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Virtual Reconstruction of the Kljajićevo Chapel

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Abstract. Virtual reconstruction, as a three dimensional realistic representation, has many advantages in the cultural heritage data distribution and storage, especially in the case of devastated architectural objects. The procedure of the virtual reconstructing of the *St. Wendelin chapel* in Kljajićevo is presented in this paper as a case study. The existing remains have been recorded using terrestrial photogrammetry. Spatial information and dimension of collapsed parts have been exported from old photographs by using perspective projection restitution methods. These two type of data are combined and used as a platform for 3D virtual reconstruction of the object. Virtual reconstruction makes spatial data complete and ready for further research or for data distribution.

Key Words: restitution, photogrammetry, photograph, modeling, architecture

MSC 2000: 51N05

1. Introduction – present state

The chapel on the Calvary in Kljajićevo is built on a hill and, being on the top of it, it dominates the surrounding terrain. The approach path continues in a slope into the axis of a horizontal line of communication, which makes the chapel the dominant end of the whole communication line.

The first chapel in this place, dedicated to *St. Wendelin*, was built in 1822, and the present chapel with all the sacral elements which articulate it was built by the Kljajićevo community in 1898.

The arrangement of functional parts of the chapel is typical for smaller chapels in Vojvodina. It does not have a pronaos, but only a rectangular cella divided into two travated segments with apsis. The apsis is more narrow than the naos. Its shape can only be assumed with respect to the remains. Most probably, the apsis was rectangular regarding the composition of bricks in the only remaining corner. It was vaulted, which can be seen from the remains of the frontal wall. On the inner side the beginning of the vault still exists. In an

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old photograph one can see the saddle roof, and this can also be concluded from the fact that the frontal wall had the form of a gable.

The chapel is shaped in neogothic style, using yellow facade bricks, which was typical on the turn of the 19th to 20th century. Angles and segments division are emphasized by buttresses, and broken arcs appear on lateral facades. The frontal facade is unusual. The portal has the form of a semicircle with a key stone. Above it there is a relief motive dominating the frontal side. The relief is unique for sacral architecture in these areas — in the middle there is an eye inscribed into a triangle, radiating with rays of various lengths.

2. Photograph restitution

2.1. Perspective projection elements of photograph

Two basic elements which influence the distribution of points on a photograph are the position of the film plane and the focal distance. A photograph, that is, a film plane is the image plane of the perspective which has to be analyzed. The optical center of the lens is the equivalent of the eye point O. The projection of the eye point (O") on the film plane is always in the center of the photograph.

From one single projection it is not possible to obtain precise information about object's coordinates, if no additional assumptions about spatial relationships are used. Because of that, a further restitution of the perspective image depends on the structure which is represented in the photograph. When analyzing the Kljajićevo chapel it is useful to notice that the majority of the lines can be assigned in one of the three groups — a, b or v. Lines a and b are horizontal lines which are mutually perpendicular and parallel to the transversal and the longitudinal axis of the building, respectively. Line v is vertical. It is obvious from the photograph that the verticals' vanishing point is not at infinity, which corresponds to the fact that the horizon line is under the eye point, implying that the film plane was inclined to the horizontal plane.

Thus, lines a, b and v form an orthogonal trihedron. This implies that the sight rays s_a, s_b and s_v are also three mutually perpendicular lines. The intersection of these three lines is the eye point O. The piercing points of these rays with the image plane define the vanishing points of these lines — N_a, N_b and N_v. Consider the trilateral pyramid with the apex in the eye point O, whose edges are parallel to a, b and v, resp., and the triangle $N_aN_bN_v$ is the base. The projection O'' of the vertex O onto the base plane (that is, projection plane — photograph plane), must be the orthocenter of the triangle $N_aN_bN_v$. This fact is crucial for the precise determination of these three vanishing points, which from the very photograph can not be precisely defined.

2.2. Rotation of eye point

Finding the characteristic vanishing points enables the direct determination of vanishing lines of facade planes. Every two characteristic lines define a set of characteristic parallel planes. Since the vanishing points of these lines are known, it is easy to determine the vanishing lines — $\alpha_n = N_aN_v$, $\beta_n = N_bN_v$ and $\chi_n = N_aN_b$. The front plane is denoted by α, the lateral facade plane is β, and the horizontal base plane is the plane χ. The eye point can be rotated about each of these vanishing lines into the image plane. In order to obtain the true distance between the eye point and the vanishing line of the plane, we have to rotate the triangle which contains the eye point O, its projection O'' and the slope line (with respect to the image plane) into the projection plane. Since the distance of the eye point is still unknown, in these rotations we use always at first the vanishing point of the normal to the plane, that is, the fact that the normal is always orthogonal to the slope line. Then it becomes possible to find the rotated position of the eye point, and the rotated parallel image plane, what is necessary for lengths and angles determination [7]. The rotated projections O_α, O_β, and O_χ are obtained by rotation of the eye point about the corresponding vanishing lines. To confirm this, a distance circle line is constructed and it must contain the distances obtained in all three rotations and which, of course, must be equal (Fig. 1).

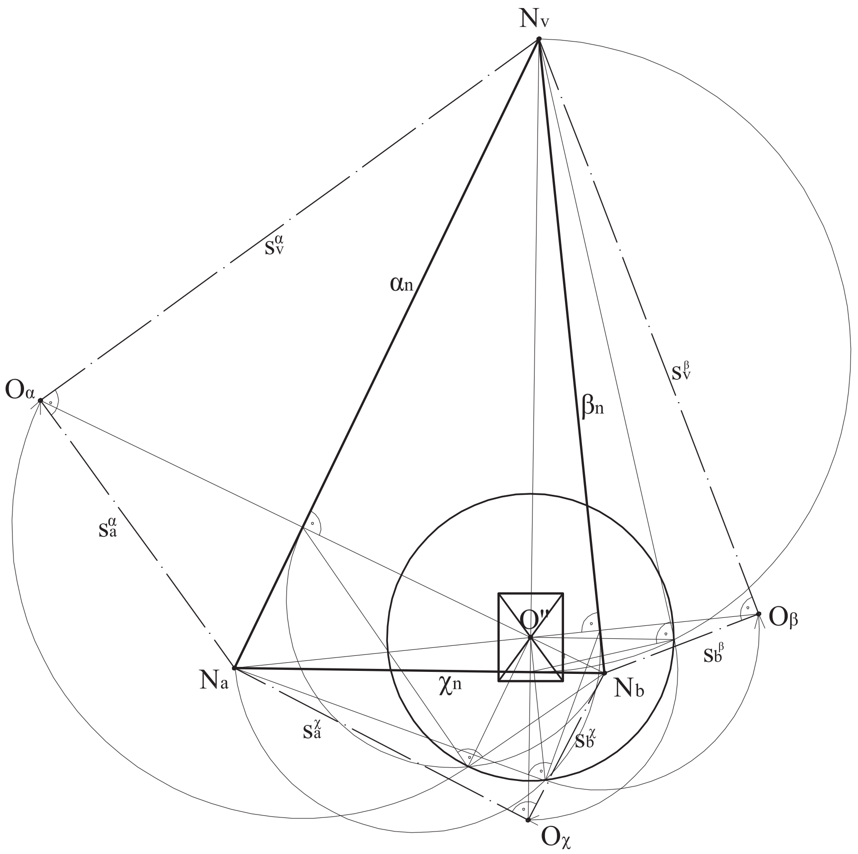

Figure 1: Rotation of eye point

2.3. Rotation of facade planes

There are several different methods and procedures which, after the basic elements of the picture are defined, can be used to determine true sizes.

If we have a plane which contains complex elements or several necessary dimensions, then it is helpful to rotate this plane into the projection plane. So we have facade planes α and β which are rotated about appropriate frontals. Frontal lines f_α and f_β , i.e., principal lines with respect to the image plane, are particularly chosen in order to preserve maximal clarity of the drawing. Parallel rays result in parallel rotated projections. The perspective image of every line must intersect its rotated projection at the axis of rotation, that is, at the frontal. Knowing these properties, it is easy to find the rotated projections of all points of planes α and β (Fig. 2).

The precision mostly depends on the clarity of the photograph. The front plane is conveniently positioned and there are no problems in finding its rotated projection. On the

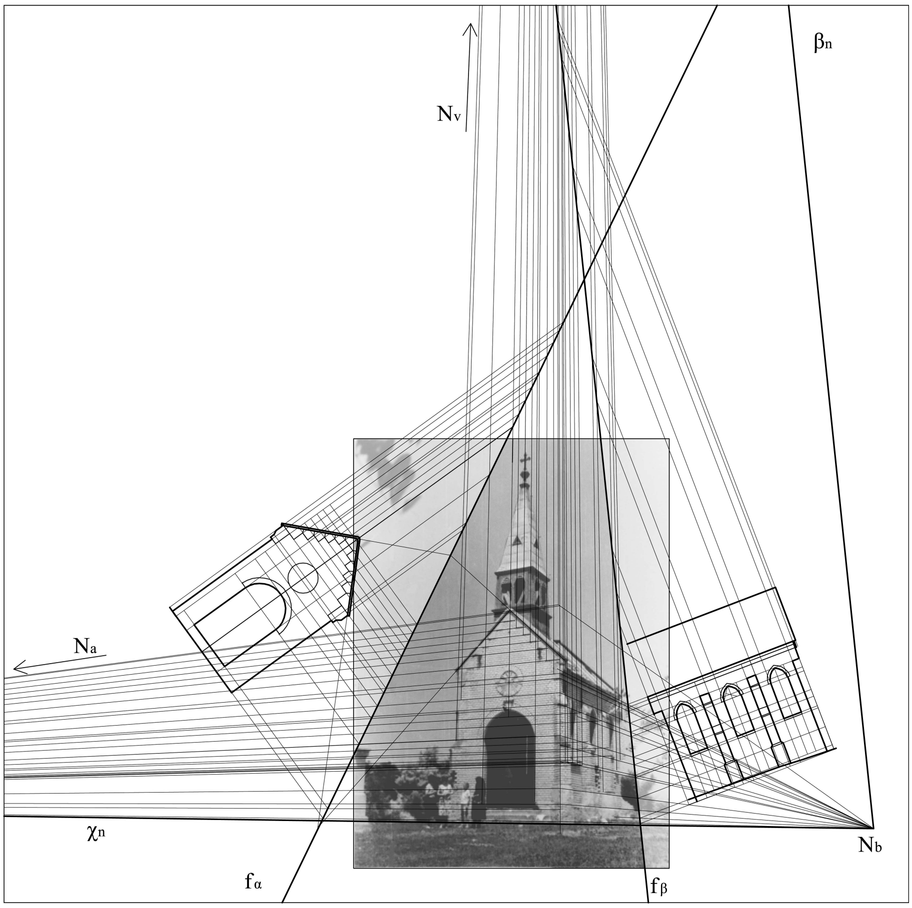

Figure 2: Rotation of facade planes

contrary, it is difficult to observe the lateral facade because of the buttress which blocks the view and also because of the position of the plane which causes all lines of the direction v to intersect the frontal under acute angle. Irregularities on the drawing which could appear due to the inconvenient acute angles and distant points, can be overcome by using advantages of vector graphics. During the rotation of the lateral facade (plane β) it is necessary to make a detailed check of the obtained results. The obtained results are compared with results obtained by the photogrammetric modeling of the present state. Apart from this, the builder's idea of symmetry and repetition of characteristic elements was also taken into consideration.

2.4. Tower

The tower is positioned out of all characteristic facade planes. Nevertheless, one can notice that the building is symmetric and the vertical plane of tower's symmetry is the same vertical plane of line b, being the axis of the front facade symmetry.

All dimensions of the tower's frontal side are transferred onto the plane α. It is assumed that the cross is in the middle, and midpoints of all other horizontal segments of direction a are obtained using the bisectrix vanishing point Δa on the vanishing line α_n . The endpoints of segments are transferred onto the plane α by perspective collineation. After that, the tower image in plane α is rotated, in the same way as the frontal plane, about the frontal line f_α. The tower base is a square which is confirmed by introducing vanishing points N_{45-1} and N_{45-2} of horizontal lines positioned at 45° in relation to lines a and b. These vanishing points

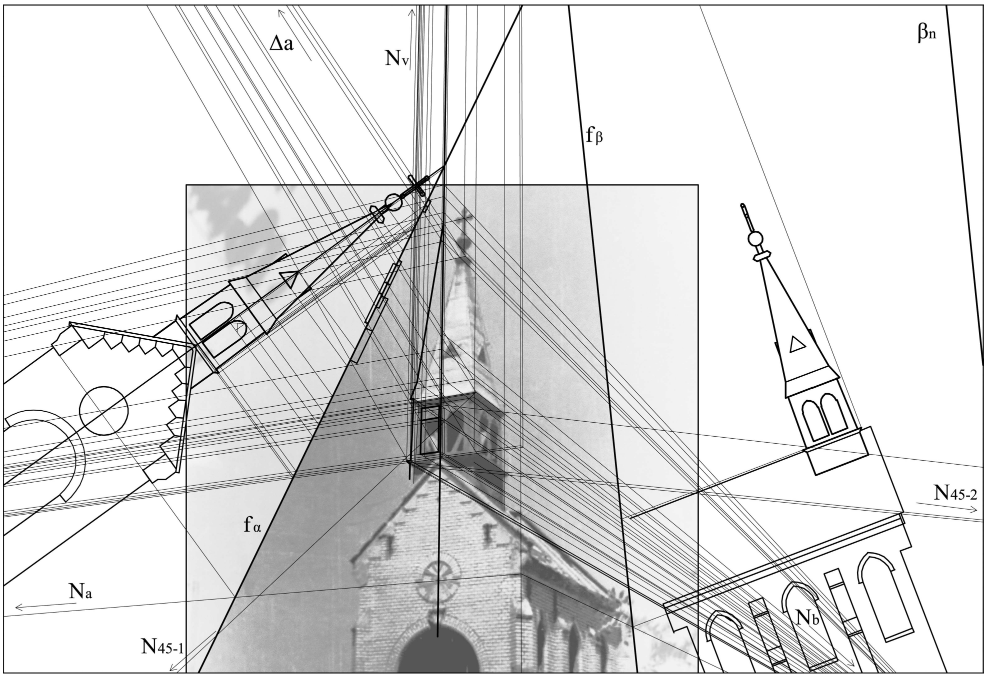

Figure 3: Rotation of the tower

also help in faster projecting the tower onto the plane α.

The true size of the tower on the lateral facade is the same as previously described. In order to define the position of the tower, the coordinates of one point of the tower lying in the plane β are determined in a similar way, and then the tower is copied in a certain proportion from the rotated plane α (Fig. 3).

2.5. Buttresses

Two types of buttresses can be noticed in the photograph. One type corresponds to lateral buttresses which are positioned in the directions $a - b$, and the other corresponds to corner buttresses which are in a skew position to the same directions.

The width of the lateral buttress is defined in the rotated projection of the plane β. The image of the buttress in the front plane is obtained by projecting onto the plane β. The angle between the slope line of the inclined planes (direction denoted by d) and the horizontal plane is checked using parallel rays. The vanishing point N_d is defined by the elements of the photograph, knowing that N_d must be on the vanishing line α_n , because these lines belong to vertical planes parallel to α. The angle obtained by rotation of parallel plane is approximately 58° (Fig. 4).

The restitution of the corner buttress is more complex. We start from the fact that its base is positioned at 45° in relation to the facade planes, which is observed on the photogrammetrical model. The buttress profile plane (ξ) contains horizontal lines which form 45° with the line a and vertical lines. This implies that the vanishing line of these planes (ξ_n) contains the vanishing points N_{45-1} and N_v. Since the profile is complex, it is optimal to rotate plane ξ about an appropriate frontal f_ξ (Fig. 5). This gives the true size of the profile, which can not be seen in true size neither in the frontal nor in the lateral view, where all widths are $1/\sqrt{2}$ of the true size. Note that the heights remain unchanged.

It is interesting to notice that by rotating the plane ξ, we realized that the slope of inclined

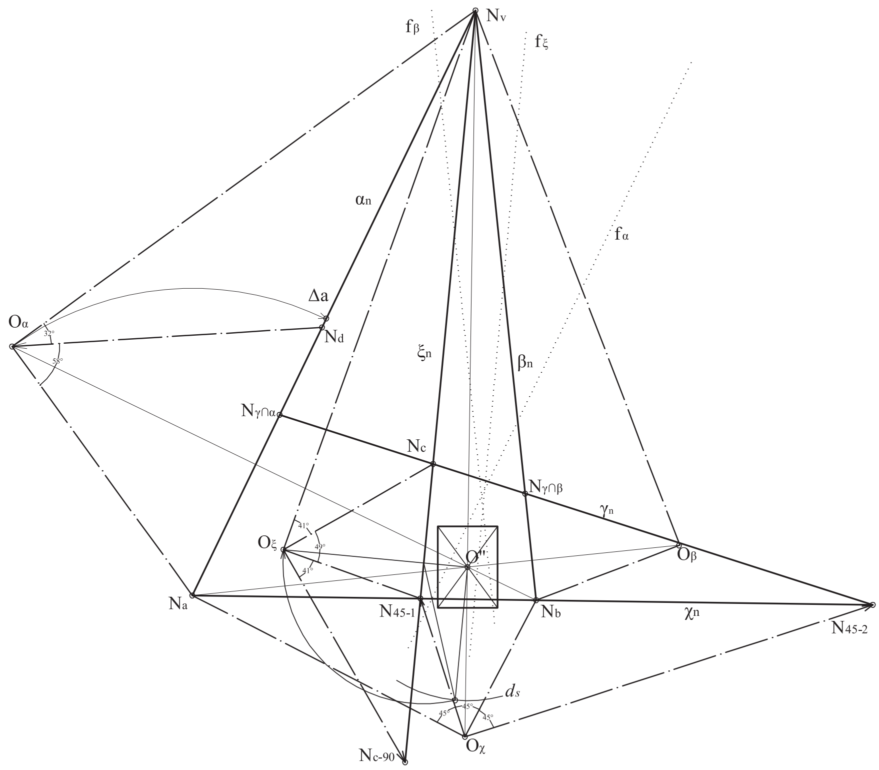

Figure 4: Elements for buttress rotation

planes of the corner buttress is approximately 49°, which differs from the slope of the inclined planes of lateral buttresses. But after projecting onto the front plane, lines which define the slopes of both buttresses are parallel, being observed from the front. Since the lengths of adjacent segments (sides of right triangle) of these angles are related in the ratio $1 : \sqrt{2}$, and the heights (the opposite sides) are equal, we conclude that the quotient of tangents of these angles is $\sqrt{2}$. If we make a numerical check we get

$$\frac{\tan 58^\circ}{\sqrt{2}} = 1,13, \qquad \arctan 1,13 = 48,6^\circ \approx 49^\circ.$$

Thus we can see that the result coincides with the angles obtained by the graphical construction.

Further, we have to examine the position of the buttress in relationship to the facade planes. If we consider inclined lines of the corner buttress (direction denoted by c) it is possible to find the vanishing point N_c which must be on the vanishing line ξ_n of the plane ξ (Fig. 5). Then we consider plane γ whose vanishing line γ_n contains N_c and N_{45-2}. It is necessary in order to find the intersecting lines between plane γ and planes α and β. The vanishing points of these intersecting lines are the points of intersection of the corresponding vanishing lines. Observing these intersecting lines we see that the axis of symmetry of the corner buttress does not pass through the corner of the object but it is somehow moved, meaning that the images of the buttress on the frontal and the lateral facade are not identical. These intersecting lines are collinearly mapped onto the rotated projections of the planes α and β, which gives the precise position of buttress in regard to other elements.

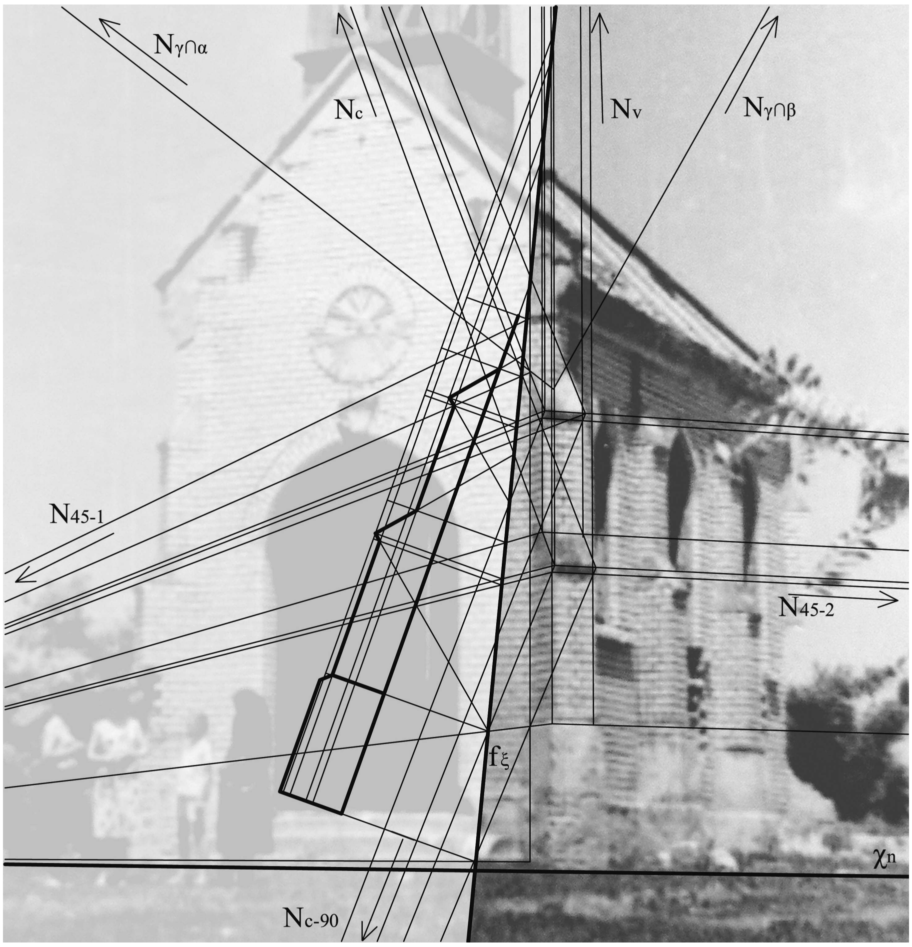

Figure 5: Rotation of corner buttress

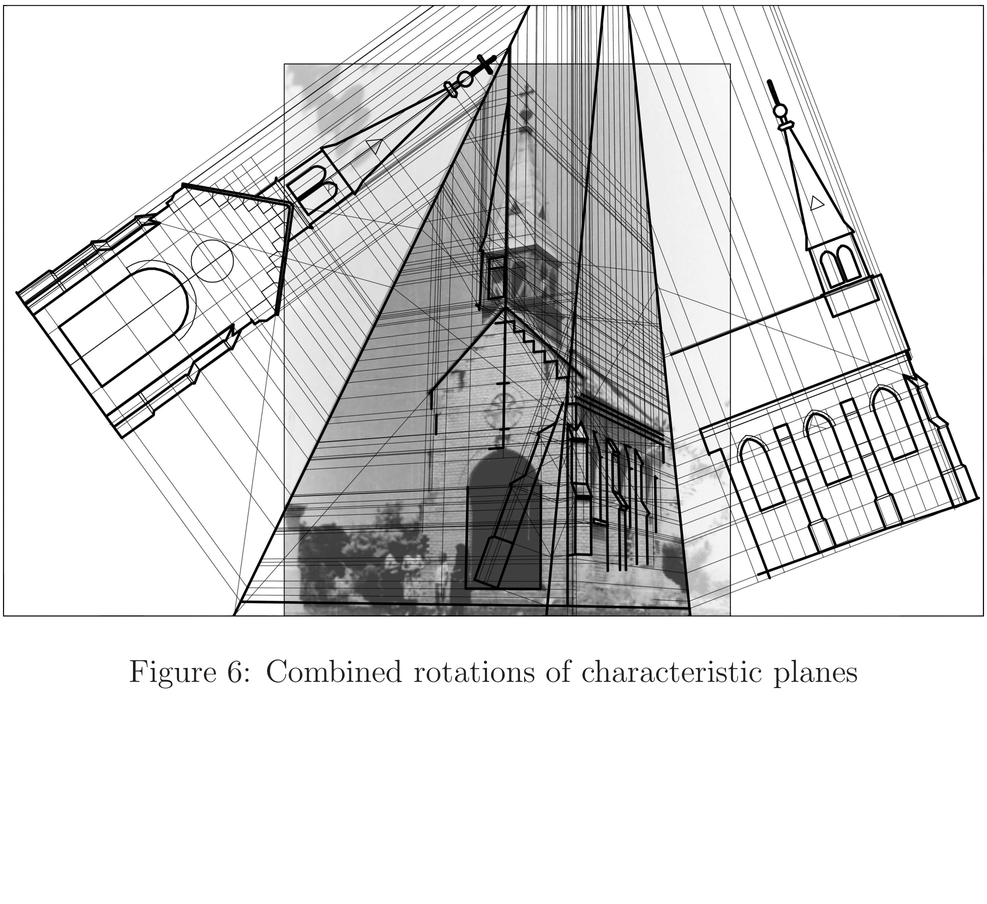

Figure 6: Combined rotations of characteristic planes

2.6. Characteristic views

After the manual restitution of the photograph the true size of the facade planes is determined. However, these planes have different proportions, because the frontals, about which the planes were rotated, were chosen independently in order to have the most convenient position on the drawing. The equalization of the proportions is easily obtained by scaling on the basis of one specified size (Fig. 6).

After the definition of two facade planes, the exact coordinates of all visible points are known, so it is possible to generate all other characteristic views, such as, for example, the top view (Fig. 7).

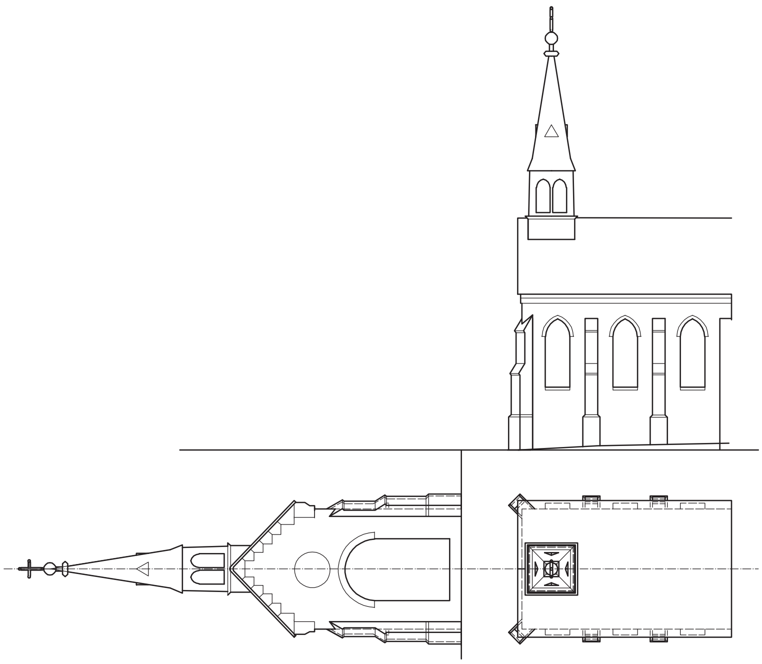

Figure 7: Extraction of top view based on two side views

3. Virtual reconstruction

A virtual reconstruction of an object can be done in several ways [4, 3, 8]. The optimal method is the one which is chosen in accordance with the present state. Since the Kljajićevo chapel lost its original form, some sort of virtual reconstruction was needed. Still, there are some remains which define its basic dimensions. We estimate that in this case the best procedure is the one which exactly describes the present state using terrestrial photogrammetry, with further upgrading the 3D photogrammetric model of the nonexisting parts on the basis of the restituted old photograph data [6].

3.1. Photogrammetric model of the present state

Photogrammetry is a method of determining exact coordinates of an object in space, by inspecting at least two central projections of its points, that is in two photographs. The photographs are calibrated using software. In this example the position and rotation of the camera is determined using pairs of corresponding points on the two photographs (compare

[5]). Then, a local coordinate system is defined, in which the exact coordinates of all visible points on the photographs are determined. The model is generated by the recognition of primitives and editing points, edges and solids. Textures (materials) were automatically generated from photographs and “pasted” onto the object. All this is done using terrestrial photogrammetry software.

Using this kind of modeling we obtain the precise three dimensional representation [2] of the Kljajićevo chapel’s present state (Fig. 8).

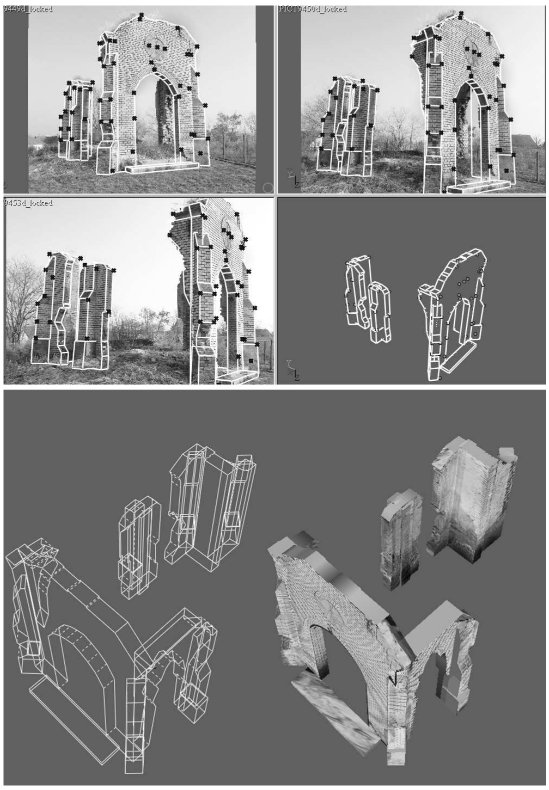

Figure 8: Photogrammetric model of the present state

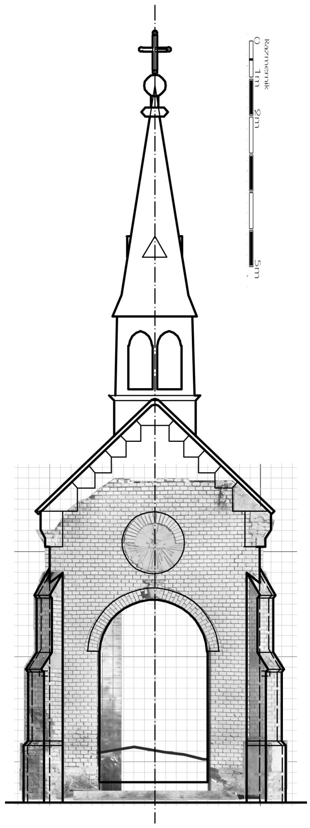

Figure 9: Combination of the photogrammetric model and the restituted views

3.2. Modeling of the nonexisting parts

Photogrammetric methods for generating three dimensional models are more economical and more precise than the manual restitution of a photograph. Nevertheless, for the photogrammetry we need at least two photographs of the same object. In addition, the angles from which the photographs are taken must be in accordance. Hence in the underlying case it is practically impossible to find input data for a photogrammetric modeling of nonexisting parts of the object.

Hence, for modeling the nonexisting parts the photogrammetric model is used as the base. The photogrammetric model is imported into the modeling and animation software and then correlated with the facade drawings which were obtained by the manual restitution of the photograph. Width and height were automatically and very precisely correlated (Fig. 9). But a small difference (about 3%) of the object’s length appeared. In the photogrammetric model a possible error in object’s length can appear because of the fact that in the remains there are no longitudinal walls in full length. When restituting the photograph there is also a possibility for an error in the determination of the object's length because the longitudinal facade is quite shortened and covered by buttresses in the photograph. That is why an average length of the object is accepted.

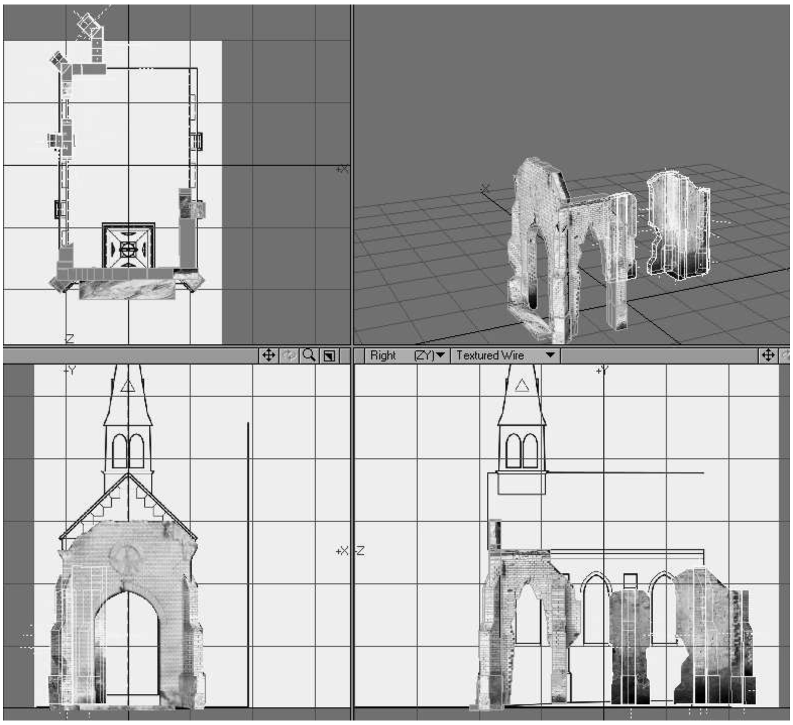

Figure 10: Modeling of non existing parts

After synchronizing facades obtained by the restitution of the photograph with the model obtained by photogrammetric modeling, the nonexisting parts are implemented, so that the complete virtual reconstruction of the chapel is obtained (Figs. 10 and 11)

4. Conclusion

A devastated sacral cultural heritage in the Danube area of Vojvodina, built in the period 1700–1950, was completely recorded and researched. The chapel in Kljajićevo is one of the most interesting examples. Its remains are collapsing rapidly since there is no preservation of this object, so that the original shape of the object is not recognizable from its remains.

In this paper a three dimensional virtual reconstruction was made in order to represent the object as it looked before, since 3D models are the kind of representation most similar to real 3D objects. The original object's shape data was extracted from an old photograph and used for upgrading the terrestrial photogrammetry model of existing remains. As a result we showed the complete virtual reconstruction of the object as it might looked before, with the possibility of a visual division between the present and the collapsed segments.

Virtual models are very useful when representing objects to users who can not reach the object for any reason. Especially, if it is impossible to preserve object itself, the virtual reconstructions may be the best solution for data storage since they make the object shape data complete.

Figure 11: Virtual reconstruction of Kljajićevo chapel

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