3D objects using data stored on 2D photographs [1]. At least two photographs are needed 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 [2, 3, 4].

A prerequisite for using photogrammetric modeling is that the images must be calibrated. To calibrate means to determine the exact coordinates and rotations of camera in the moment of taking pictures and object in a local coordinate system [5].

Measuring of the object is done in a local coordinate system. So, to explain the usage of terrestrial photogrammetry it is useful to introduce epipolar planes [7]. The epipolar plane (ε) contains both optical centers of the lens (V_1 and V_2) from which photographs were taken and the point M on the object, the coordinates of which are searched for. Epipolar plane intersects planes of both photographs (1 and 2) in lines which can be defined as epipolar traces (ε_1 and ε_2). Perspective images of point M on each photograph must belong to the corresponding epipolar trace, $M_{C1} \in \varepsilon_1$, $M_{C2} \in \varepsilon_2$, consequently, the point M belongs to the epipolar plane (Figure 1).

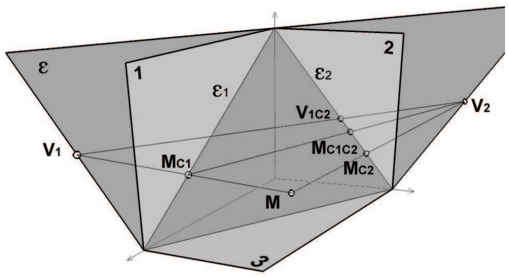

Figure 1: Properties of epipolar plane ε, and its traces ε_1 and ε_2

When photographs are calibrated, the positions of photo planes are known. To simplify representation we can observe photos in direction of their intersecting line $1 \cap 2$. We take the line to be one of the axes of the local coordinate system.

Projections of optical centers onto the planes 1 and 2 are always at the center of the photographs. Focal length of the lens is known from photo properties, so, top view of the optical centers can also be determined. Hence, the exact positions of both optical centers (V_1 and V_2) are known.

Let M_{C1} be the central projection of an arbitrary point M on one photograph (for example, plane 1). Now, it is possible to find a second trace ε_2 of the epipolar plane. It must contain central projections of the points V_1 and M_{C1} onto the photograph 2, because of previously described properties of the epipolar plane ($V_{1C2} \in \varepsilon_2,\ \ M_{C1C2} \in \varepsilon_2$). Also, central projection of point M onto plane 2, must belong to the second epipolar trace $M_{C2} \in \varepsilon_2$. Therefore, this second trace makes easier to find central image M_{C2} of the point M onto the photograph 2. After the point M_{C2} is determined by the user, it is possible to find real coordinates of the point $M(M', M'', M''')$ in the local coordinate system (Figure 2).

This procedure can be proceeded automatically and it makes calibration easier and more precise. Terrestrial modeling software contains tools for detecting epipolar traces automatically, calibration is iteratively upgraded for every imported point.

Similarly to the previously described method, it is possible to introduce right angle on the object observed on the photograph, which can have practical usage if architectural structures are modeled. The procedure of implementation of the right angle can be explained similarly to the previously described method.

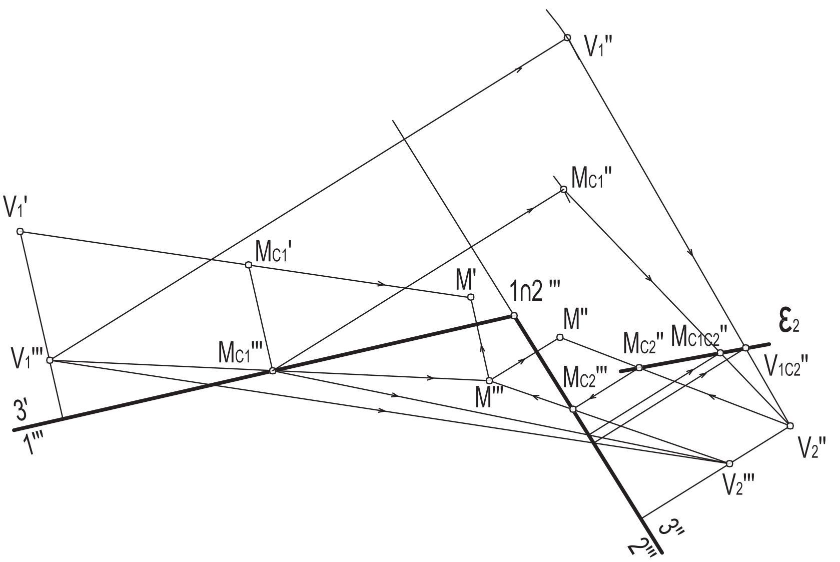

Figure 2: Detecting point coordinates using two photographs

We assume that one photograph contains two points which lie on one ray of the right angle, M_{C1} and O_{C3}. Point O is the vertex of the angle. Using the same method, exact coordinates of the points M and O in a local coordinate system are determined. The other right angle ray must contain point N which belongs to the plane $\beta (\beta \perp AB)$. The ray lies on the plane β, so we can assume that the point N is a point on the ray, which also belongs to the plane 1, so it belongs to the first trace of the plane β, $\beta_1 = \beta \cap 1$. We shall now determine the central projection of the point N on the plane 2 ($N_{C2} \in \beta_3$). Central projection N_{C2} of the point N onto the plane 2 must belong to its epipolar trace $\varepsilon_{2(N)}$, and also to the central projection β_{1C2} of β_1 to the plane 2. Therefore, central projection of the point N on the plane 2 is on the intersection of these two lines (Figure 3).

Hence, it is possible to determine coordinates of the point $N(N', N'', N''')$ in a local coordinate system, without using and marking point N on the photograph 2. Therefore, we have proved that the described process of defining each right angle improved calibration by one level.

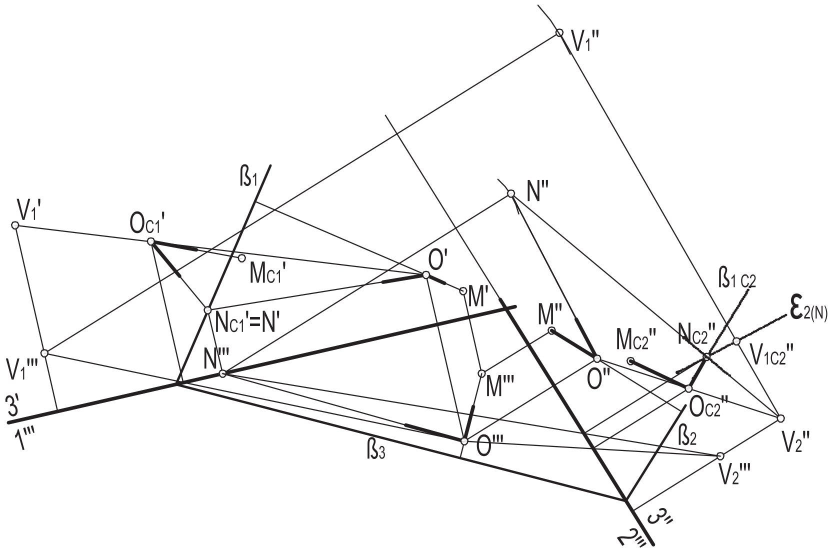

Figure 3: Detecting coordinates of the right angle using two photographs

Because of its complexity, photogrammetry is not a method which is suitable for manual drawing, without software processing. Using software the model is generated by the recognition of the basic geometric shapes and transforming points, edges and bodies. Textures or materials are extracted from the photographs and attached to the model [6, 9].

3. Modeling based on one photograph - photo restitution

From one projection (one photo) it is not possible to obtain precise information about object coordinates if intuitive assumptions about the space are not used. However, if an object does not exist any more its geometry is most precisely registered in old photographs.

 

Figure 4: Old photo and present state

The goal of photo restitution is to determine real dimension using just one photograph. We can assume that the photograph is the frontal plane. The optical center of the lens is the equivalent to the view point O.

Shapes of architectural objects are basically cubic. Therefore, three vanishing points (N_a, N_b and N_v), which define the longitudinal direction, cross direction and direction of verticals will be basic photo elements. Basic photo elements are necessary for any photo restitution, because they make up for one projection indeterminacy. Other specific elements depend on the exact photo.

Manual photo restitution is shown on the example of the chapel in Kljajicevo, the remains of which are very poor at this moment (Figure 4). Frontal projection of the view point (O'') must be the ortho-center of the triangle formed of described vanishing lines - $N_aN_v = \alpha_n$, $N_bN_v = \beta_n$ and $N_aN_b = \chi_n$ [8]. This fact is used as extra checking for assumed basic photo elements. After finding basic photo elements all other specific directions and planes along with their vanishing lines, points and rotated projections are found (Figure 5).

When basic elements are detected, the frontal and lateral facades were rotated into frontal plane. The tower, which is distant from these planes, was first projected in them, and then altogether rotated (Figure 6). For rotating corner buttresses, new elements were needed, because of specific sloping planes. Corner buttresses do not have the same position and shape as the lateral buttresses. So they were rotated separately. As an overall result, orthogonal views were exported. These will be used for virtual reconstructing the chapel.

Software procedure of one photo restitution is less precise, but much faster. User defines two vanishing points of perpendicular directions, and all other elements are detected automatically. The object can be modeled in the same software.

An example of software restitution is shown on St Rudolf Banostor's church tower interior. The space from where photos of tower staircase remains were made is very narrow. Therefore the photographs are not suitable for photogrammetry, and the construction is too complex for manual restitution. The photo-

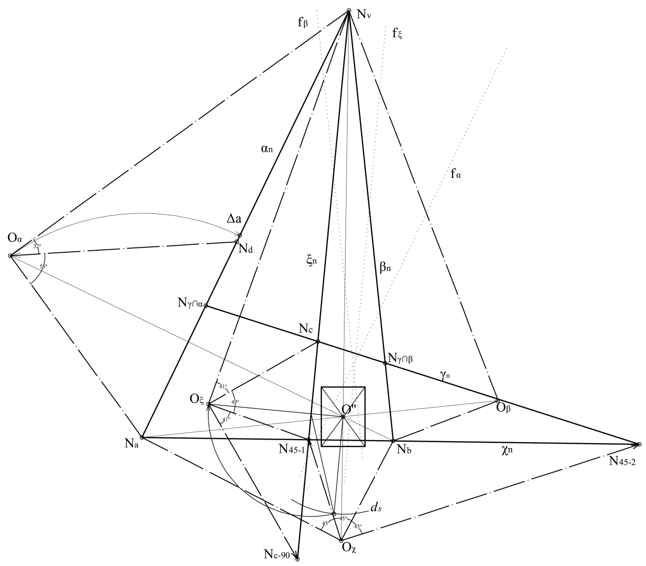

Figure 5: Finding photo elements for the Kljajicevo chapel

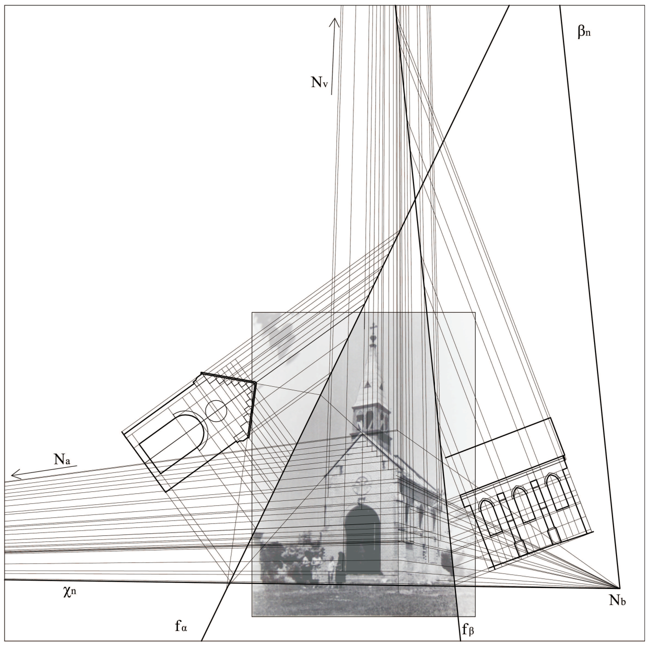

Figure 6: Rotation of facade planes of the Kljajicevo chapel

Figure 7: Software photo restitution of staircase in Banostor's church tower

graph used for restitution and finished model is shown in Figure 7.

4. 3D virtual reconstructions - results

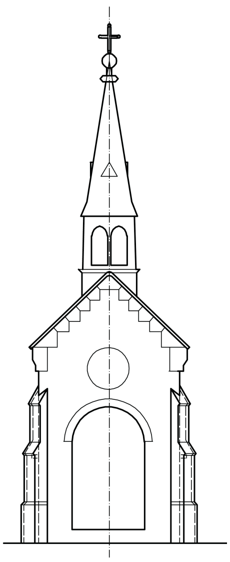

Figure 8:
Photorestitution

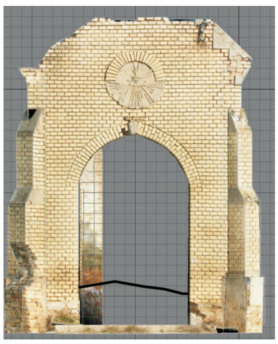

Figure 9:
Photogrammetry
3D model

Figure 10:
3D virtual reconstruction

Combined results formed by the restitution of the photograph and by terrestrial photogrammetry modeling, make object space data complete. Therefore, it is possible to add the non-existing parts (Figure 8) to the photogrammetrically created model (Figure 9), and to create virtual model of the object which allows different further analyses. In Figure 10, virtual reconstruction of the previously described Kljajicevo chapel is shown.

For preservation of cultural heritage it is very important to make quality record of architectural structure existence. Sometimes the object can not be measured manually. Therefore, photographs are most precise and less costing input medium which can be used for 3D modeling.

Depending of the site conditions and level of object damage, combination of photo based modeling is used to create 3D virtual reconstruction of Vojvodinian sacral architecture. These models represent disappeared and damaged objects as they looked in the past.

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Received by the Editors October 31, 2008