From Image to Investigation 3D Reconstruction with Perspective Restitution

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Abstract. The memory of hundreds gone buildings is preserved by few photographic images. Perspective restitution with digital representation tools can be used today to reconstruct these buildings directly in 3D space. Digital representation has overcome many limitations that affected perspective restitution in the pre-digital era. In this paper the inner space of the church of San Michele in Trapani, destroyed at the end of the 50', is reconstructed with the aid of three period photographic images. Some architectural elements that escaped destruction and are today located in a new church near Trapani have been surveyed with laser scanning and SfM photogrammetric techniques. Surveyed elements provided the metric information needed to scale the reconstruction model and to verify the accuracy of perspective restitution. SfM photogrammetric techniques have been furtherly used to generate and orient in 3D space a panoramic image of the survived elements in their present location; the image can be overlaid to the reconstruction model and thus display these elements in their original location inside the lost church.

Keywords: Perspective restitution · San Michele in Trapani · 3D reconstruction

1 Introduction

1.1 3D Reconstruction from Photos

The reconstruction of gone, or never built, buildings has ever been one of the privileged subjects of digital representation. Many experiments have been addressed to the reconstruction of buildings whose original layout has changed along the centuries, both for human actions, e.g. renovation programs or wars disasters, and for natural events, e.g. earthquakes, decay, or the like.

One of the peculiar features of the famous reconstruction of the Parthenon realized in 2004 by Paul Debevec was the integration of digital surveying and representation for the documentation of the ruins of the Parthenon on site and the recontextualization of its architectural decorations and sculptures exhibited at the British Museum in London.

The laser scans of the Parthenon's marbles in London were integrated to the 3D model of the ruins of the Parthenon, thus displaying the building in its magnificence and helping the comprehension of the shape and function of these decorative elements.

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Many relevant buildings are definitely gone and most of them are not documented by surveys or drawings; some gone buildings have yet been photographed before their final disappearance; this is why the memory of hundreds gone buildings is today preserved by few photographic images.

Digital representation can be effectively used to reconstruct gone buildings from photos: it is well known that a photographic image, save those taken with wide angle lenses, can be compared to a perspective cast.

Perspective restitution, i.e. the inverse path of perspective drawing, is a well-known problem for scholars in Descriptive Geometry.

In the past this technique has been used to reconstruct the perspective layout of paintings or trompe l'oeil.

In the pre-digital era perspective restitution has rarely been used to reconstruct a building from a photo because the results of restitution were usually unsatisfactory.

Plans, fronts or profiles resulted strongly inaccurate and perspective restitution could not stand the comparison to other photogrammetry techniques.

Digital representation can overcome many of the limitations that made perspective restitution with traditional drawing tools so inaccurate and useless.

Digital representation tools can detect a vanishing point even if it is located at a great distance from the image frame; such capability is particular useful in photos of architecture, where the point of view of vertical lines is often very far from the image barycenter, due to the attitude of photographers to mitigate the convergence of vertical lines.

In the past the furthest vanishing points were ignored because the length of rulers did not allow to reach them. The availability of the vanishing point of vertical lines makes perspective restitution much easier and precise; nonetheless, in the rare images of pre-digital perspective restitution from photos, vertical lines were usually assumed as parallel lines [3].

Digital representation allows the reconstruction of a building directly in 3D space. In the past, perspective restitution operated by means of revolutions: plane figures (mainly fronts) were revolved onto the picture plane and restituted by means of homology. Today projecting lines can directly fix the position of a point in 3D space and the correspondence between 3D reconstruction and the photographic image can be visually checked.

Perspective restitution from photos can be considered as the entry level of photogrammetry; like any other photogrammetric technique, it can directly restitute the proportions of the pictured elements; the reconstructed elements are not scaled nor oriented and cannot be used to extract the dimension of the pictured building.

If the size of one or more elements pictured in the image is known, then the photogrammetric model can be scaled and measures can be extracted.

The photogrammetric process is usually classified in two steps: inner (or intrinsic) and outer (or absolute) orientation. Inner orientation is the process that leads to the reconstruction of the mutual position of the center of projection and the image frame. When a photo is taken with a standard camera, the center of projection lies on the straight line that intersect the image frame at right angle in its barycenter, at a distance that corresponds to the focal length of the lens. The barycenter of the image is the 'principal' point of the perspective scheme.

In perspective restitution the solution of inner orientation can be performed in many ways; when three couples of mutually orthogonal lines are pictured in the photographic image, the solution is given by the ‘three spheres’ solution. If the three vanishing points of mutually orthogonal lines are the vertexes of a triangle, it is possible to model three spheres whose diameters are the sides of the triangle. The intersection point of these spheres will be the center of projection [6, p. 23].

Sometimes the projection line orthogonal to the picture frame does not intersect the image in its barycenter. When the image is taken from a book, such occurrence may be due to one or more trims made to fit the image to the book layout; when the image has preserved its original shape, the eccentricity of the ‘principal’ point can be due to the use of non-standard cameras, i.e. ‘view’ cameras, that allow to move the lens up and down or to rotate it, thanks to a peculiar flexible connection between the lens and the camera body.

These cameras were used, and are still used, by professional photographers, for a better control on focus and to mitigate the convergence of vertical lines.

The images used in this research work are taken from a published paper and could be therefore affected by both alterations.

Outer orientation, as stated above, can be performed when metric data of pictured elements are available. When a part of the gone building has survived destruction, it is possible to develop a workflow that echoes Debevec’s work on Parthenon. The 3D survey of the survived element provides the metric data needed to scale and orient the photogrammetric model; the surveyed elements will finally become a part of the reconstruction model.

1.2 Related Papers

Books dedicated to perspective restitution are almost rare. Manuals on descriptive geometry usually do not discuss this subject, since it is considered the way back of the perspective construction process.

Manuals on photogrammetry do the same, since they consider perspective restitution too rough and inaccurate.

A comprehensive discussion on this subject, with a detailed historic review and a particular attention to the use of perspective for the restitution from photos, is the content of a book entirely dedicated at perspective restitution [6]. The final chapter of the book reports an interesting pioneering application of digital representation to the restitution from photos.

In the last decades of the past century, scholars in computer engineering tried to automate the process of perspective restitution. The most interesting results were achieved by Van den Heuel [9] and by Paul Debevec [2]. Further experiments aimed more recently at the automatic extraction of 3D models by a single image [1].

The quoted researches, though surely interesting, seem today discontinued and no software tool is today available for automatic perspective restitution.

Recent papers have discussed perspective restitution from photos with the use of digital representation tools and a non-automatic workflow. Inner orientation is solved with the ‘three spheres’ solution and digital tools are used to extract planar drawings from the pictured scene [5].

More recent studies discuss the use of perspective restitution to calculate inner photos orientation [4] and propose the restitution of planar figures (fronts, or the like) [7]; in these papers no use of 3D modelling tools is proposed or discussed.

2 The Case Study

The case study is the gone church of San Michele in Trapani (Sicily); San Michele was a small hall church, presumably built as a private chapel annexed to a noble palace. The church, as we know it from the precious study published by the historian Michele Scuderi [8], showed the traces of elements that clearly belonged to different historic periods; it is possible to argue that this church was modified and 'renewed' along the centuries (Fig. 1).

Fig. 1. Period photos from the paper of Scuderi [8].

The BW photos that illustrate the study show a ruined and abandoned church, with the nave uncovered; the only area that seems partially preserved is the presbyteral area; this part of the church is an evidence of the penetration of Renaissance style in Sicily in the 15th century and had to be a relevant part of the renovation of the previous church. The photo shows a three-bay area with rounded arches and an hemispherical dome on rib vaults. The church was finally demolished few years later the publication of the paper of Scuderi. The site was occupied by a new residential building.

Some elements escaped the destruction of the church and were moved to a 'new' church of San Michele, located in the peripheral area of Trapani: the columns that bear the central arch of the presbyteral area; the pilasters and the arches of the southern front of the hall, with a couple of windows that opened on the higher part of the wall; the marble statue of San Michele that clearly shows the influence of the Renaissance style in sculpture as well.

The new church of San Michele is a three-bay church; pilasters and arches from the southern front of the hall have been mounted on the wall of the left aisle; to the external face of this wall, facing an open courtyard, are attached the columns of the central arch of the presbyteral area; the statue of San Michele is located at one end of the right aisle, close to the entrance (Fig. 2).

Fig. 2. The elements that survived destruction inside the 'new' church of San Michele.

3 Proposed Methodology

3.1 Survey

The first step of the research work addressed the survey of the residual elements of the church; all elements have been surveyed both with laser scanning and with SfM photogrammetric techniques.

Laser scans have been registered and then rotated to make the vertical surfaces of the church parallel to XZ or YZ reference plane. Laser scans have been used to extract the coordinates of features that could be easily detected in the photogrammetric model as well (Fig. 3).

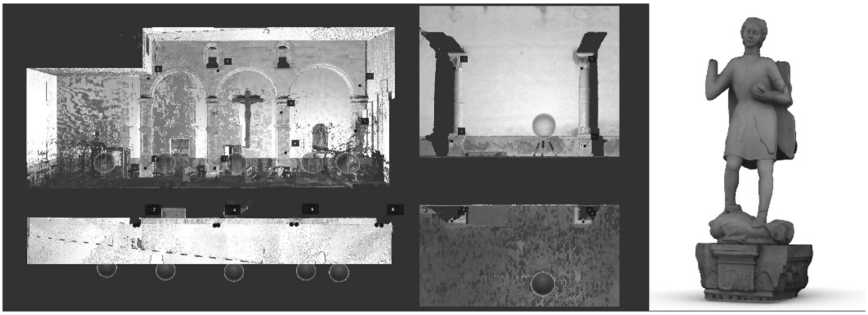

Fig. 3. Survey of the survived elements.

SfM photogrammetric processing followed a well-known workflow: in the first step photos have been aligned; the following step was dedicated to the creation of markers, i.e. peculiar points well visible in an adequate number of photos. The coordinates of these points, extracted from the laser scans, were uploaded and the software could calculate the error due to the discrepancy between the proportions of the photogrammetric model and the proportions documented by laser scans. The calculation, referred to the wall with pilasters and arches, produced an average error of 1 cm; this error has been considered acceptable for the purposes of the research; similar calculations referred to the columns of the arch and to the statue of San Michele were lower than 5 mm.

The final step of the photogrammetric process addressed the calculation of the mesh model of the surveyed elements; meshes have been finally textured.

The textured meshes have been processed to remove all external elements and isolate the only parts that were originally located in the lost church of San Michele.

The model of one column has been used to scale the perspective restitution model, whereas the model of the pilasters and arches verified the accuracy of the restitution process.

3.2 Perspective Restitution

The first image that has been used to start the restitution process is the photo of the arches and columns that separate the presbyteral area from the nave; the vanishing points of the horizontal lines that are respectively parallel and orthogonal to this front have been detected and named *Fr’* and *Fs’*; the vanishing point of vertical lines resulted at a great distance from the image frame. The ‘three spheres’ solution, applied by means of circles drawn on the image plane, provided the position of the center of projection, and thus the solution of inner orientation (Fig. 4).

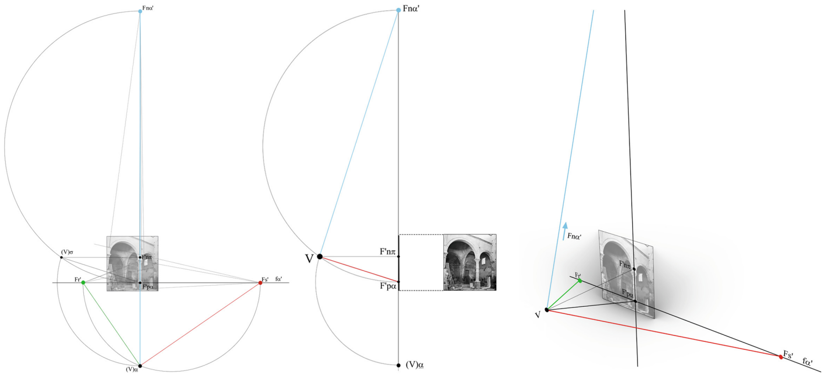

Fig. 4. Inner orientation and 3D perspective scheme.

The projection line orthogonal to the image plane intersected the photo in one point that does not match the barycenter of the image; the reasons that can explain such occurrence have been discussed above; finally, since the vanishing point of vertical lines is not at infinite, we know that the principal point will not lie on the horizon line.

The perspective layout has then been moved in 3D space; the center of projection is now in front of the image and the projection lines to the vanishing points appear in their proper direction. At this stage the image plane is vertical and the plane detected by the horizontal projection lines to *Fr’* and *Fs’* is inclined.

In the following steps the perspective scheme is rotated twice: the first rotation makes the projection line to the vanishing point of vertical lines parallel to Z axis.

This rotation makes the image plane inclined and the direction of the projection line to the principal point shows the inclination of the shooting axe when the image was taken. The plane made by the projection horizontal lines to Fr’ and Fs’ is now parallel to XY reference plane.

The second rotation, around Z axe, makes the horizontal projection lines to Fr’, corresponding to the horizontal section of the front of the presbyteral area, parallel to X axe; this way, the front becomes parallel to XZ reference plane (Fig. 5).

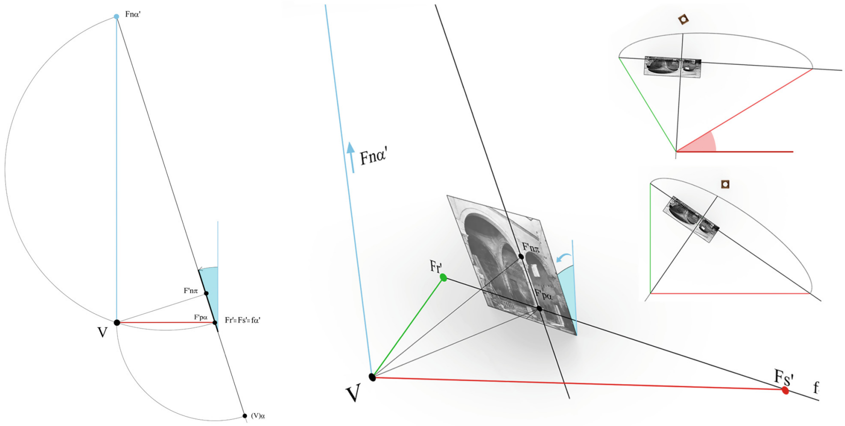

Fig. 5. Rotation of the perspective scheme.

The final step of outer (absolute) orientation aimed at scaling the perspective scheme; such operation has been performed with the aid of the 3D model of the column at the right end of the central arch of the presbyteral front; the projection lines through the images of one corner of the abacus and one corner of the plinth have been drawn in 3D space.

Both points lie on a vertical line and the orientation of the laser scans of the columns, and thus of the SfM photogrammetric model, had been designed to make the front of the plinth and abacus parallel to XZ reference plane.

The distance between these points has been measured and a segment with this length has been drawn on the projection line to the vanishing point of vertical lines; one end of the segment is V; at the opposite end a line, parallel to the projection line through the plinth’s corner, has been positioned; this line intersects the projection line through the corner of the abacus in one point; this point is the reconstruction in 3D space of the corner of the abacus (Fig. 6).

In the final step of outer orientation the 3D model of the column has been uploaded and positioned to match the corner of the abacus and the reconstructed point; the effectiveness of the perspective scheme has been visually verified with the aid of a camera positioned in the point of view; the application of a transparency factor allows the visual verification of the match between the column pictured in the image and its ‘real’ 3D model (Fig. 7).

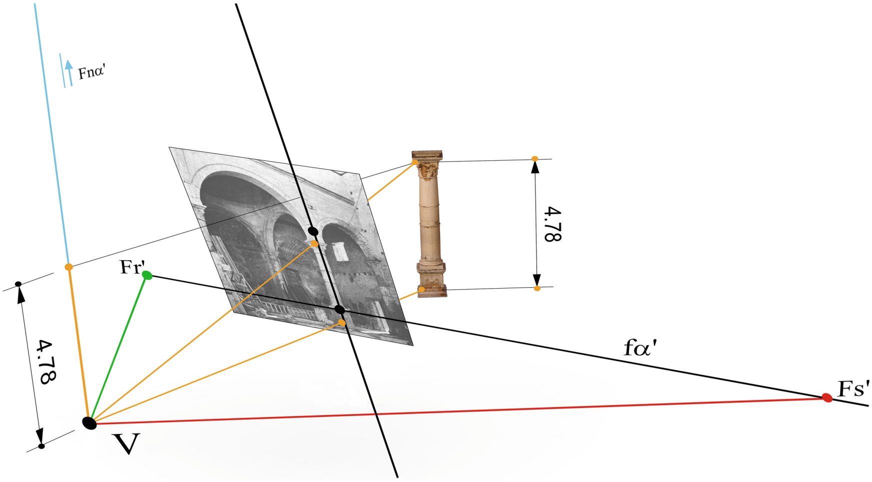

Fig. 6. Absolute orientation of the perspective scheme.

Fig. 7. Visual check of the match between image and 3D object.

At this stage the restitution process is completed and the reconstruction work can start.

A final observation must be dedicated to the use of more images for a 3D reconstruction; in this study the inner space of the church has been reconstructed with the aid of three images; the inner orientation of the second image has followed the discussed workflow; the outer orientation has been calculated to make the second perspective scheme referred to the first perspective scheme. Such result can be reached if one or more common elements appear in both images; a reconstructed element from the first image will lead the external orientation (rotation, scaling) of the second perspective scheme; this way the elements reconstructed from the second image will be properly attached to the previously ones. The same workflow has been used for the outer orientation of the third image, that resulted linked to the first one (Fig. 8).

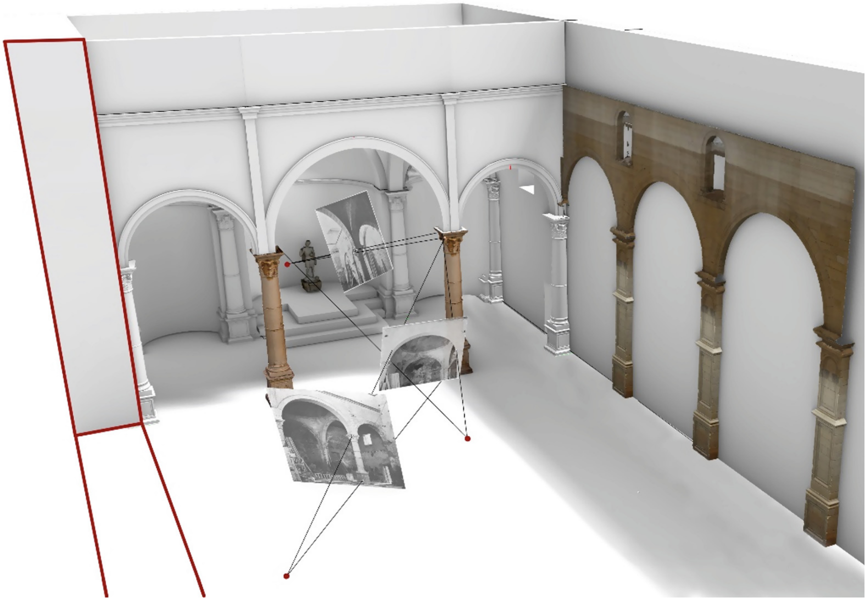

Fig. 8. The images used for the reconstruction of the inner space of the church.

4 Conclusion

The result of the reconstruction process is the 3D model of the inner space of the gone church of San Michele as it is pictured in the period photos published by Scuderi few years before the demolition. The fragments that survived the destruction have been placed into the 3D reconstruction model; the 3D model of the column provided the scale factor, whereas the 3D model of the pilasters and arches tested the accuracy of the restitution and the reconstruction process.

A final experiment addressed the fruition of the 3D reconstruction model; the proposed solution aims at connecting this model to the elements that survived destruction. Inside the 'new' church of San Michele some photos have been taken with a mirrorless camera mounting a wide angle lens; the camera was mounted onto a Nodal Ninja mechanical bracket. The photos were uploaded in the photogrammetric model of the pilasters with arches and the position of the center of the panoramic image has been referred to the same coordinate system. A sphere has been modeled and textured with the panoramic image and the match between the panorama and the corresponding view of the 3D reconstruction has been validated (Fig. 9).

A person inside the new church of San Michele, standing approximately on one point along the middle axe of the nave, could view the arches in their original location inside the gone church.

Perspective restitution is today capable to reconstruct gone buildings with the aid of few period photos; such capability opens new opportunities for the study, the knowledge, the fruition and awareness of our cultural heritage. The method proposed in this study can be applied to a wide range of case studies. The reconnection between fragments and

Fig. 9. The panoramic image positioned inside the church.

their original location, experimented with success by Paul Debevec in 2004, supports the outer orientation of perspective schemes and the comprehension of the shape and function of these elements. Finally, these elements, located in museums or in other monuments, can be used as a reference for the realization of AR or VR solutions where the 3D reconstruction model appears connected to the fragments.

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