Single-image-based Modelling Architecture from a Historical Photograph

Jolanta Dzwierzynska 1

1 Department of Architectural Design and Engineering Graphics, Rzeszow University of Technology, Poznanska 2, 35-084 Rzeszow, Poland
joladz@prz.edu.pl

Abstract. Historical photographs are proved to be very useful to provide a dimensional and geometrical analysis of buildings as well as to generate 3D reconstruction of the whole structure. The paper addresses the problem of single historical photograph analysis and modelling of an architectural object from it. Especially, it focuses on reconstruction of the original look of New-Town synagogue from the single historic photograph, when camera calibration is completely unknown. Due to the fact that the photograph faithfully followed the geometric rules of perspective, it was possible to develop and apply the method to obtain a correct 3D reconstruction of the building. The modelling process consisted of a series of familiar steps: feature extraction, determination of base elements of perspective, dimensional analyses and 3D reconstruction. Simple formulas were proposed in order to estimate location of characteristic points of the building in 3D Cartesian system of axes on the base of their location in 2D Cartesian system of axes. The reconstruction process proceeded well, although slight corrections were necessary. It was possible to reconstruct the shape of the building in general, and two of its facades in detail. The reconstruction of the other two facades requires some additional information or the additional picture. The success of the presented reconstruction method depends on the geometrical content of the photograph as well as quality of the picture, which ensures the legibility of building edges. The presented method of reconstruction is a combination of the descriptive method of reconstruction and computer aid; therefore, it seems to be universal. It can prove useful for single-image-based modelling architecture.

1. Introduction

These days a three-dimensional reconstruction of architectural object becomes more and more actual and finds its application in various areas, including cultural heritage. Developing scanning system methods, photogrammetry and computer vision techniques give us powerful tools for rendering virtual space [1,2]. However, modelling architectural buildings by these tools can become impossible when the building is destroyed or the structure does not exist. In this case, the architectural form can be reconstructed on the basis of historical images, including photographs [3-7]. The reconstruction problem increases, when a number of images representing the building is not big. However, the most challenging reconstruction task is to reconstruct the object from a single image [8,9]. Depending on the starting assumptions and information about the object, the problem can be treated on different levels. It is especially hard in the case of reconstruction from a single historical photograph, when camera calibration is completely unknown and the accuracy assessment of the results is impossible due to nonexistence of the building. Then, only reconstruction based on projective geometry is
possible. However, some researchers developed approaches for obtaining camera geometry and its internal parameters from a single view to provide dimensional analysis and control of the reconstructed model [10,11].

In the paper, it is addressed the problem of the analysis and 3D modelling of architectural object from a single historical photograph. We consider this issue focusing on the case of New-Town synagogue located in the city of Rzeszow (Poland). The reconstruction methods developed by us are the extension and generalization of single view reconstruction methodology presented in [12].

We begin in section 2 giving a historical background of the case. Section 3 describes our attempt. Section 4 discusses the reconstruction methods applied and section 5 concludes.

2. Historical background
New-Town synagogue in Rzeszow is one of the most highlighted cases that belong to the architectural heritage of the city of Rzeszow. It was erected between years 1705 - 1712, according to the design of Giovani Baptiste Belotti [13]. During its long-term presence, the synagogue underwent several rebuilding transformations. That is due to the fact that the building caught fire on three separate occasions: in 1660, 1739 and 1842. After the last of these fires it was given new appearance. Originally, it was a monumental solid on a square plan covered with a pyramid roof. In the first half of the 19th century, the building was comprehensively renovated and the roof was rebuilt to a gable roof [13]. Stanislaw Patiatycki’s water-colour with the view of Rzeszow synagogues from XIX century, which is in collection of National Museum in Warsaw, displays the synagogue as a monumental building on a rectangular plan with a gable roof and with an outbuilding covered with a mono-pitched roof. New-Town synagogue building was strengthened from the outside with prominent buttresses because of its defensive character. Similar shape of the synagogue presents a photograph taken by Edward Janusz between the second half of 18th century and the beginning of 19th century, which will be a subject of our consideration, figure 1.

![New Town synagogue – photograph by Edward Janusz, from the archives of Rzeszow Gallery of Photography](image)
During the Second World War, Germans stationing in the city used the building as a stable and later as a warehouse. It burned down again in 1944. The synagogue’s ceiling collapsed, the walls crumbled and many elements supporting the attic were destroyed. Then, the synagogue underwent a fundamental reconstruction. In the years 1961 - 1965 it was rebuilt again and adopted for Art Exhibition Office. During this reconstruction, an initial architectural structure was modified to a large extend and a new storey was added. Due to this fact, the original look of the building was lost. On 24 January 1978, New-Town synagogue was included in the national register of monuments.

3. Reconstruction attempt

In our reconstruction attempt a historical photograph of New-Town synagogue in Rzeszow is taken into consideration. The photograph was taken by Edward Janusz and currently it is in the collection of Photography Gallery of the City of Rzeszow. Edward Janusz was a talented photographer, granted the title “Imperial and Royal Court Photographer” in 1898 [14]. Therefore, the preserved collection of his perfect photographs is undoubtedly of great historical value and can be a source of different scientific research.

3.1. Evaluation of photograph usefulness for a reconstruction process

The photograph is white and black and displays a synagogue building in a perspective view. The building structure bases on a cuboid which is covered with a gable roof and strengthened by several buttresses. The photograph’s quality seems to be good enough for reconstruction purpose due to the fact that the contour lines of the building and its details are visible.

Depending on the prior information available, the single image-based reconstruction problem can be treated on different levels. In this case camera calibration is unknown, however, some geometric relations between building edges, enable affine restitution. In addition, thanks to sort of Euclidean information our reconstruction process can be strengthened to Euclidean restitution. Due to the fact that the vertical lines such as wall and window edges appear parallel in the photo, we can state that the photograph presents a two-point perspective of the building. The additional information, that the building erected on a rectangular floor plan, with dimensions 20 by 30 meters will be a key in our metric reconstruction. There are two ways of retrieving the metric information of the object from the single image; automatic and manual. The first one is always preferable when the image exhibits a high resolution. As far as our photograph is concerned, the perspective geometry of the image is sharp. However, the border line between the ground and the building is not clear. Due to this fact, it will be applied a blended reconstruction method: partly manual and partly automatic. It will be used AutoCAD software for drawing and simple modelling, as well as Mathcad Professional software for calculations.

3.2. Reconstruction process

The first step in our reconstruction process is evaluation of geometric content of the photograph and establishing base elements of perspective as: a horizon line, a ground line, a principal point and the radius of the circle of depth. The horizon line is established by means of vanishing points which are the intersection points of the horizontal eave lines and a ridge line, as well as a window line. The horizon line is perpendicular to vertical lines of the building, which means that the photograph presents the synagogue in vertical perspective. It also confirms geometric accuracy of the photograph. In order to establish a principal point, it is used the angle between the diagonal of rectangular plan and one of its sides, see figure 2. A pair of vanishing points $V_1$ and $V_2$ defines a circle, intersection of which with the line $l$ gives a projection centre after rotation. It enables establishing a principal point $O_r$ and a circle of depth $o$. In most perspective projections, the ground line is an intersection line of the reference plane on the ground level with an image plane. However, in our case a perspective view of a base rectangle congruent and parallel to the ground rectangle is draw. Retrieving coordinates of the building characteristic points is based on it.
Figure 2. Establishing base elements of perspective in a descriptive way

A ground line $p$ is established as a straight line parallel to the horizon line and going through point $P$, see figure 2. Next, the reconstruction process is realized with computer aid. Measuring points for two perpendicular lines of the base rectangle are established and the image is adjusted to the 1:1 scale. The horizon height $h$ and the radius $r$ of the circle of depth is measured.

The position of the characteristic points of the building is calculated on the base on reconstruction formulas given in [12]. There, the perspective image of any point $F$ is a pair of projections $F^v(v, d)$ and $F^{OS}(v, do)$ determined by two Cartesian coordinates with axes $v, d$, figure 3.
Figure 3. Construction of the perspective image \((F^s, F^{os})\) of the given point \(F\)

Figure 4. Location of the Cartesian coordinate system of axes \(v\) and \(d\) in order to establish coordinates of the characteristic points of the building
On the base of it, we can determine the position of the reconstructed point \( F \) by parameters \( w(v, d_o, d) \) and \( k(v, d_o, d) \) defined by formulas (1) and (2).

\[
\begin{align*}
  w(v, d_o, d) &= \frac{h \cdot (d - d_0)}{h - d_0} \\
  k(v, d_o, d) &= \frac{h \cdot r(v, d_o, d)}{h - d_0}
\end{align*}
\]

However, for our case the equations (1) and (2) need to be modified due to the fact that they refer to the coordinates of building points included in a bottom ground plane. Here, we base on the coordinates of the characteristic points included in the base rectangle plane, which is lower than the ground plane. These coordinates are the orthographic projections of the characteristic points of the building received on the base plane. Therefore, the parameter \( w(v, d_o, d) \), which is the distance of the reconstructed point from the base plane, needs to be reduced by the distance between the ground plane and the base plane.

On the base of the above formulas it can be calculated the position of the characteristic points of the building in 3D Cartesian coordinate system of axes by means of Mathcad professional software. It defines the wireframe of the building, which is the basis of a solid model, figure 5.

![Image](image.png)

**Figure 5.** Our reconstruction result

4. Results and discussions
The success of the presented reconstruction method depends on the quality of the picture which ensures the legibility of building edges. Our reconstruction process proceeded well, although slight corrections were necessary. We reconstructed the shape of the building in general and two of its facades in detail. The reconstruction of the other two facades requires some additional information or the additional picture.

5. Conclusions
In the hereby paper, we focused on reconstruction of the original look of New-Town synagogue from the single historic photograph taken by Edward Janusz between the second half of 18th century and the beginning of 19th century. The photograph faithfully followed the geometric rules of perspective
therefore, it was possible to develop and apply the blended reconstruction method to obtain a correct 3D reconstruction of the building. The presented method of reconstruction was a combination of the descriptive method of reconstruction and computer aid. It can prove useful for single-image-based modelling architecture.

References

[1] M. Shashi, K. Jain, “Use of photogrametry in 3D modeling and visualisation of buildings”, ARPN Journal of Engineering and Applied Sciences, vol.2, pp. 37-40, 2007.
[2] D. Lu, Y. Pan, “Digital preservation of heritages; technologies and applications”, Zhejiang University Press, 2009.
[3] R. Hartley, A. Zisserman, “Multiple View Geometry in Computer Vision”, Cambridge University Press, vol. 2, 2000.
[4] I. Kalisperakis, M. Rova, E. Petsa, G. Karass, “On Multi-Image Reconstruction from Historic Photographs”, proceedings of of the XIX CIPAInternational Symposium, Antalya, Turke., pp. 212–219, 2003.
[5] A. D. Styliadis, “Historical photography-based computer aided architectural design: Demolished buildings information modeling with reverse engineering functionality.” Automation in Construction, vol.18, pp. 51-69, 2008.
[6] A. D. Styliadis, L. A. Photography –“Based facade recovery and3-D modeling: A cad application in cultual heritage “, Cultural heritage, vol.12, pp. 243-252, 2011
[7] J. Rosebush, D. Kushner, 3 dimensional reconstructions a case study of a perspective problem. Computer Graphics, 1983, Springer-Verlag Tokyo, 374 p.
[8] F. Fang, Y.T. Lee, “3D reconstruction of polyhedral objects from single perspective projections using cubic corner”, J. 3D Research, Springer-Verlag New York, vol.3, pp. 660-6674, 2012.
[9] C.K. Fong, W. K.Cham, 3D reconstruction from single perspective distorted line drawing image using vanishing points. Proceedings of 2005 International Symposium on Intelligent Signal Processing and Communication Systems, 2005, pp. 53-56.
[10] D. Gonzalez-Aguilera, J. Gomez-Lahoz, P. Rodriguez-Gonzalez, “ An automatic approach for radial lens distortion corection from a single image”, IEEE Sensors Journal, vol.11, pp. 956-965, 2011.
[11] B. Caprile, V. Torre, “Using vanishing points for camera calibration”, International Journal of Computer Vision, vol.4, 127-139,1990.
[12] J. Dzwierzynska, “Reconstructing Architectural Environment from a Perspective Image”, Procedia Engineering, vol. 161, pp. 1445-145, 2016.
[13] E. Dawidziak, “Synagogues in Rzeszów—yesterday and today”, Renovation and Monuments, vol.3, pp.162-171, 2015. (Polish)
[14] I. Gałuszka, “History of photography in Rzeszów”, Renovation and Monuments, vol.3, pp.162-171, 2015. (Polish)