Close-range photogrammetry enables documentation of environment-induced deformation for architectural heritage

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Abstract

Deformation, damage and permanent loss of heritage assets due to various physical and environmental factors has always been a major problem. As the availability of funds for conservation and restoration is limited, the digital documentation of heritage objects and monitoring of environment-induced deformations are increasingly important for cultural heritage preservation. Our study elucidates developments in the digital image capturing and processing for recording architectural heritage objects focusing on the digital camera calibration, close-range imaging, and photogrammetric modelling of complex structures using image matching techniques. A particular consideration in this paper is given to the ortho-photographic image compiling and accuracy assessment procedure. The practicality of the methodology is demonstrated by applying photogrammetric system *PhotoMod* for documentation of decorative elements in Uzutrakis manor, a national heritage site in Trakai, Lithuania.

Keywords: heritage, close-range photogrammetry, surface and geometric deformations, ortho-photographic model, Uzutrakis manor

1. Introduction

Cultural heritage is an invaluable asset of a human culture and creativity. A large proportion of it is formed of architectural objects such as buildings and other physical structures that are historically inherited from the past and sought to be sustained for the future. These objects distinguish themselves by their historic, architectural, and technological significance. Regrettably, the architectural heritage suffers from an irreversible deformation and damage caused by physical factors of the natural environment such as aging, humidity, dust, weathering, pressure and others (Castellini et al., 2008; López-Aparicio and Grašiene, 2013; Varas-Muriel et al., 2014), as well as human activities and negligence (Norrström, 2013). A deterioration of the artwork can be monitored by recording surface and geometric deformations (Hinsch et al., 2007; Castellini et al., 2008; Remondino et al., 2011).

Often, original architectural drawings, which are necessary for heritage object restoration, are not available or archaic and low quality. Work aimed at planning the restoration of architectural heritage demands an up-to-date and accurate documentation on architectural and structural characteristics, geometric shapes and materials. Therefore, the documentation and deformation monitoring of complex heritage objects are of a vital importance (Chen and Romice, 2009; Mazzanti, 2002; Nelle, 2009; Pickard, 2002; Shipley and Reeve, 2010).

Currently used strategies for architectural heritage documentation are based on spatial data acquisition techniques such as tacheometry (conventional surveying), laser scanning and photogrammetry (Grussenmeyer et al., 2008). Laser scanning and photogrammetric methods or their combination can generate an accurate documentation of the cultural heritage with high-resolution models of physical structures representing different perspectives of view (Al-kheder et al., 2009; Beraldin et al., 2000; Campana and Remondino, 2007; Guarnieri et al., 2013; Han, 2012; Kersten et al., 2009; Martorelli et al., 2014; Remondino, 2011; Remondino et al., 2009; Yastikli et al., 2007; Yilmaz et al., 2008; Zheng et al., 2012). However, seeking to reduce costs or due to a lack of technical skills, architectural conservators involved in heritage conservation still often use traditional manual methods, despite that their application may result in a reduced accuracy or even complete loss of information in the process of data transmission from the original object to the theoretical model (Yilmaz et al., 2007).

The laser scanning technology and digital image photogrammetry provides possibility for three-dimensional (3D) digitalization of architectural structures and their elements, which enables a digital documentation and continuous monitoring of the spatial information at different time periods (Al-kheder et al., 2009; Remondino, 2011; Pesci et al., 2013; Tapete et al., 2013). Both technologies generate sets of data points that can be transformed into point clouds in 3D space, which are required for the creation of two- or three-dimensional models (Akman et al., 2010; Gruen and Akca, 2005; Yastikli et al., 2007). Although acquiring data for point clouds using laser scanning is a faster technique in the field of surveying, the arising issues such as affordability, restricted accessibility of hidden-enclosed building areas, limited portability, required special expertise and other factors reduce the possibility to use the laser scanning in favour of photogrammetric methods (Arias et al., 2006; Chandler et al., 2005, 2007; Martínez et al., 2013; Sužiedelyte-Visockiene et al., 2011).

As a result of the fast development of user-friendly close-range photogrammetric software packages such as *ImageMaster* (Topcon Positioning Systems, Inc., Livermore, USA), *PhotoModeler* (Eos Systems Inc., Vancouver, Canada), *PhotoMod* (Racurs, Moscow, Russia), *ShapeCapture* (ShapeQuest Inc., Nepean, Canada) and others (Adrov et al., 1995; Aguilar et al., 2005; Deng and Falg, 2001; Sužiedelyte-Visockiene et al., 2011), there is evident increase in the use of 3D image-based digitalisation methods in the field of cultural heritage (Barazzetti et al., 2011; Remondino et al., 2009; Yilmaz et al., 2008). With a variety of different approaches being available, digital models can provide highly accurate both 2D and, when required, 3D drawings, which contribute to the documentation of complex buildings, detailed decorative elements and other architectural structures (De Reu et al., 2013; Tiano et al., 2008; Barbetti et al., 2013). In contrast to the theoretical or simulated models, these drawings are able to reproduce accurately the morphology of the object capturing differences of irregular elements and multiform geometry (Arias et al., 2007; Remondino, 2011; Riveiro et al., 2011). A great deal of interest has been attracted to the 3D image-based technology that combines the close-range photogrammetry with an automatic image matching (AIM) and enables to create dense point clouds with 3D data from stereoscopic pair of images, which can be captured using conventional digital cameras (Koutsoudis et al., 2013; Martínez et al., 2013, Ortiz et al., 2013).

The paper reviews the pipeline for generation of ortho-photografic and 2D models using digital close-range photogrammetry. It provides a detailed example of the process starting with the calibration of the digital camera and leading to the generation of 2D models, which are required for national heritage documentation in Lithuania. In this study, the close-range photogrammetry is used to record and monitor the environment-induced deformation of the decorative elements on the internal wall of Užutrakis palace (Deveikiene and Deveikis, 2011), which is a historical building listed as a national heritage site. The palace has been built by order of Joseph Tyszkiewicz in 1898 – 1901 (LSE, 1983). The architect of palace was Warsaw architect Jozef Huss (1846-1904). Buildings architectural features consist of few styles, historicism, neo-renaissance, and neoclassicism. Interior was designed by following Ludwig XVI classicism.

2. Use of the close-range photogrammetry for documentation of the architectural heritage

Image-based modelling using photogrammetry is regarded as one of the best techniques for processing of image data, which provides accurate and detailed 3D information. This technique allows determining the precision and reliability of data parameters from the measured image tie points and control points (CP), which represent the location of matching/correspondence points in two or several adjacent digital images and can be used to link images. Therefore, at least two images are required, and then the 3D information can be derived by applying projective and perspective geometry expressions.

The close-range photogrammetry is largely preferred over other techniques for data acquisition and processing when working with architectural structures and elements, which have small objects of irregular shape, for mapping applications and, in particular, for reconstruction of a missing elements in the larger object or for documentation of surface and geometric deformations. It is usually less cost demanding, with fewer time and location constrains and provides an enjoyable experience of working in the team (Remondino and Rizzi, 2010). It can be employed in many different applications relevant to the cultural heritage including documentation, conservation, digital restoration, deformation analysis, monitoring, visualization and painting analyses (Arias et al., 2005; 2006; Fassi et al., 2011; Remondino et al., 2011; Yastikli, 2007; Yilmaz et al., 2007; 2008).

A substantial number of studies have reported on how the close-range photogrammetry can be used to survey objects with different levels of complexity and arrangement suiting high quality requirements and entailing only a few restrictions (Barazzetti et al., 2013; Barbetti et al., 2013; Bitelli et al., 2011; Grussenmeyer et al., 2008; Ordóñez et al., 2010; Pérez-Gracia et al., 2011; Sanz et al., 2010; Solla et al., 2012).

Currently available technology allows using terrestrial, aerial or satellite platforms (synthetic aperture radar or lidar surface topography) for 3D information acquisition, some of which can then be used in a typical photogrammetric pipeline starting with digital camera calibration and finishing with ortho-photographic model generation (Fig. 1).

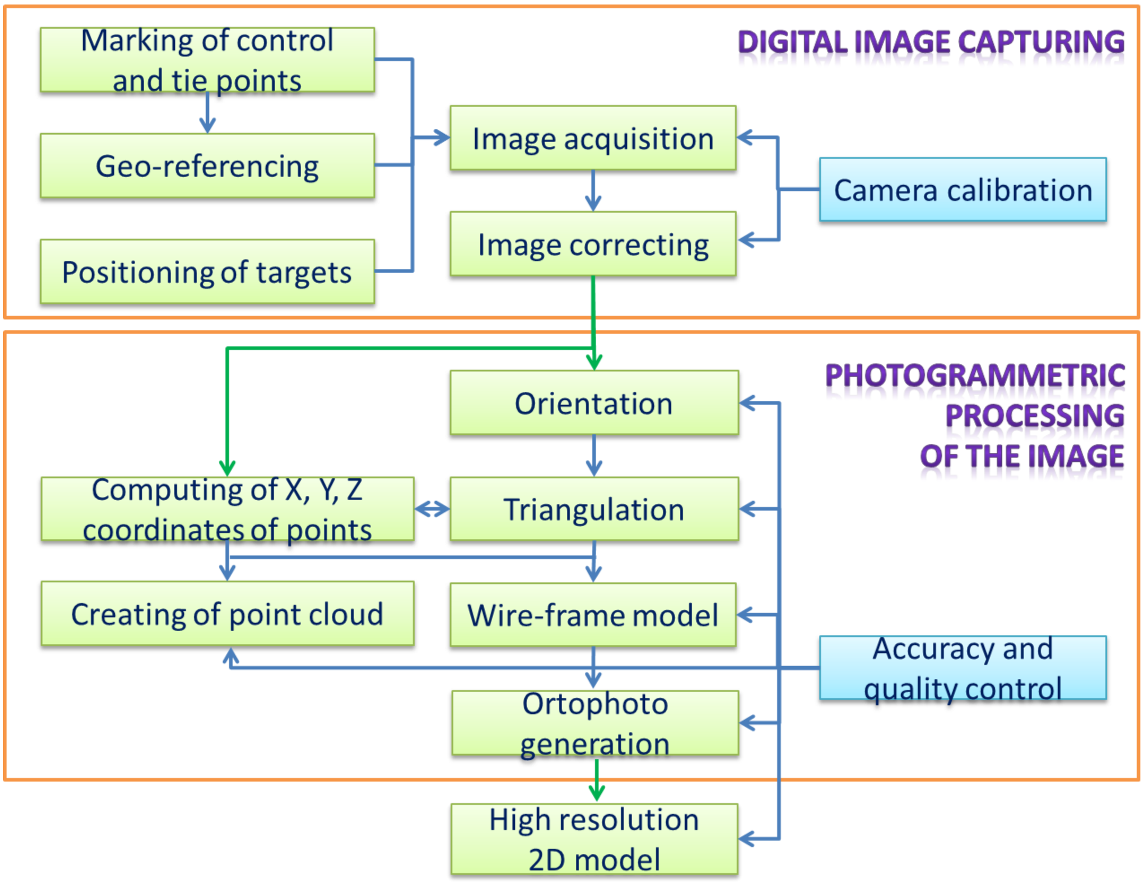

Fig. 1. Pipeline for digital image capturing and photogrammetric processing. Digital image capturing platform consists of six main elements. It includes *camera calibration* (element 1; error values due to camera optics distortions are established), *marking of control and tie points* (element 2; coordinates of control points on the object are determined, which are used for *geo-referencing*, element 3), *positioning of targets* (element 4; identification of targets for image acquisition) *image acquisition* (element 5; overlapping images of the object are acquired), and *image correction* (element 6; on the basis of camera calibration data the image is corrected). Photogrammetric processing of the image can include eight different elements. These are following: *orientation* (element 1; image orientation in respect to tie and control points are established), *triangulation* and *computing of X, Y, Z coordinates of points* (element 2 and 3; X, Y, Z coordinates of points from overlapping images are computed), *creating of point cloud* (element 4; on the basis of established X, Y, Z coordinates the point cloud can be generated), and *wire-frame model* (element 5), which the contributes to *ortophoto generation* (element 6) that forms the basis for *high resolution 2D model* (element 7). Many elements of these elements in the photogrammetric processing must meet *accuracy and quality control* requirements (element 8).

The photogrammetry involves steps that are performed in an automated way (e.g. geo-referencing, image correction, camera calibration, orientation, ortophoto generation) with a little expert knowledge required or manually, where a high level of precision is critical (e.g. for image processing of very small objects) (Sužiedelytė-Visockienė, 2013; Sužiedelytė-Visockienė et al., 2014). Depending on the project type and quality requirements, a high level of professional expertise can be required for the interaction with and intervention at specific stages of the modelling pipeline of the photogrammetric process.

Manual procedures are still necessary for accurate element extraction from the satellite, aerial or terrestrial image. Predominantly automated methods are becoming increasingly available to the cultural heritage community. They can be used effectively for visualization, object-based navigation, annotation or image browsing (Vergauwen and Van Gool 2006; Remondino, 2011). However, they are often insufficient for the accurate heritage object reconstruction and documentation. Therefore, the automation of image-based modelling of architectural structures and elements remains an important research subject (Barazzetti et al. 2010; 2011; Oniga and Diac, 2013), as the expert intervention is still necessary for the accurate camera calibration, accuracy and quality control of the photogrammetric processing, geo-referencing and few other stages (see Fig. 1).

3. Image acquisition and photogrammetric processing

Professional-terrestrial digital cameras are commonly used for image acquisition by close-range photogrammetry. They come in different forms and shapes containing CCD, CMOS or Live MOS sensor, single or multiple and/or panoramic heads, frame or linear array, consumer, SLR-type or industrial, low- or high-speed, etc (Remondino, 2011). Minimal requirement for terrestrial cameras is to have a sensor with a resolution of at least 12 megapixels while high-end digital cameras span to 60 megapixel sensors. Although panoramic linear array cameras are available on the market and they can deliver a very high quality and resolution images with exceptional metrics, due of their high cost, panoramic images frequently are generated by combining together set of overlapping images acquired from a single point of view with a consumer range digital camera. Such a low-cost solution is used not only for Google Street View, but is common close-range photogrammetry applications focussed on documentation of the architectural heritage.

During the photogrammetric measurements, digital two-dimensional (2D) or three - dimensional (3D) images of the object or its details, as well as ortho-photographic model, are derived. This allows recording the status of the object with its visible surface and geometric deformations. In most cases, such deformations could be recorded by manually performed measurements. Therefore, it is appropriate to present the analysis of the digital photogrammetric method instead. The object is usually imaged using calibrated professional camera with sensor of high resolution. Obtained overlapping images are processed using specialised photogrammetric software. The following stages of photogrammetric measurements are essential in order to compile the ortho-photographic model of images (see Fig. 1):

- Interior orientation;
- Relative orientations;
- Calculation of triangulation;
- Adjustment of accuracy for the ortho-photographic model creation.

While executing all the above mentioned processes it is necessary to monitor the accuracy of derived results. The precision and reliability of photogrammetric process heavily depend on that.

4. Methodology

In this study the following initial preparations were performed as recommended by Kutut (2011):

- Inspection and survey of the object and photo-fixation;
- Photogrammetric measurements;
- Analysis of the available documentation and historical research study records;
- Geodetic measurements;
- Analysis of composition of the object.

Objects of this survey were an internal wall of the chamber and associated wall ornaments in Uzutrakis palace. The imaging of the wall and all related work was conducted in 2012. The following preparatory tasks were performed at the site of this heritage object:

- Marking and measurement of the geodetic control points with the geodetic equipment;
- Imaging of the wall;
- Image correction, due to the errors of the camera optics.

Photogrammetric processing of the images was performed as following:

- Measurement of image central points (inner orientation);
- Measurement of geodetic control points and tie points of the model by means of the photogrammetric program (relative orientation);
- Calculate of triangulation adjustment;
- Stereo digitalization of the wall (determination of structural lines);
- Compiling of the detailed ortho-photographic models;
- Drawing of the details on the ortho-photographic models.

The measurements of the geodetic CP of the wall and ornaments as well as tie points together with the triangulation adjustments were carried out by using the photogrammetric system *PhotoMod* (Adrov et al., 1995). The processing of images in *PhotoMod* included the interior orientation and relative orientation, the input and measurement of geodetic control points and tie points located in the overlapping areas between the adjusted images (RACURS, 2012).The accuracy of the tie and CP point measurements was assessed on the basis of following criteria:

1. Correlation coefficient. On the basis of image quality, the user can determine the acceptable value of the correlation coefficient. For contrast, clear and high quality images, the correlation coefficient threshold was adjusted to 0.9–0.95, while for lower quality images this threshold was reduced to 0.8;

2. Vertical parallax residual. The mean value of the vertical parallax was not allowed to be greater than 50% of the matrix pixel size of the digital camera. Since the matrix pixel size of the camera *Canon EOS 1D Mark III* was 6 µm, the mean value of the vertical parallax was not allowed to be greater than 3 µm. The maximum error ($E_{\max}$) and root mean squared error (*RMS*) were calculated using following equations:

$$E_{\max} = 2 \times E_{mean}, \quad (1)$$

$$RMS = \sqrt{2} \times E_{mean}, \quad (2)$$

where E_{mean} is a mean error of the measurement points in the geometric model.

3. Control of accuracy by tying the adjacent models (in the overlapping area or triplets). Following measurements of the tie points on the stereo pairs, the points that belong to the overlapping area of adjacent models (i.e. triplets) were transferred. The relative accuracy of the orientation was verified by comparing the difference of point measurements (triplets) of the adjacent models. Triplet errors E_x, E_y, E_z in 3D coordinate system (X, Y, Z coordinates) were calculated for two adjacent models. The mean of triplet errors in XY plane and Z coordinate were calculated using the following equations 3 and 4:

$$E_{mean}^{xy} = \sqrt{2} \times 0.5\,pxl, \quad (3)$$

where pxl – is the size of the matrix pixel;

$$E_{mean}^{z} = \frac{c}{b_x} \times E_{mean}^{xy}, \quad (4)$$

where c – is the focal length of the camera, b_x is the survey basis on the image scale (mm):

$$b_x = l_x \times (100 - p_x)/100, \quad (5)$$

where l_x – is the image size along the X-axis (mm), p_x – is the size of the overlapping zone (%).

The digital professional *Canon EOS 1D Mark III* model camera equipped with two different lenses with focal length of either 14 mm or 85 mm was used for imaging. The camera was calibrated at the Department of Photogrammetry, Institute of Geodesy and Geoinformation, University of Bonn, Germany, using *Tcc* software as described previously by Abraham and Hau

(1997). The characteristics and the calibration results of *Canon EOS 1D Mark III* are presented in Tables 1 and 2 (Sužiedelytė-Visockienė and Bručas, 2009).

Table 1. Characteristics of digital camera *Canon EOS 1D Mark III*

Characteristics	***Values***
Focal length *c* (mm)	14 and 85
Resolution (pixel)	21 mln.
Pixel pitch (μm)	6.4×6.4
Image size (mm)	35.9×23.9
Image size (pixel×pixel)	5616×3744

Table 2. *Canon EOS 1D Mark III* calibration results (Department of Photogrammetry, Institute of Geodesy and Geoinformation, University of Bonn)

Parameters	***Results (pixel)***	***Results (pixel)***
Focal length		
c	2145.98	12928.51
Scale of image (constant)		
S_{xy}	0.99	0.99
Correction of the main point of the image		
x_0	2.41	16.83
y_0	-4.093	-9.89
Radial symmetric camera distortion		
A_1	–9.52E-09	– 5.93E-10
A_2	8.29E-16	-3.67E-18

5. Results and discussion

To test practicality of methodology, which was developed on the basis of the close-range photogrammetry, an applied study was carried out using digital images of the heritage object. Below we describe key steps of the image acquisition using professional camera and image processing, which were performed on decorative elements (ornaments) in Uzutrakis palace.

The images of the chamber wall were taken using the lens with the focal length of 14 mm, while the smaller of the wall containing ornaments were captured with 85 mm lens. Ornaments were stuccoworks, a fine plaster-based artwork often used as three-dimensional ornamentation during a period from 1500 to 1700 (Nardini et al., 2007). The overlapping images of the wall and of the ornaments were corrected to eliminate errors caused by the camera lens distortion reported in Table 2 and are presented in Figures 2, 3 and 4.

Fig. 2. Two overlapping images of the wall (c = 14 mm). Ornaments A and B are in dashed circle and dashed rectangle, respectively

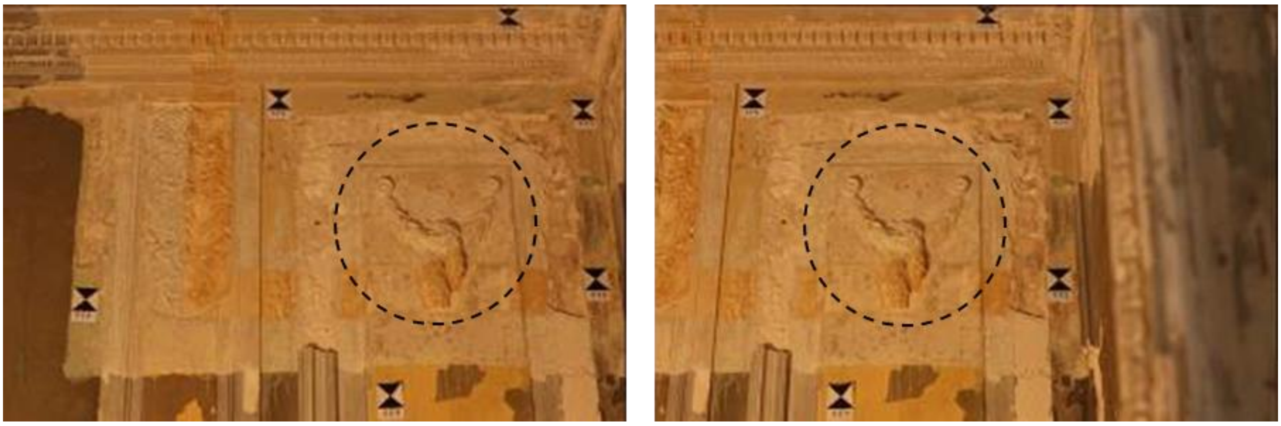

Fig. 3. Two overlapping images of the ornament (A) (c = 85 mm)

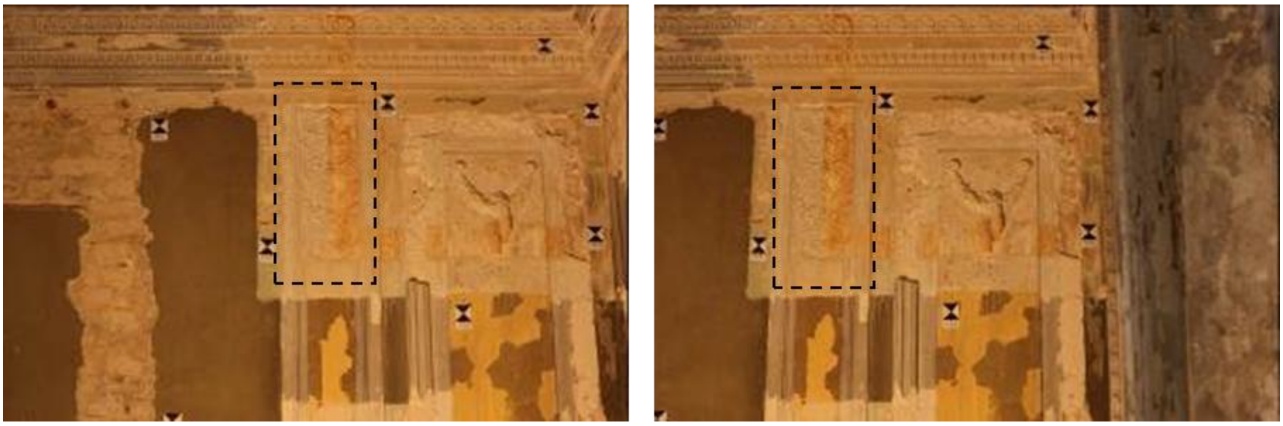

Fig. 4. Two overlapping images of the ornament (B) (c = 85 mm)

In order to perform the interior orientation of images, the central point of images was measured, the coordinates of which were equal to the half size of the image matrix (in pixels). Based on the camera calibration results (Table 2), the position of the point was corrected automatically to eliminate errors of the camera lens distortions. These errors can also be corrected even before starting the image processing (Sužiedelytė Visockiene and Bručas, 2009).

Table 3 presents the calculated theoretical mean triple error for *Canon EOS 1D Mark III* digital camera images with the matrix pixel size of 6 µm, 14 and 85 mm focal length of the camera lens, the image size is 5616×3744 pixels or 35.9×23.9 mm, and the images are overlapping by 60, 80 and 90%. The calculated error of the horizontal and vertical model is computed from the vertical or horizontal images (Equations 3–5).

Often, the relative accuracy of the orientation was assessed using reduced survey basis b_x when the overlapping was 60-90%. As a consequence, the ratio of c/b_x increased, and therefore, the values of triplet errors E^{z}_{mean} were also increased (see Table 3).

Table 3. Acceptable triplets mean error for images

Focal length c (mm)	Overlapping zone p_x (%)	Survey basis b_x (mm)	E^{xy}_{mean} (µm)	E^{z}_{mean} (µm)
14	60	13.2	4.2	4.5
14	60	8.8	4.2	6.7
14	80	6.6	4.2	8.9
14	80	4.4	4.2	13.4
14	90	3.3	4.2	17.8
14	90	2.2	4.2	26.7
85	60	13.2	4.2	27.0
85	60	8.8	4.2	40.5
85	80	6.6	4.2	54.0
85	80	4.4	4.2	81.1
85	90	3.3	4.2	108.2
85	90	2.2	4.2	162.2

Following the relative orientation and assessment of triplet accuracy the triangulation adjustment was performed. The acceptable errors for triangulation differ depending on topographic or ortho-photographic models. When compiling topographic maps with the controls points, the adjustment was not allowed to be greater than 0.2 mm in XY plane and $0.15\times h_{\mathrm{int}}$ on Z coordinate, where h_{int} contour's interval of the output map.

Acceptable mean of the residuals of tie points was 0.3 mm for the output map scale. The acceptable mean of the residuals of tie points on Z coordinate was $0.2\times h_{\mathrm{int}}$, $0.25\times h_{\mathrm{int}}$, or $0.35\times h_{\mathrm{int}}$, depending on the contour interval and scale (RACURS, 2012).

In *PhotoMod* system, the acceptable mean of the residuals on CP in XY plane was 0.2 mm on the output map scale and $1/3\,\Delta h_{DTM}$ on Z , where Δh_{DTM} is mean of the residuals of the Digital Terrain Model (DTM). The value of Δh_{DTM} was calculated using the following equation:

$$\Delta h_{DTM} = 0.3mm \times c \times \frac{M}{r}, \quad (6)$$

where M – is the output map (plane) scale; r – is the maximum distance from the image point to the nadir point (mm), which is equal half of the diagonal of the "working area". Table 4 presents calculated accuracy requirements for the otho-photographic model.

Table 4. Parameters representing a quality of ortho-photographic model

c (mm)	Output plane scale	Δh_{DTM} (mm)	E_{XY} (µm)	E_Z (µm)
14	1:100 1:50 1:10	32.5 16.3 3.3	20 10 2	10.8 5.4 1.1
85	1:100 1:50 1:10	197.7 98.8 19.8	20 10 2	65.9 32.9 6.6

In order to evaluate derived values, the ortho-photographic model compiling was assessed. Using equations 1-4, parameters characterising the quality of triangulation were estimated (Table 5).

Table 5. Parameters representing the quality of triangulation

Focal length (mm)	Accuracy points	Accuracy result (µm)	E^{x}_{mean} (µm)	E^{y}_{mean} (µm)	E^{z}_{mean} (µm)	E^{xy}_{mean} (µm)
14	CP (10)	E_{max}	2.4	1.8	3.9	2.4
		RMS	1.5	0.7	2.1	1.7
	Tie (8)	E_{max}	7.4	1.4	-	1.4
		RMS	2.1	5.3	-	5.3
85	CP(5)	E_{max}	4.4	5.0	2.3	5.6
		RMS	0.7	0.5	1.5	0.9
	Tie (4)	E_{max}	0.2	11.5	-	11.5
		RMS	0.1	4.3	-	4.3

The comparison of obtained data (Table 5) with the theoretical values in Table 4 revealed that achieved results are of a high accuracy and reliability. It should be noted that due to imprecisions in the approximation of tie points, it was observed greater mean of triplet errors in some cases where tie points were used for triangulation. Altogether, these results allowed to expect positive outcomes form the stereo-digitalization, ortho-photographic model and wall surface data analysis.

After stereo digitalizing the topography of the model it was identified that ornaments contained surface and geometric deformations, which were induced by the crack in the surface of the wall and damage/loss of a certain part of the ornament caused by the corrosion. The extent and size of the damaged area was evaluated and thus made it possible to identify the costs and other measures required for the restoration of this architectural heritage. The method of stereo-digitalization was used for compiling structural lines (Figure 5).

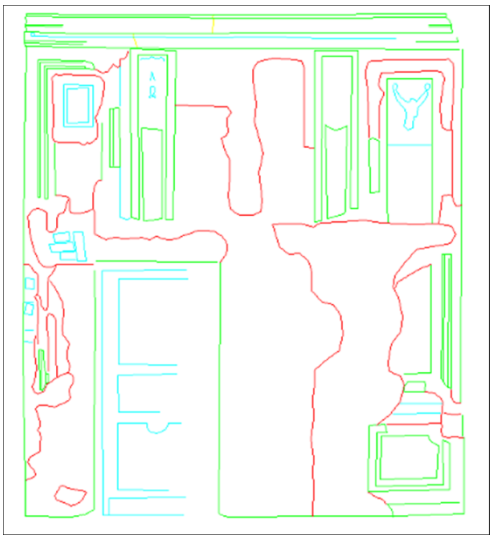

Fig. 5. Structural lines of the wall

The green line was used to mark the main contour of the wall, the red line indicated the surface and geometric deformations of the wall caused by compression and corrosion, and the blue line indicated the contours of the ornaments. The total area of the tested wall was 14.95 m^2. The determined area of the deformations amounted to 9.0 m^2, which comprised 60% of the total area for the required restoration works.

Two ortho-photogarphic models (Figure 6) were compiled to allow drawing of ornaments located on the internal wall by using technique as described previously (Sužiedelytė Visockienė and Bručas, 2010).

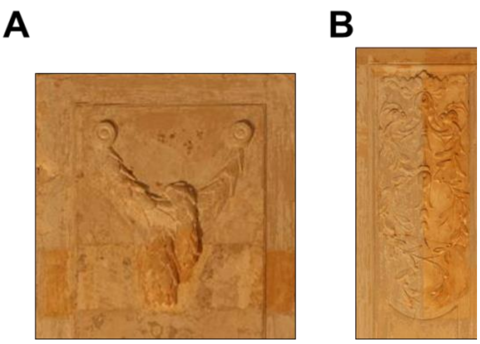

Fig. 6. Ortho-photographic models of ornaments A and B

Using equations 1 and 2 the accuracy of the ornaments of ortho-photographic models were calculated and presented in Table 6.

Table 6. Parameters representing accuracy of the ortho-photographic model

Accuracy	E_X (μm)	E_Y (μm)	E_{XY} (μm)
Ornament A			
RMS	2.7	2.9	4.1
Max	4.4	5.0	5.4
Ornament B			
RMS	0.7	0.4	0.8
Max	1.1	1.0	1.2

The obtained ortho-photographic models were of high quality. The accuracy of first ornament met the scale requirement of 1:50 (Table 4). The accuracy of second ornament met the requirement of the scale 1:10. The ortho-photographic models are geometrically correct and coordinated, because of the usage of *AutoCad* software to be able to draw the structural lines of the ornaments (Figure 7). The surface of the ornaments was not disturbed.

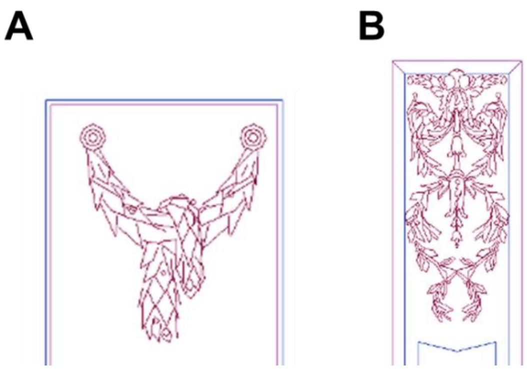

Fig. 7. Structural drawings of ornaments A and B

The structural drawings of ornaments were used for restoration of decorative elements in Uzutrakis palace. They are also stored in the archives of the cultural heritage in Vilnius, Lithuania.

6. Conclusions

The built heritage including the architectural heritage is now recognized not only as an object of cultural value and exclusive property but also as a multidimensional socio-economic asset (Shipley and Reeve, 2010; Gražuleviciute-Vileniske et al., 2011; Hernández-Mogollón et al., 2013; Mark, 2013; Rodríguez-Oromendía et al., 2013). As our cultural heritage suffers from various physical and environmental factors and becomes inevitably lost, the documentation and monitoring of heritage objects plays an important role in the architectural heritage preservation. The development of 2D and 3D models of architectural heritage objects in their current state requires methodologies that can digitally preserve and model information about geometry and appearance of such objects for future generations.

Here we reported the photogrammetric measurements in conjunction with the exploration studies of the heritage objects to record architecturally valuable elements and their possible surface and geometric deformations. For this purpose, the pipeline of a compilation of the ortho-photographic model for investigation of the heritage object was proposed. With the assistance of appropriate software, such as *PhotoMod*, it was demonstrated a procedure of entering the area of the geometric deformation onto the ortho-photogtraphic model, which enabled to evaluate the amount of the materials required for the restoration works and to determine the costs required for restoration work.

The images of Užutrakis palace walls were used for the analysis. The ortho-photographic model of the wall was compiled by means of the photogrammetric method. The evaluated accuracy was 1-5 µm. Obtained results met the scale requirements of 1:10 and 1:50. The high accuracy of the photographed object was ensured and influenced by the optical quality of the lens of the camera and by the accuracy of the CP and tie points for the object during the photogrammetric measurements. The obtained ortho-photographic model during the photogrammetric measurements was geometrically accurate and orientated. Developed model permitted to depict a precise structural description of the ornaments.

The established close-range photogrammetry pipeline can be used for documentation and geometric deformation monitoring of cultural heritage artwork and decorations. Moreover, acquired digital data can be exploited in assessing their state and conditions and help with determination of the quantity of material, which is required for restoration of the ornament. Most importantly, the model, developed utilising the digital data generated by means of the close-range photogrammetry, is easy to store in the digital archive and can be reused for restoration of the architectural heritage object or for other purposes if required in the future.

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