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DIGITAL RECTIFICATION AND GENERATION OF ORTHOIMAGES IN ARCHITECTURAL PHOTOGRAMMETRY

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ABSTRACT

This paper gives an overview over different photogrammetric single image techniques, like digital rectification, unwrapping of parametric surfaces and differential rectification methods. It shows the new possibilities for the generation of orthoimages and image mosaics using digital image processing methods even on low-cost personal computers. After a short description of the implemented methods, there are presented some results in the field of architectural photogrammetry and monument preservation.

1. INTRODUCTION

Photogrammetric single image techniques, like the generation of rectified images and orthoimages are well suited for use in architecture and monument preservation. They combine true scale geometric measurements with full image information under quite inexpensive production costs. Especially in the field of architectural orthoimage generation, the combination of image processing with photogrammetric systems provides new solutions.

Digital image processing methods play a more and more important role for the production of rectified images. Because of the increasing performance of personal computers as well as the availability of necessary peripheral hardware, like CD-writers and photorealistic printer units, rectification with analogue equipment is no longer necessary today. Especially the PhotoCD delivers good requirements for digitizing and storing digital image data for photogrammetric purposes (HANKE, 1994).

There are different approaches for the photogrammetric rectification of images. The simplest method is the projective rectification, used in the past with analogue rectifiers. Digital orthoimage techniques, like differential rectification are well known in aerial photogrammetry, but they are rarely used in architectural photogrammetry. With digital image processing methods some new rectification techniques became possible, like polynomial rectification or unwrapping methods (BÄHR, 1980), (KARRAS et al., 1996). Especially these unwrapping methods provide new interesting and non-expensive solutions in architectural photogrammetry.

The selection of an appropriate approach depends on different facts. First of all it is necessary to describe the surface, which should be rectificated. If it is nearly plane, a projective rectification should be chosen. In case of small uneven areas within the surface, a polynomial rectification could be useful. If the object could be described as a parametric volume, like a cylinder or a cone, a rectification is possible with digital unwrapping techniques. Complex surfaces have to be rectified with differential rectification methods.

In some cases complicated surfaces have to be rectified with combinations of the described methods. To combine these methods it is necessary to cut the images in different parts and rectify the pieces part-by-part. This requires an enormous amount of interactive work to cut and merge the images and a lot of control information is necessary. Small errors become distinct at the edges of the pieces. Under consideration of these problems this approach yields good results (MARTEN et al., 1994).

2. SELECTION OF THE SUITABLE APPROACH

2.1. Geometric Considerations

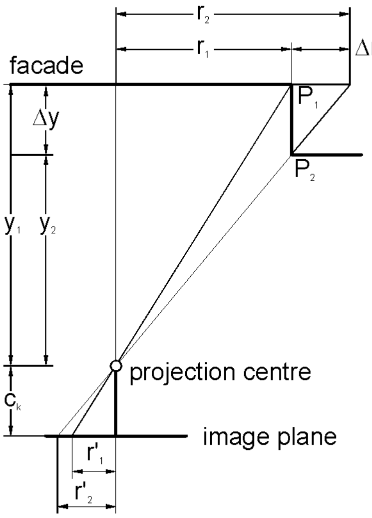

Figure 1: Geometric constraints using rectification techniques

As already mentioned, it is necessary to decide about the most suitable technique to provide pictorial orthoprojections first. By calculating the resulting folding of points in front or behind the main object surface objective decisions about the required techniques for the rectification of this images can be made.

The radial folding Δr of the points P_1 and P_2 on the facade depend on the focal length c_k of the camera and on the difference Δy between the object distances y_1 and y_2:

$$\Delta r = \frac{r'_2}{c_k} \Delta y$$

If the maximum image radius in the corners of the images is r'_{max} and a maximum radial folding Δr_{max} is permitted, the maximum differences between the object distances Δy_{max} are:

$$\Delta y_{max} = \frac{c_k}{r'_{max}} \Delta r_{max}$$

2.2. Parametric versus Non-Parametric Approaches

There are two classes of rectification approaches: The parametric and the non-parametric approaches. Whereas for the parametric approach the knowledge of the interior and exterior orientation parameters is required, non-parametric approaches require more control-points.

The parametric approach uses a reverse ray tracing to determine the grey-values for all pixel positions in the rectified image. The resampling of the grey-values requires the position of the corresponding position in the distorted image. This can be calculated by the collinearity equations using interior and exterior orientation parameters and the position of the corresponding point in the object coordinate system. The interior orientation may be known from a calibration protocol of the image and a measurement of fiducial marks or a reseau. The exterior orientation parameters can be calculated by a resection in space using at least three control points or a bundle adjustment. Interior and exterior orientation parameters can also be estimated together within a spatial resection. In this case the spatial distribution of the control points plays an important role in order to obtain correct results. Whereas at least five control points are necessary, more of them are recommended to stabilise the calculation and to get statistical information about the accuracy.

In case of non-parametric approaches a planar coordinate transformation between the matrices of the distorted and the rectified image is used.

Transformation Type	Number of Parameters	Required Control Points
Similarity-Transformation	4	2
Affine Transformation	6	3
Projective Transformation	8	4
Polynomial 2nd Grade	12	6
Polynomial 3rd Grade	20	10

Table 2: Non-parametric approaches

The object coordinates of the control points have to be reduced to 2D-coordinates on the projection surface first. Table 2 shows the necessary control points for non-parametric approaches, depending on the number of needed coefficients.

3. DIGITAL RECTIFICATION METHODS

3.1. Projective Rectification

If the objects surface describes sufficient precise a plane, a projective rectification should be used. To perform a projective rectification, a geometric transformation between the image plane and the projective plane is necessary. For the calculation of the eight unknown coefficients of the projective transformation, at least four control points in the object plane are required. The equations for projective rectification are given as follows (Albertz, Kreiling, 1989):

$$x' = \frac{b_{11}x + b_{21}y + b_{31}}{b_{13}x + b_{23}y + 1}$$

$$y' = \frac{b_{12}x + b_{22}y + b_{32}}{b_{13}x + b_{23}y + 1}$$

The positions of the grey-values of the given image have to be transformed with these equations into the rectified image. For this task, called resampling, there are two possibilities: In dependence on the direction of the transformation we distinguish between a direct and an indirect rectification. Digital rectification generally uses the indirect method, because the rectified image will be calculated pixel by pixel. For that reason it is necessary to find a method for the interpolation of the grey-values, because the calculated position of the needed grey-value in the given image is mostly between the image raster. There are different methods for grey-value interpolation: For instance Nearest Neighbour, Bilinear and Bicubic Interpolation. The better the quality of the rectified image should be, the more calculation time is needed (table 3). But today the performance of personal computers provides good compromises: Even high resolved images can be rectified with Bilinear Interpolation or better methods.

Interpolation Method	Interpolation Window	Number of Arithmetical Operations
Nearest Neighbour	1x1	0
Bilinear Interpolation	2x2	8
Bicubic Interpolation	4x4	110
Lagrange Interpolation	4x4	80

Table 3: Comparison of different interpolation methods

To examine the accuracy of the rectification, the control points have to be superimposed with the rectified image. The control points only have to be transformed in the used image scale. Measurement errors and differences because of uneven surfaces are easily to detect.

The digital projective rectification and other digital rectification methods provide some new advantages like the production of rectified colour images. Even images with arbitrary angles - like in our example - are suited for the processing. Therefore, images of buildings with difficult mapping configurations, like small courtyards, may be easily rectified. If necessary, a number of these rectified images may be merged to an image mosaic. For that reason it is necessary to use a uniform reference system to calculate an offset for each image, that gives the geometric position of the rectified single images in the image mosaic. At least, a radiometric adjustment is necessary. That will take place interactively, because automatic approaches are not yet usual for architectural images.

Figure 4: Historical metric photograph from the Great Hall in the Marmorpalais in Potsdam, New Garden

Figure 5 shows an example for a digital rectification. It is the ceiling of the Great Hall of the Marmorpalais in Potsdam (Germany). The aim for this rectification was the production of a working basis for the reconstruction of the ceiling painting, which was destroyed in former times. We used three historical images, two of them from the Meydenbauer-Archiv, which is known for its high number of high-quality metric photographs (see figure 4).

3.2. Polynomial Rectification

It seems to be very dangerous to use higher grade polynomial transformations for the rectification of images. The required amount of control points and the risk of an oscillation is growing with the grade of the polynome. Their use may be suitable for curved elements of facades if sufficient control information is available (MARTEN et al., 1994).

3.3. Unwrapping of Developable Surfaces

Another approach is the unwrapping of developable surfaces. Using digital image processing methods it is possible to unwrap parametric objects, for instance cylindrical or conical objects. The shape of many towers and vaults may be approximated by such parametric volumes. As the result of the unwrapping process, we obtain a true scale image plot of the whole object.

To perform an unwrapping, we use a parametric approach. That means we have to calculate a spatial resection for each image to get the parameters of the exterior and in most cases the interior orientation on the basis of the collinearity equations (ALBERTZ, KREILING, 1989):

$$x' = x_h - c_k \frac{a_{11}(x - x_0) + a_{21}(y - y_0) + a_{31}(z - z_0)}{a_{13}(x - x_0) + a_{23}(y - y_0) + a_{33}(z - z_0)}$$

$$y' = y_h - c_k \frac{a_{12}(x - x_0) + a_{22}(y - y_0) + a_{32}(z - z_0)}{a_{13}(x - x_0) + a_{23}(y - y_0) + a_{33}(z - z_0)}$$

On the other hand we need to describe the parameters of the object surface (cylinder or cone) with the help of control points. The height values h_1 and h_2 and the angles α_1 and α_2 of the developable area are given. The origin coordinates of the cylinder x_m and y_m and the radius r are calculated with a least-squares-adjustment.

Figure 5: Digital rectified image mosaic of the ceiling of the Great Hall in the Marmorpalais in Potsdam, New Garden

The equations for the least-squares-adjustment looks as follows:

$$x = x_m + \sqrt{r^2 - (y - y_m)^2}$$

$$y = y_m + \sqrt{r^2 - (x - x_m)^2}$$

For a cone we additionally need two radii r_1 and r_2. The equations are:

$$x = x_m + \sqrt{(r_2 + \frac{r_1 - r_2}{h_2 - h_1}(h_2 - z))^2 - (y - y_m)^2}$$

$$y = y_m + \sqrt{(r_2 + \frac{r_1 - r_2}{h_2 - h_1}(h_2 - z))^2 - (x - x_m)^2}$$

The resampling process (like already explained in chapter 3.1.) uses the orientation parameters from the spatial resection and the calculated object parameters for the unwrapping on the basis of the collinearity equations. For practical work it is useful, to measure a number of control points, which are well suited for both the spatial resection and the estimation of the volume parameters. Because of the digitizing of the images the interior and the exterior orientation should be estimated together. Therewith it is possible to consider offset, rotation and scaling problems with the used scanner.

All calculations use least-squares techniques with statistical methods like the detection of gross errors to get information about the accuracy of the rectified and unwrapped image.

Our first example for the unwrapping of a developable surface is a tower from the Moritzburg in Halle (Germany), which has nearly a cylindrical shape. The image mosaic consists of seven single rectified images.

Figure 6: Metric photograph of the West-Tower of the Moritzburg, Halle

Figure 7: Digital unwrapped image mosaic of the West-Tower of the Moritzburg, Halle

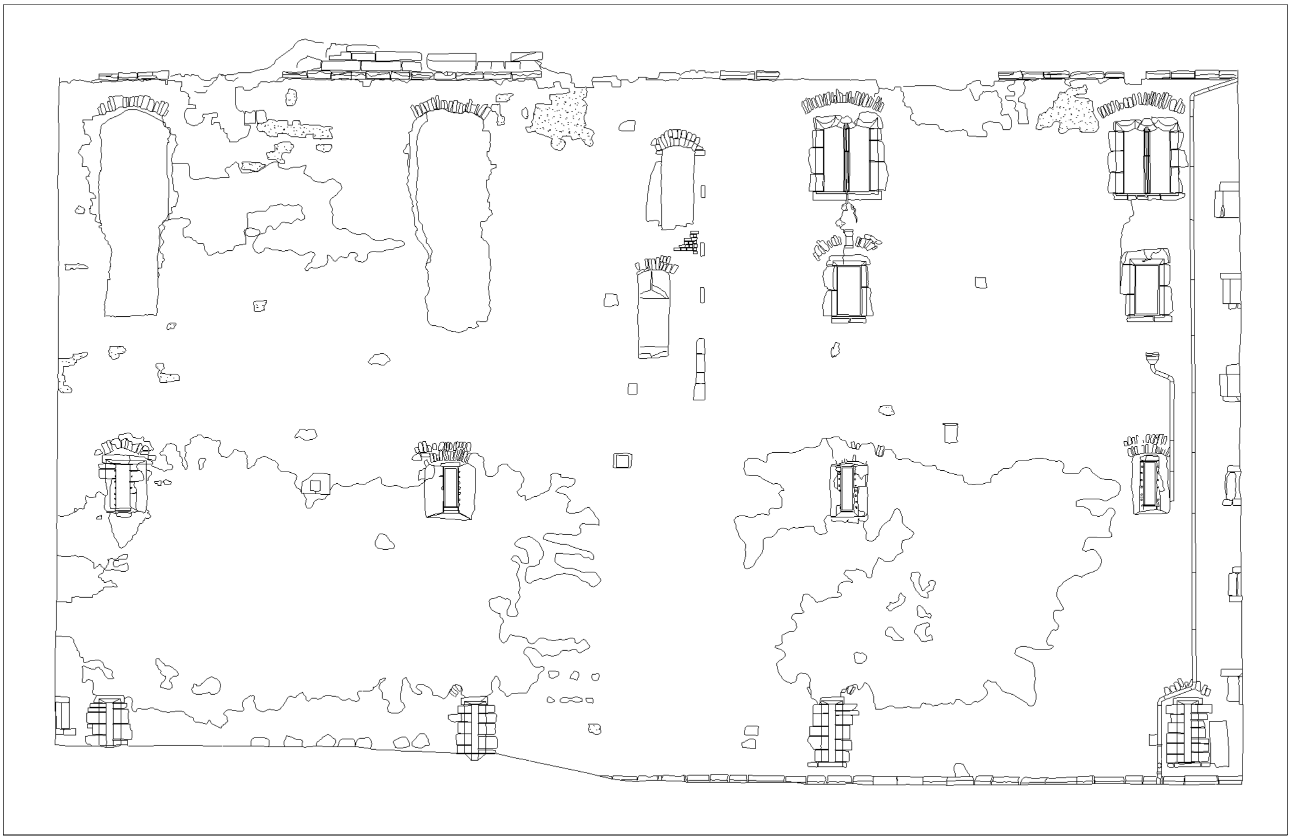

Figure 8: Photogrammetric plot of the West-Tower of the Moritzburg, Halle

Our second example is the ceiling painting of the Iwein-cellar in the Hessenhof in Schmalkalden (Germany). This painting is about 750 years old. The vault is nearly a cylinder, but in order to get precise plans of this painting we used a cone as the basis for the unwrapping, because this was the true shape of the vault. The image mosaic consists of only three images, because the cellar is very small.

Figure 9: Iwein-cellar in the Hessenhof, Schmalkalden, one of three used metric photographs

3.4. Differential Rectification

If none of the already mentioned techniques is suitable for the rectification of images a differential rectification is necessary. Therefore a geometric description of the object surface, relative to the projection surface is necessary. This is usually provided by a Digital Surface Model (DSM), which is a raster data set storing the elevation above the projection surface.

Beside a precise documentation of the elevation it is necessary to store the exact location of discontinuities of the surface of the object. Resulting from the large amount of discontinuities on building surfaces, e.g. windows or balconies, the geometric resolution of the DSM has to be equal to the resolution of the orthoimage to produce, whereas on continual surfaces an interpolation between the DSM meshes may be suitable. The main problem in the generation of digital orthoimages of facades is the delivery of a sufficient DSM (WIEDEMANN, 1996).

The first approach was to generate a DSM by image matching techniques. Most tests delivered insufficient results. Image based matching techniques failed at the edges because of different backgrounds. The provision of initial values using image pyramids was disturbed by obstacles in the foreground. Blunders resulted from the similarity of features.

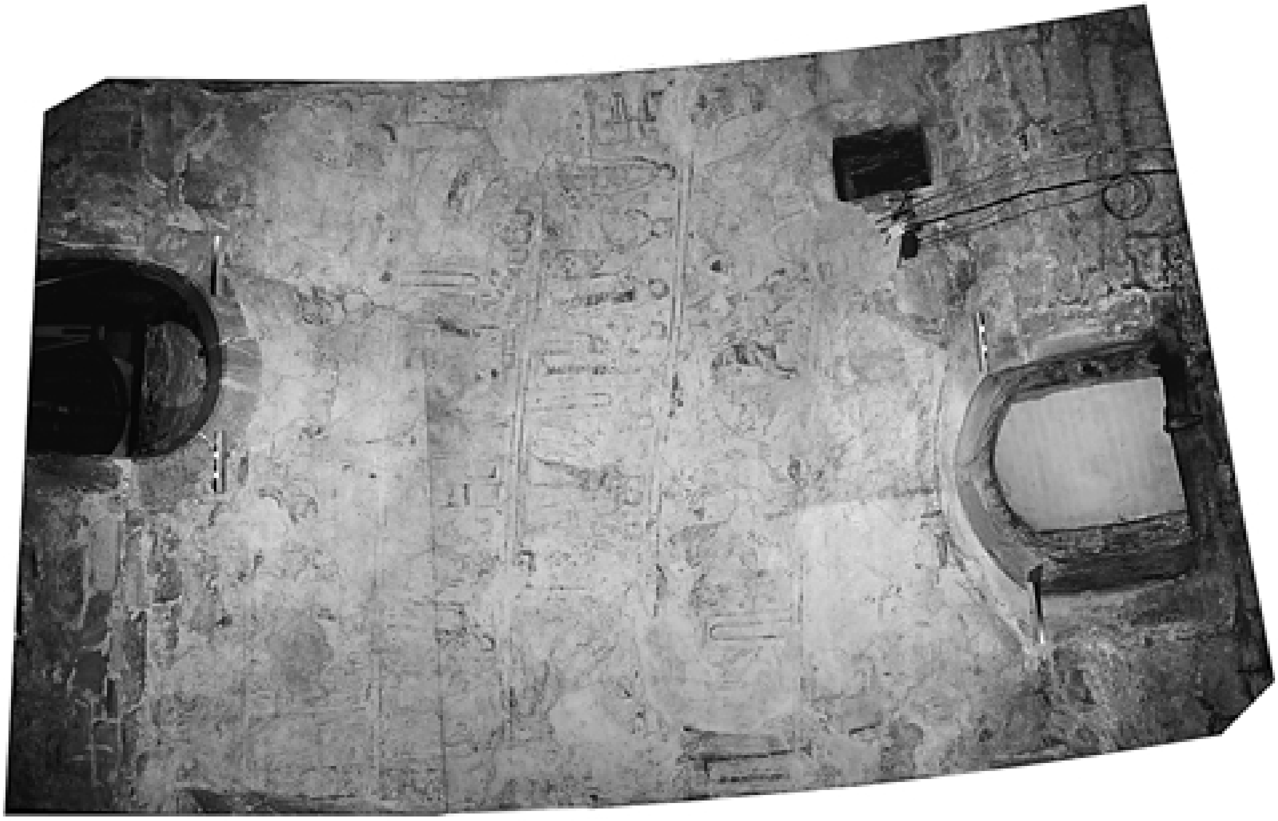

Figure 10: Digital unwrapped image mosaic of the ceiling painting in the Iwein-cellar

A better approach is to derive the DSM from a CAD model. The CAD model has to consist of surface elements, a wire model is insufficient. The model is processed face by face. For each raster position a point-in-polygon algorithm is used to decide, whether it lays below the face. In this case, the elevation of the face above the projection surface is calculated and stored in the DSM. If there is already an elevation the bigger of the two elevations is selected for storage in the DSM.

A common way to create a CAD model is a reduced photogrammetric restitution. This restitution has to take into account only features, which have an influence on the DSM. Stereophotogrammetric and improved bundle-adjustment techniques have been used for this purpose. Beside this technique other data sources for the DSM may be used, e.g. Laser Scanners (WEHR, 1997) or already existing CAD models.

After the generation of the DSM the differential rectification will deliver a digital orthoimage. During the rectification process each pixel is tested, whether the corresponding object point is covered by a different part of the object. This will be done by counting the intersection of the image ray with the DSM. Whereas the derivation of the DSM is a time consuming task, the generation of the digital orthoimage can be repeated with the same DSM but another image within a few minutes. Different exterior orientations lead to different occluded areas. By merging a few images most occluded areas may be filled with information. An example of a process for generating digital orthoimages is shown in Figure 11.

4. CONCLUSIONS

The pictorial representations generated with the presented approaches provide an enormous amount of information to the user, who can extract geometric information while considering the image. Further usage of these products can be anticipated in the field of architectural visualisation.

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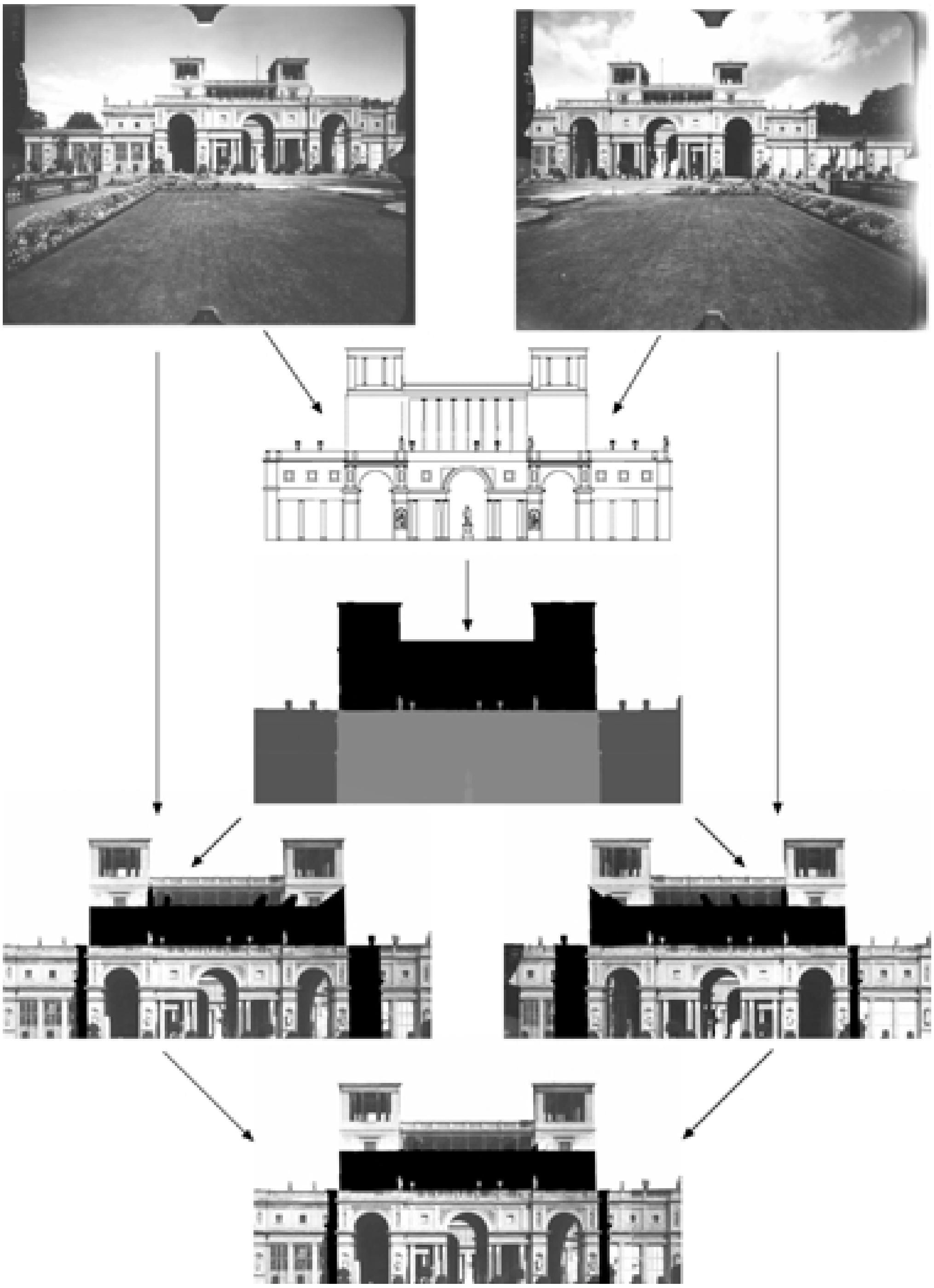

Figure 11: Data flow for the generation of digital orthoimages

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