SOPHISTICATED USE OF VIRTUAL SHAPES OF ARCHITECTURE + VISUALIZATION OF QUALITY

W. Karel

Institute of Photogrammetry and Remote Sensing Vienna University of Technology Gußhausstraße 27-29 / 122, 1040 Vienna, Austria wk@ipf.tuwien.ac.at

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ABSTRACT

The object of this project was the creation of a precise photorealistic model of the Romanesque church of San Juan del Hospital in Valencia, Spain. The church building should be modelled with a geometric accuracy, a level of detail, and a texture resolution of 5cm, the neighbouring pavilion even with 2cm, respectively. To reach this with economically reasonable efforts despite the complex geometry and difficult accessibility, virtual shapes of architecture (also called 'fictitious observations' or 'Gestalts') were integrated into the modelling process. The application of virtual shapes takes advantage of the fact that even ancient buildings were created on the basis of a plan, delimiting the object mainly with planes and straight edges. This means that in the simplest case, it can be presumed that points on the same face of a wall reside on a (vertical) plane. More sophisticated surfaces and curves can be applied to arcs and cupolas. The same virtual shapes were used for all objects built the same way (e.g. columns). Furthermore, symmetries were considered. Many areas on the building could only be pictured in one photograph. Thus, photogrammetric or polar spatial intersection was impossible there. Nevertheless, vertices within these areas could be determined by usage of shape assumptions. Additionally, the application of virtual shapes enhanced the determination of points on lines in poorly textured areas. The extensive use of virtual shapes is not the only innovation in this project, but also the visualization of the photorealistic model. Users may not only inspect the model itself, but also the modelling quality as a meta-information. Having activated a model vertex, the quality of point determination is visualized numerically by the three coordinate standard deviations and by the number of observations that were employed to determine the point. Moreover, quality is viewed graphically by the point's photogrammetric and tachymetric observation rays in space and by fading in the point's error ellipsoid.

1. INTRODUCTION

This publication deals with the two most interesting aspects of a project dedicated to the creation of a photorealistic model of the Romanesque church of San Juan del Hospital in Valencia, Spain. The task was to create a spatial model with rectified texture in the VRML97 format, complying with two preconditions:

- Model Quality: the standard deviation of model vertices, the level of detail, and the pixel size of the rectified texture of the church model should be better than 5cm. The according value for the model of the neighbouring pavilion amounted to even 2cm.
- Efforts: by all means, the demanded model quality should be reached, but all available methods should be applied to keep efforts as little as possible.

For photogrammetric data capture, there was a digital amateur camera at hand, with a resolution of 6.3MPx and a lens with a variable focal length of 15 to 30mm. Activities started with the calibration of the camera, using a known field of control points. This method was preferred to an on-the-fly calibration because of three matters:

- Vegetation hindered the sight to tie-points, and the surrounding buildings did not offer access to necessary points of view for a stable block.
- Not only the mean interior orientation of the camera was of interest, but due to the variable, non-fixable objective, also the recoverability of the interior orientation after transportation, etc. should be examined.
- The application of virtual shapes was planned. This can complicate an on-the-fly calibration of a camera.

All calibration photos were taken with the same setting of the focal length. After the capture of various images, the focal length was shifted and then restored again to the original setting. Subsequently, the rest of calibration photos was taken. Now, an interior orientation was computed for each of the two subsets of images. Statistical tests proved a significant difference between the focal lengths of the first and the second set. For that reason, the block of San Juan was stabilised globally by tachymetric measurements. To comply with the stated precondition of model texture pixel size, special rules were derived for the realisation of photogrammetric data capture. These rules allow for the computation of possible camera orientations that adhere to a minimum pixel size all over a model face. The second precondition of minimum efforts led to the application of virtual shapes of architecture, which were integrated into the modelling process with great success. Virtual shapes employ the fact that even historic buildings were constructed on the basis of a plan, wherefore edifices are delimited mainly by planes intersecting in straight lines, and by curved surfaces of higher degrees with curved lines as intersections. Virtual shapes of architecture are the idealized mathematical description of these object parts and they were integrated into the block adjustment. This way, observations could be saved to accelerate the creation of the photorealistic model. By combining and reusing them, and by stating interrelations between them, production could be accelerated further. Frequently, the spatial intersection of model vertices was impossible due to occluding vegetation or hindered access to necessary points of view. Nevertheless, the application of virtual shapes permitted the determination of these points.

Virtual shapes were also used to ease the determination of points on edges in poorly textured areas by substituting the search for corresponding points in different images by measurements of arbitrary, non-corresponding points. Due to software limitations, it was necessary to model curved areas with planes. But the manual determination of these inflexion points would have resulted in evil appearance of symmetrical curves. This problem could be solved with virtual shapes, too. This first issue of applying virtual shapes of architecture in order to accelerate and enhance the creation of photorealistic models is discussed in section 2, and examples from the project of San Juan are presented. Additional applications are debated there as well. They do not serve to enhance or accelerate model creation, but they may be applied to answer questions like the verticality of a wall, the deformation of a cupola, or the accuracy of construction. In the final block of San Juan, various types of observations and unknowns were integrated. There took part 6500 image, 1500 polar, and 3800 shape observations. 7000 unknowns were determined, namely 69 photo, 21 tachymeter, and 9 shape orientations, 1500 point positions, and 1650 form parameters of shapes. With the used analysis software package ORIENT / ORPHEUS, all observations and unknowns could be adjusted simultaneously, wherefore all correlations could be considered, the most probable results could be achieved, and even corresponding qualities could be computed correctly. The final model consists of 1500 vertices, 2900 edges, and 1300 faces. Before its export into the VRML97 format, a coarse radiometric adjustment of images was done. Furthermore, requirements to present the model on the internet were regarded. In the exported, static model, further dynamic features were programmed:

- To decrease memory usage, object parts that are far away from the observer are displayed with less detail.
- An animated walkabout through the model may be started.
- Historic information may be viewed.
- The observer's position and attitude may be indicated both numerically and graphically.
- The length and attitude of a measure line between points on the model may be faded in.

Photorealistic models have become an integral part of heritage documentation. Models are created with diverse methods, resolutions, and levels of detail. But usually, the model's quality is not presented to the user, or it is not even known. But the value of a coordinate without knowledge of its quality is questionable. Thus, the visualization of model quality was programmed, too, which constitutes the second innovation presented in this article. The subject of both numerical and graphical visualization of model quality is treated in section 3. Finally, the benefits and handicaps of the utilized techniques and the visualization of quality are discussed in section 4. Readers interested in further explanations of these issues are asked to confer the project report (Karel, 2004). Moreover, (Kraus, 1997, pp. 25-34) gives detailed explanations of virtual shapes, while (Waldhäusl, 1994, pp. 426-429) gives further information on quality requirements.

2. VIRTUAL SHAPES OF ARCHITECTURE

2.1 Definition

A virtual shape of architecture is the idealized mathematical description of a face (e.g. plane, cylinder) or an edge (straight line, curve) of a building. The describing function is an im-or explicit polynomial in a local coordinate system. This local coordinate system is referenced to the project coordinate system by a 3-D congruency transformation. Points are assigned to virtual shapes. For these members of a virtual shape it is observed that they reside on the shape ± some accuracy. The unknowns of a virtual shape are determined by their member points in the block adjustment. These unknowns are:

- in general six unknowns of the congruency transformation between the local and the project coordinate system (translation: 3, rotation: 3) and
- the form parameters of the polynomial itself.

Setting the right kind and amount of unknowns to constant values is essential. On the one hand, adjusting too many unknowns may produce singularities in the adjustment. On the other hand, leaving free too little or wrong parameters may constrain the member points to a false form. The local coordinate system or its mirrored representation may be used by several virtual shapes. Likewise, groups of virtual shapes may utilize the same form parameters. Moreover, interrelations between different shape coordinate systems may be defined. As stated above, the observation that a point is member of a virtual shape does not constrain the point to lie exactly on the shape, as some amount of accuracy / uncertainty is inherent to every observation. Most often, it will be easy to estimate this accuracy quite well by experience. Additionally, it is possible to check and refine assumed accuracies with the statistical method of Variance Components Analysis. For more information on this calculus, cf. (Kraus, 1997, pp. 231-234).

2.2 Applications for Accelerated Creation and Model Enhancement

The applications presented in this subsection facilitate object reconstruction, i.e. they either permit the acceleration of model creation, or they enhance the appearance of the final model.

2.2.1 Main Application: Planes: Most faces of a building form parts of planes. In particular, the faces of walls use to be parts of vertical planes. Moreover, interrelations between these planes exist, for instance right angles between adjacent faces. Having defined the corresponding vertices as member points of these virtual shapes, other observations (image, polar, etc.) may be omitted in order to save time. Thus, model creation is accelerated significantly. See an example for this application from the San Juan project on Figure 1.

Figure 1. Planes (mostly vertical) as the main application of virtual shapes. Model vertices were defined as member points of the corresponding plane shapes. This way, other, more time-consuming observations could be saved, and model creation was accelerated. Shapes with similar colours were defined as parallel.

2.2.2 Faster Modelling through Multiple Usage of Sets of Virtual Shapes: Many parts of an edifice are built the same way (e.g. columns, arcs of a vault). For all similar object parts, a single set of virtual shapes shall be used. This way, the creation of a photorealistic model is accelerated, because observations can be omitted. As denoted above, this does not mean that similar object parts are constrained to the identical form, because virtual shapes hold some accuracy or uncertainty, respectively. Therefore, the resulting 3-D model vertex positions will be an adjusted mean of other observations (photogrammetric, polar, etc.) and of the geometry stated by the

virtual shapes. In the pavilion of San Juan, there exists a group of eight broad and a group of six narrow columns. For each group of columns, the same set of virtual shapes was adjusted. Also, the vertical plane of symmetry of the columns was considered: the local coordinate system of all shapes of the left side of a column was defined in the plane of symmetry.
Reusing these coordinate system in a mirrored representation, the shape parameters for the left side could be applied to the shapes of the right side, too. See figure 2 and figure 3 for better understanding.
Moreover, interrelations between these sets of virtual shapes were applied. While the broad columns were placed at the corners of a rectangle, the columns of type 'narrow' were arranged at the vertices of an octagon centred under the cupola, see Figure 4.

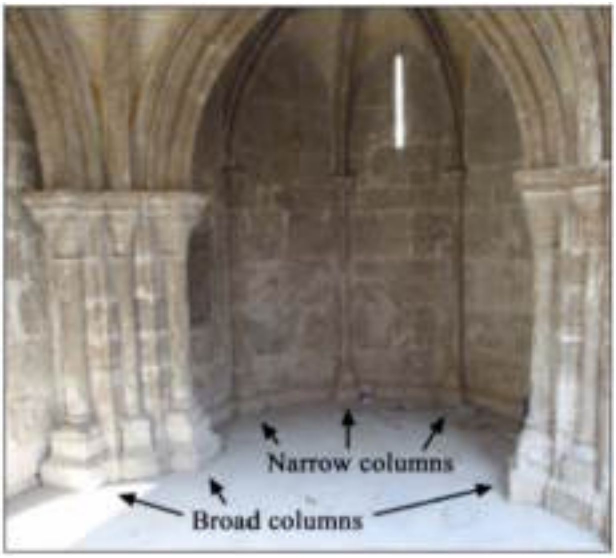

Figure 2. In the pavillon of San Juan There exist two types of columns. By applying the same set of virtual shapes to all columns of same type, model creation could be accelerated further

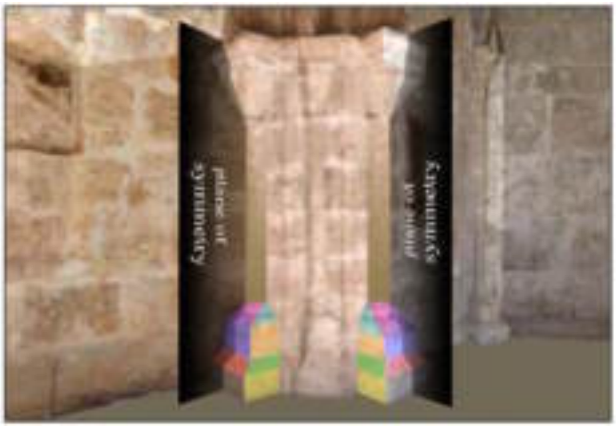

Figure 3. Two columns of type 'broad'. The same set of virtual shapes was applied to both. In the definition of the set f shapes, the vertical plane of symmetry was considered.

2.2.3 Model Completion: The spatial intersection of a model vertex requires observations from at least two different points of view. Due to hindered access to a second point of view or because of occluding vegetation, there may only be possible one observation ray. Using virtual shapes, such a point can still be determined as the intersection of a single observation ray with a virtual shape.
Moreover, vertices in curved areas may be defined much better indirectly, by surroundings points. Such a point can be determined as the intersection of virtual shapes among themselves (see Figure 5). Furthermore, areas of the edifice may not be observable at all because it is not possible to access the right point of view. In this case, virtual shapes may be used to estimate the model geometry. Neverthless, these areas will be modelled without texture.

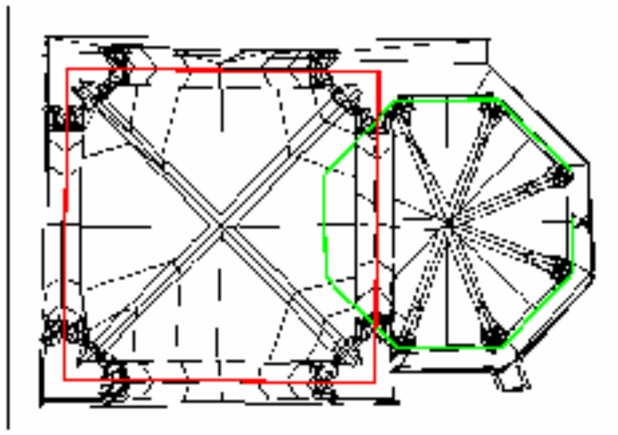

Figure 4. Ground view of the pavillon. Interrelations between sets of virtual shapes: the local column coordinate systems of the broad columns were arranged at the corners of a rectangle (red), while the narrow columns were placed at the vertices of an octagon centred under the cupola.

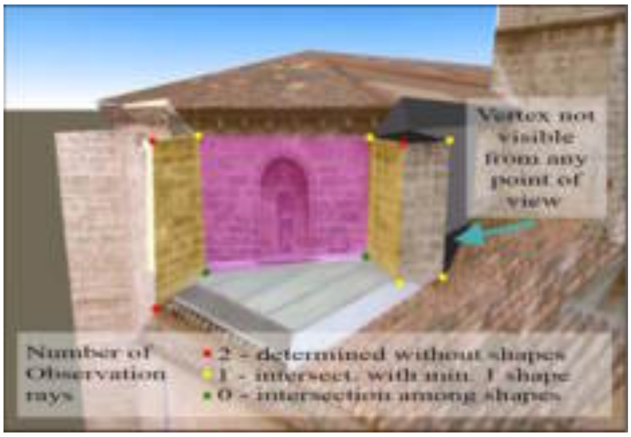

Figure 5: Various model vertices could only be observed from one point of view, which impeded the spatial intersection of these points. But using virtual shapes, they could still be determined as intersections of observation rays with shapes. Moreover, vertices in curved areas were better defined indirectly by neighbouring points. These vertices were determined as intersections of shapes among themselves. This technique of exclusively intersecting virtual shapes was also applied to estimate positions of points that were not visible at all due to hindered access to the right point of view.

2.2.4 Enhanced point determination on Straight lines and curves: In poorly textured areas, finding corresponding points can be quite difficult and time-consuming, which may result in inaccurate model vertices and gross errors. Along straight lines and curves, virtual shapes can help significantly, because they allow for using arbitrary, non-corresponding point measurements. Look at Figure 6 for an example application at San Juan.

Figure 6: Enhanced determination of points on a curve through application of virtual shapes. Gross errors are avoided and time is saved, because usage of virtual shapes along curves allows arbitrary, non-corresponding point measurements.

2.2.5 Symmetrical model inflexion points for symmetrical real-world curves: Although VRML is capable of handling general surfaces and curves, the used analysis software is trained to process planar models only. Therefore, it was necessary to model curves as polygons. But if the determination of the inflection points is done manually, then symmetrical parts of real-world curves will appear to be different in the model. This effect can be avoided by intersecting virtual shapes among themselves, see Figure 7.

Figure 7: Due to the restriction of planar model faces, real-world curves had to be modelled as polygons. But determining the flexion points manually would have resulted in asymmetric appearances of symmetrical parts of arcs. This could be avoided by intersecting the curved virtual shapes of arcs with horizontal planes.

2.3 Applications for Construction Examination

The applications of virtual shapes presented in this subsection allow for examining the properties of a building, they do not relate to the creation of a photorealistic model. Common to these applications is the matter that two consecutive adjustments are necessary, as the employed shapes must not influence point positions. In the first adjustment, virtual shapes must not be employed, thus all vertices under investigation have to be determined exclusively by 'real' observations (photogrammetric, polar, etc.). In the second adjustment, object point positions are kept fixed, only the virtual shape orientations and form parameters are adjusted. Nevertheless, the points' standard deviations and correlations computed in the first adjustment have to be considered in the second one. Preferably, points should be distributed equally all over the surface / edge in order to get correct and reliable results.

2.3.1 Attitude analysis: Frequently, the question comes up, whether a wall is still upright, or whether a whole building has become inclined due to a subsidence of the fundament. Using virtual shapes, even these questions can be answered. In order to check e.g. the verticality of a plane wall, points equally distributed on the wall have to be determined by 'real' observations in a first adjustment. Then, one has to define a plane virtual shape with unknown attitude, and the points must be included. In the following second adjustment, the only unknowns will be the shape rotations, while the point positions will not be affected. The computed inclination of a wall will never be exactly vertical, so the resulting rotation angle of the virtual shape should be checked on significance using a statistical test. Various other aspects may be examined, like parallelism, rectangularity, symmetry, and so on.

2.3.2 Deformations: If a virtual shape constitutes the planned form of a part of an object, the discrepancies between the shape and its corresponding building part may be employed for deformation analysis. Once again, object points as equally distributed as possible have to be determined in a first adjustment without usage of virtual shapes. Then, the shape has to be defined and the points have to be included. In the subsequent adjustment, once again only the shape is adjusted, not the point positions. Especially a plot of the distances between the object points and the shape along the normal of it may be very helpful to determine and evaluate deformations, see Figure 8.

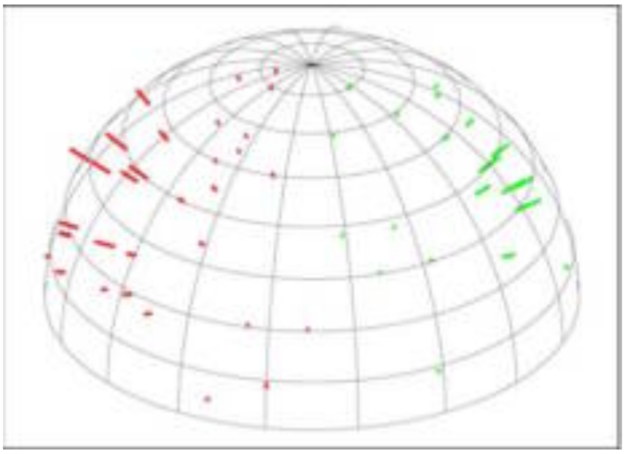

Figure 8: Deformation of a cupola. The planned form of a hemisphere is sketched in black. Real-world cupola points lying outside of it are marked with vectors in red, while points residing inside of the hemisphere are drawn in green. Obviously, the discrepancies are not random.

2.3.3 Accuracy of Construction: With the help of virtual shapes, even the accuracy of the realisation of a plan, i.e. the geometric quality of construction becomes computable. The distances/residuals computed in section 2.3.2 can be averaged to a standard deviation of construction. Different measures are thinkable: from the deviation from planarity of a single wall up to the deviation from a set of interrelated virtual shapes covering the whole building.

3. VISUALIZATION OF QUALITY

Usually, quality measures of a photorealistic model are not presented to the user, although quality is essential to evaluate such a model. Furthermore, exact quality measures are indispensable in deformation analysis. Reasons why quality is not presented may be:

- users are not conscious of the importance of quality measures and / or
- producers are not able to determine them correctly.

In order to compute quality measures correctly, all correlations between the observations have to be considered. For instance, polar measurements of control points are usually adjusted separately in advance due to software limitations. In the subsequent adjustment of photogrammetric observations, only the control point coordinates are introduced, disregarding correlations between the polar and the photogrammetric observations. This results in underestimated, too accurate standard deviations. In the project of San Juan, all correlations between the various observation types were taken into account in a hybrid block adjustment. This way, not only the most probable vertex coordinates, but also the correct standard deviations could be determined. The computed vertex qualities are not only stored in some list, but they can be viewed point-wise, directly in the model. The numerical output of the three coordinate standard deviations informs users exactly about accuracy. Moreover, the number of observations used to determine the vertex describes local redundancy. Quality visualization is also done graphically, in 3-D space: photo projection centres and tachymeter stations are indicated by symbols at their reconstructed positions. Photogrammetric (yellow) and polar (red) lines between these instruments and the vertex denote the observation rays and give an impression of the intersection angles at the point. Moreover, the point's error ellipsoid is faded in magenta, ten times enlarged. See Figure 9 and Figure 10 for examples of quality visualization.

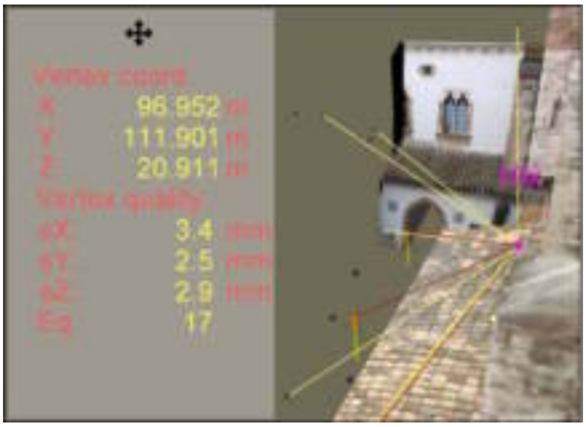

Figure 9: Point-wise visualization of model quality. Numerically, quality is presented on the table on the left by three coordinate standard deviations and the number of observations that were introduced to determine the point. Graphically, the user gets informed via the photogrammetric (yellow) and polar (red) observation rays in space that give an impression of the intersection angles at the vertex. Furthermore, the error ellipsoid is faded in (magenta, ten times enlarged).

Figure 10. Another example for the visualization of qualità: the activated vertex was determined by a spatial intersection of three photogrammetric abservation rays and one virtual shape (3*2+1 = 7)

4. CONCLUSIONS

Virtual shapes of architecture can be applied with great benefit to the creation of a photorealistic model. They help in two major aspects. First, virtual shapes permit an accelerated and enhanced creation of the model. Second, virtual shapes allow for examining a building's features like the inclination of walls, deformations, and construction accuracies. What is left to do, is to convince producers of photorealistic models of the great potential of virtual shapes. Although model quality can be estimated coarsely by checking the correspondence of model geometry and texture, detailed and correct quality measures should be provided, like in any other photogrammetric product. VRML97 permits the presentation of quality directly in space, which is a much more demonstrative and faster way than indicating it in some list.

In the photorealistic model presented in this article, quality measures were determined correctly and they are presented to the user point-wise, directly at the vertex. It would be desirable that photorealistic models presenting quality information become the standard case. Nowadays there is always the question why to compute geometry using image observations, since there are laser scanners available. The answer must be that both techniques have their advantages and handicaps. Photographs are cheap, photo cameras are widely spread. Furthermore, edges are of great importance for the creation of a model of a building. They can be detected much better in photographs than in laser scans. But scans provide 3-D point clouds directly, and with high density. In order to model general curved surfaces, e.g. statues, this will ease work significantly. Interested readers may load the model from the internet at: http://www.ipf.tuwien.ac.at/teaching/vrml/sanjuan/sanjuan.htm

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