3D RECONSTRUCTION OF THE HISTORIC BAALBEK/LIBANON BASED ON HISTORICAL AERIAL, OBLIQUE AND TERRESTERIAL PHOTOS

A. Alamouri [a], L. Gruendig [b]

Institute for Geodesy and Geoinformation, Technical University of Berlin, Straße des 17. Juni, 10623 Berlin, Germany
alamouri@mailbox.tu-berlin.de, gruendig@inge3.bv.tu-berlin.de

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ABSTRACT:

Baalbek is an important urban heritage site due to the 5000 years of history in the city. Therefore, the documentation of historic Baalbek should be respected. For this purpose the historical images of Baalbek were used which are classified into three types: vertical, oblique and terrestrial photos. The photos have poor properties (different cameras used and no primary data of the camera parameters, high image noise, in addition the images were taken in different dates). Due to these properties an optimal images orientation should be enforced to know by which combination and order of the images orientation the optimal orientation parameters could be estimated. Based on Baalbek's oriented photos 3D object points could be measured to reconstruct 3D objects. *This paper investigates the combination between the different image types to achieve an optimal 3D object reconstruction; moreover, the geodetic and geometric accuracy of additional 3D points extracted will be controlled.* Additionally, it will be determined in which photo/photos an object point is existed and from which photo this point could be optimal recorded. The results of this study will be considered a data base for other applications in Baalbek's space (e.g. Geoinformation System GIS, 3D CityGML: 3D City Geography Markup Language). This leads to create a concept, with it, the other users (e.g. archaeologists, architects, etc.) can derive the requested data without the primary geometric information from oriented photos; that means an interactive and web-based evaluation has to be taken in the account.

1. INTRODUCTION

Baalbek is situated on the northern of the Beqaa-Plain/Libanon which was settled in the beginning of 3rd millennium BC (Van Ess, 1998). The old preserved dwellings validate the historical importance of this city. Existing of the Roman Colonia Iulia Augusta Felix Berytus 15 BC was the reason that Baalbek had a settlement of the Roman veteran.

Additionally, the constructions such as the temples: Jupiter, Bacchus and Venus are witnesses of Baalbek's wonderful construction. The sanctuary was designed in a new form and built in a monumentality which was not known before. Through the 4.th - 7.th century Baalbek got more Christain churches which could displace but slowly in the old cults. The Islamic empire (12th – 14th century) had converted the site of the temples into a great fort. Since 1984 Baalbek is considered through the UNESCO as an important one of the urban heritages in the world. According to the historic importance of this site the documentation of the historic Baalbek should be achieved to help us to understand the historical changes of Baalbek from the prehistoric date up to 20th century. The intended documentation of Baalbek will be enforced using the photogrammetric evaluation of the graphical materials of Baalbek. Basically, there are three image types of Baalbek: vertical, oblique and terrestrial photos. These images have poor properties (such as: no a priori data about the cameras used, different scales of images, different altitudes of flight, the contrast of gray values is relative high, in addition the images were taken in different dates). Therefore, an optimal image orientation process should be performed to know by which combination and order of the images orientation the optimal results (interior and exterior orientation parameters) could be estimated.

The orientation process was achieved based on a new approach for relative orientation of the historical photos. This approach consists of three strategies; the first one is the orientation of each image type in a separated block with its special properties (e.g. for each type a special camera was assumed) then the bundle block adjustment was implemented. The second is the performance of the orientation process only for the vertical and oblique photos together. The last one is all types of Baalbek's photos were assembled in the same block then the triangulation process was enforced (see Alamouri et al., 2008). Building on the oriented model of the photos, the space object points could be measured in order to re-construct 3D objects. In this step, the re-construction of the 3D applicable points will be investigated as well as the geodetic and geometric quality of the applicable 3D points measured will be controlled. This check is essential for further work steps (e.g. Baalbek's 3D CityGML)

On the other hand object points extracted should be classified so that it could be known: from which camera a point was taken and from which photo this point will be optimal shown. Basically, there are important requirements which have to be respected by the re-construction process (e.g. the reconstructed model should be useable for next applications which will be achieved by other users, e.g. historians, archaeologists, etc.).

The re-construction procedure of 3D object points measured consists of the following stages:

- Creation of Baalbek's orthophotos based on the oriented historical images. In this step it is necessary to create a Digital Terrain Model (DTM) of the studied area.
- Generation of Baalbek's mosaic.
- 2D coordinates extraction of object points depending on the region mosaic created.

- The values of the 3rd dimension Z of measured 2D points were integrated using the oblique and terrestrial photos on one hand and the stereoscopic analysis on the other hand.

The work led to the result that the geometric modelling of the studied area was achieved. The geometric information will be considered a data base for the Geoinformation System of the Baalbek's space. Therefore, a concept could be enforced; with it the other users (e.g. archaeologists, architects, etc.) can acquire their requested data without the primary geometric information from the oriented images that means an interactive and web-based evaluation is essential to support and provide different requirements of customers or users. On other hand the quality of 3D features derived allows to use the data to generate a 3D CityGML model of Baalbek (according to the City Geography Markup Language, City GML; the international standard for 3D City models, Gröger et al., 2008).

2. CORRESPONDING SEARCHES

The current activities in the city Baalbek are being conducted in different areas of the Roman town of Baalbek. In this context, basically, different documentations, drawings and stratigraphic analyses of areas and buildings were achieved and discussed. The projects could be classified as following (according to Van Ess et al. 2003):

- ***Bustan el Khan*** in the 1960s, 1970s and 2001-2004
- Area of the ***Venus temple*** since 2002
- ***Qala'a*** in 1960s and ***Sheikh Abdullah*** since 2002

The results of the abovementioned works based on the town history and geodesy indicated some new important assumptions concerning the chronological sequences of the wonderful constructions of the temples and their interrelationships.

In the years (2005 and 2006) A. Klotz and M. Gessner worked only with the aerial vertical images of Baalbek to create orthophotos and rectified 2D plans. Although the scientific works and the researches in Baalbek started in the 18th century, there are many unexplained questions which are posed concerning the town planning and its urban progress. These questions are considered as additional motivations for this work especially with using the oblique and terrestrial photos of Baalbek, which could be given more information about the city.

3. WORK FLOW AND RESULTS

3.1. Creation of Digital Terrain Model (DTM) of Baalbek

According to (Köthe, 04/2000): "Digital Elevation Model (DEM) is the digital stored XYZ-triples of a surface. It is very necessary to mention which surface is meant by using the DEM (for example: DEM of the vegetation surface, DEM of the ground water surface, DEM of the earth surface, etc.). On the other hand the DTM is the digital stored XYZ-triples of the earth surface, therefore the DTM is considered, in practice, as one special case of the DEM; that means DTM = DEM of the earth surface".

Basically, we concern the height values of the ground by using a DTM. In the case of evaluation of digital images the height differences of the earth surface will lead to radial distortions. These distortions could be minimized in the digital images by using a DTM.

In practice, a generation of DTMs depends mainly on the input data (e.g. oriented digital images, topographical maps which should cover the whole area of interest, etc.). Depending on the Baalbek's aerial images (vertical images type) it was difficult to create a well quality DTM from the oriented images, because they do not have a good state due to their poor properties. Therefore, a DTM was generated using topographical maps of Baalbek. However, there are two topographical maps of Baalbek which were obtained from the institute of *Francais du Proche Orient* (*IFPO*) in Damascus. Both maps were scanned with the scan resolution (300 dpi). The Properties of Baalbek's maps implemented can be expressed as following:

- Emission date is in the year 1962
- The maps cover the whole area of Baalbek
- They have the scale (1: 20 000)
- Ground resolution is ca. 1.7 m (with respect to pixel size)
- Ellipsoid used is Clark 1880
- Maps' projection is stereographic
- The interval of contour lines is 10 m
- Longitude line is 38°
- Latitude line is 43° 50´

In order to focus only on the same area appearing in the vertical images type of Baalbek a new map was derived based on the abovementioned topographic maps. This map is indicated with the name *submap_baalbek*. The derived map should be georeferenced onto the local system of Baalbek's vertical images; that means the new map should be associated with the vertical image coordinate system (Baalbek's local system).

Geometric Control Points (GCPs) take an important role in the georeference process in order to enforce the transformation between the map and the images. The critic number (n) of GCPs requested depends on the order of the transformation. This number is given (Leica Geosystems, 2005):

$$n = \frac{(t+1)(t+2)}{2} \tag{1}$$

where: t is the order of the transformation

If the minimum number of the GCPs is not satisfied, it will not be possible to resample the input data (Baalbek's map); this means the georeference process will not be executed. In our case eight GCPs were applied into the process and the resample method selected was *"Nearest Neighbour"*. The map resulted has the output cell size ca. (0.98 m) for X and Y. The next step is the *vector process* with it the contour lines were digitalized using the vector tools which are based on the ESRI[1] data models. Through the digitalization process the contour lines interval was preserved as (10) m. The height values of the contour lines (regard to the new resampled map) are in the range (1080-1450 m).

The surfacing process was performed successfully and the DTM of Baalbek was generated (a section of Baalbek's DTM created is shown in the Figure 1). The DTM properties could be summarized as following:

- Output file name: *dgm_karte_lokal*
- Cell size for X and Y is 9.00 m

[1] ESRI: Environmental Systems Research Institute

- The coordinates of the upper left point: X=7605.35 m and Y=12298.39 m (in Baalbek's local system)
- The coordinates of the lower right point: X=12534.97 m and Y=8313.97 m (in Baalbek's local system)

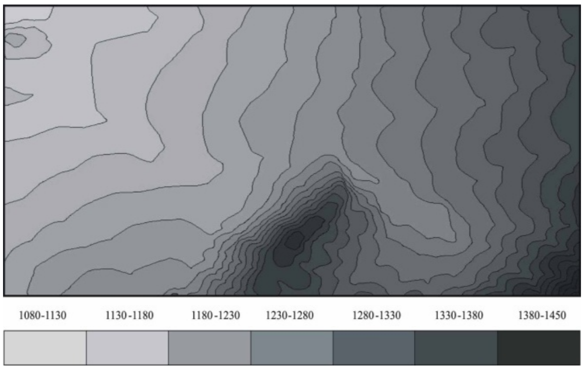

Fig. 1: A section of Baalbek's DTM (Height values in m)

3.2. Baalbek orthophotos' generation

3.2.1. Definition

An orthophoto is an image transformed geometrically; this transformation converts the original photo, which is in general distorted, into orthogonal projection. The orthogonal projection of an image enables to display the object surface included in this image in an orthogonal view.

The aforementioned transformation process is called *"image rectification"*. The rectification process could be classified into planar or differential rectification. In our case the second one is requested, because the height differences of the object points (or control points) exceed the critic value Δh_{max} which is calculated as following (Wiedemann, 2004):

$$\Delta h_{max} = \frac{c_k}{r'_{max}} \Delta r_{max} \tag{2}$$

where: Δr_{max} …. maximal distortion
r'_{max} …….maximal radius of the image
c_k ……... focal length

3.2.2. Orthophotos creation using LPS

Leica Photogrammetry Suite (LPS) is defined as a collection of integrated software tools which offer different photogrammetric processes (e.g. an orthophoto creation, etc.) for the geospatial imaging applications. The primary component of LPS is *"LPS Project Manager"* which reduces the cost and time associated with different photogrammetrical procedures (more details are presented in LPS user's guide, Leica Geosystems, 2005).

The vertical images used (in this step, seven vertical images) were saved in the block file *"Baalbek.blk"*. Orthophotos of the oriented images - associated with the block file *"Baalbek.blk"*- were generated with respect to the orientation parameters estimated on one hand (Alamouri et al., 2008) and to the generated DTM in other hand. The cell size of the orthophotos was computed automatically based on the scale and resolution of the images; in this context, the cell size is approximately bounded to 0.13 m for X and Y. The resample method *"Bilinear Interpolation"* was implemented due to the well quality of the gray values' calculation. By this method the requested gray value of a pixel in the output image is computed building on the four nearest neighbours (four nearest pixels, Fig. 2). The new gray value (g) is calculated based on the gray values g_1, g_2, g_3 and g_4. It is given (Pum, 2003 & Luhmann, 2003):

$$\begin{aligned} g = {} & g_1 + dx(g_2 - g_1) + dy(g_3 - g_1) \\ & + dx \cdot dy(g_4 - g_2 - g_3 + g_1) \end{aligned} \tag{3}$$

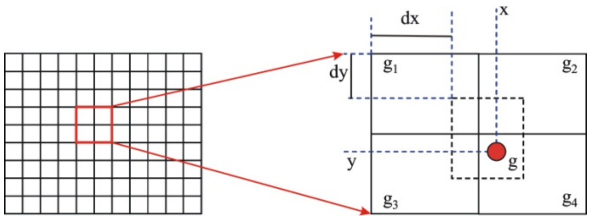

Fig. 2: The principle of the bilinear interpolation

The Figure (3) shows two original vertical images and their orthophotos created; (a: original image 1981, b: orthophoto 1981, c: original image 2025 and d: orthophoto 2025).

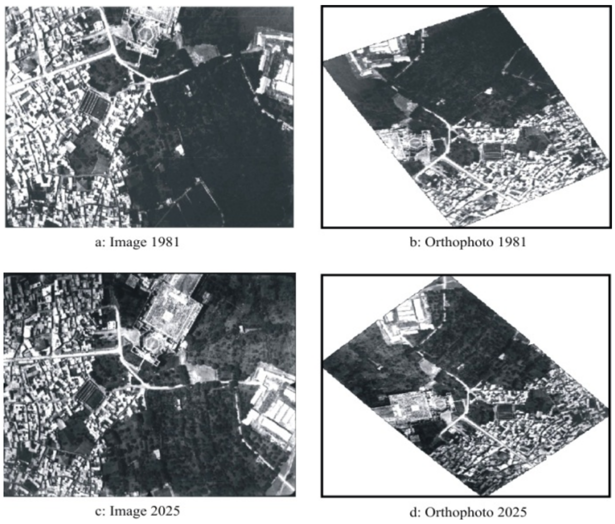

Fig. 3: Two original vertical images of Baalbek (left) and their orthophotos generated (right)

3.3. Region mosaic creation

"The term ***mosaic*** can be defined as the montage process of multiple rectified images (multi-orthophotos) in order to merge them in uniform image" (Wiedemann, 2004). In this context; the geometric and radiometric adjustment of orthophotos has to be taken into the consideration.

The main task in this step is the generation of the cut lines between the orthophotos used. Cut lines performance depends on the overlaying between the images. Non-planar objects in the rectified images, in addition, the image noise led to challenges through the overlaying between the historical images (e.g. objects matching and recognition, etc.). To define cut lines in an optimal way, a digitizing approach (semi-automatic) was used. An example of adjusted cut lines is presented in the Figure (4).

On the other hand the histogram matching approach was used to adjust the radiometric failures (noise, contrast, brightness, etc.); so that the (orthophoto -1985) was implemented as a muster for the gray values transformation of orthophotos into the region mosaic (gray values adjustment). An illustration of Baalbek's mosaic based on the orthophotos is shown in (Figure 5).

Fig. 4: A section of three cut lines created between 3 orthophotos of Baalbek

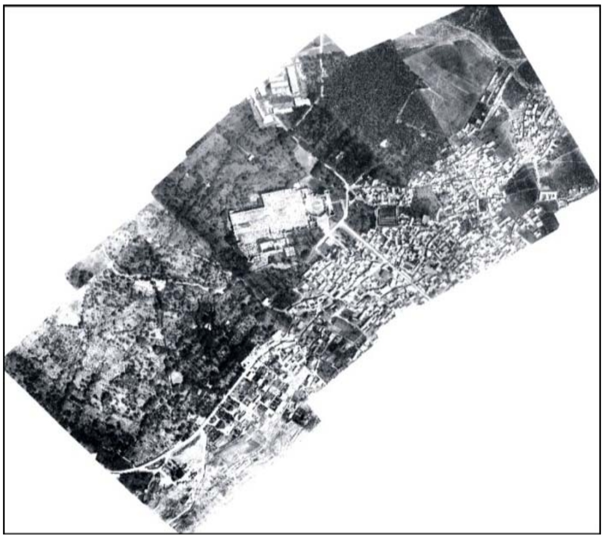

Fig. 5: Baalbek's mosaic based on seven orthophos

3.4. Features acquisition and fusion

3.4.1. Extraction of 2D objects

Baalbek's mosaic created was regarded a basic source to extract 2D coordinates of requested objects. In our project the most of objects (included in images) are buildings, therefore it was easier to express these buildings (also some streets, routes) through polygon (or multiple polygons) and save it as vector data (Figure 6). The vector tools are based on ESRI data models, therefore ESRI shape files can be used for further works without conversion. Each vector layer has attributes which include different parameters (for e.g. area of polygon, perimeter of a polygon). The non-building objects (e.g. trees, vegetation) can be modelled as discrete points. The distinction of objects in the mosaic was the main problem in the features' acquisition process because of the high noise and contrast in the images of Baalbek.

Fig. 6: 2D data of extracted buildings (shape-data)

3.4.2. Integration of height values

For each 2D object extracted there is a Z-value associated with. In other words, each Z-value is given as a function of the 2D position with the assumption that a polygon (i) has the height value Zc_i related to the polygon centroid (Xc_i, Yc_i):

$$Zc_i = Z(Xc_i, Yc_i) \tag{4}$$

However, two approaches were used to determine the height values. The first is based on the oriented model of the terrestrial and oblique images of Baalbek, whereas a geometric position of an image point existing at least in two oriented images can be determined using the *Epipolar Geometry* (Rodehorst, 2004). An intersection of at least two Epipolar lines in an image determines the position of a requested image point as well as the 3D coordinates associated with (Fig. 7).

The second one is the stereoscopic analysis which enables us to obtain height values using a pair images oriented. Due to the poor properties of Baalbek's images it was difficult to certain a point position in an image pair selected exactly. This challenge led to a point displacement which affects the determination of height values. Figure (8) displays the Digital Stereo Model (DSM) created based on a selected oriented pair of the vertical images of Baalbek.

Fig. 7: Determination of the point position based on the intersection of Epipolar lines

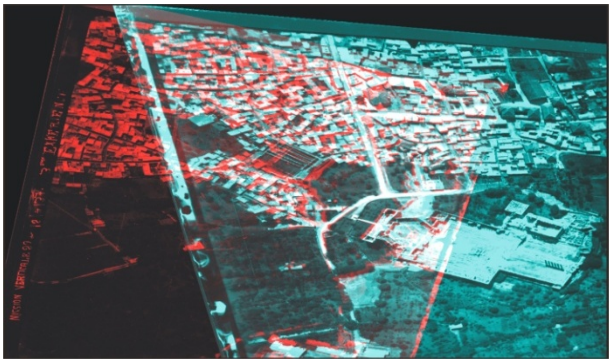

Fig. 8: Digital Stereo Model based on pair images of Baalbek

3.5. Classification of applicable 3D object points

An important task of this work is a creation of applicable 3D points' classification. It will enable us to know: *from which camera an object point is taken as well as from which photo this point is optimal shown*. This classification is necessary for other applications (e.g. GIS, architecture, etc.).

The principle of this classification intended could be classified into following steps:

- Identification of a 3D object point location; that means in which image/s the point requested exists (Figure 9, a).
- Estimation of the standard deviations (S_{X_i}, S_{Y_i} and S_{Z_i}) for the object point coordinates (X_i, Y_i and Z_i). The General Estimated Standard Deviations (GESD$_i$ = S_i, Fig. 9, b) can be expressed:

$$S_i = \sqrt{S_{X_i}^2 + S_{Y_i}^2 + S_{Z_i}^2} \qquad (5)$$

where: i=1,…n; n number of applicable object points

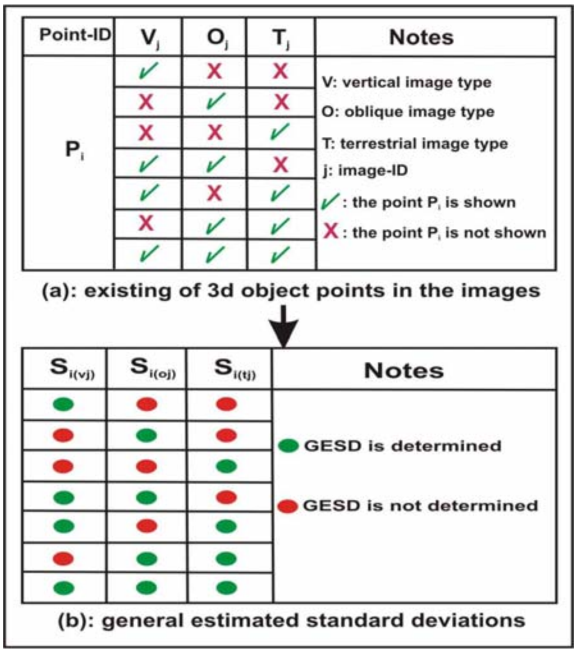

Fig. 9: classification principle of 3D applicable points

The image index (ID) as well as image types (in this case: V = vertical, O = oblique and T= terrestrial) should be taken into the account. Therefore, the formula (5) could be given:

$$S_{i(kj)} = \sqrt{S_{X_i}^2 + S_{Y_i}^2 + S_{Z_i}^2} \qquad (6)$$

where: j is the image_ID and k is the image type

- Based on the minimum value of the $S_{i(kj)}$ we can know that the object point (P_i) is optimally shown in the image which has an ID = j as well as the type (k).

4. RESULTS QUALITY AND INTERPRETATION

4.1. Baalbek DTM quality

"The grid cell size is the most common criterion concerning the quality of the DTM. An increasing of the grid cell size leads to a decreasing of DTM resolution that means an increasing of the generalization of the real surface. The DTM precision with respect to the grid cell size and its altitude depends on the slope gradient of the real surface and the size of the terrain unit. The DTM will be accurate created, if the real surface is steep and the terrain units are small. Units smaller than the grid cell size will not visible in the DTM because they just slip through the grid" (Köthe, 04/2000). The ground resolution of the input data (map/image) takes an important role in the calculation of the DTM grid cell size. With respect to the assumption that the grid cell size computation based on a 1 pixel to 10 pixels in the DTM, that means the ground resolution of 1 meter leads to cell size for the DTM of 10 meters. The ground resolution of Baalbek's map is ca. of (1.7) m which leads to an appropriate critic cell size of (17) m, therefore the assumed cell size of the DTM has not to exceed the critic value (17) m. In our case, the applied cell size is (9) m and this reveals that the generalization of the real surface throughout the model was relative decreased.

Other control of the generated DTM quality is the creation of a new contour map as (*Point Status Output Image PSOI, shape file*) using the DTM created. The *PSOI* illustrates the quality associated with the correlated DTM postings which are classified in: *Excellent*, *Good*, *Fair*, *Isolated* or *Suspicious*. By comparing between the *PSOI* and the *digitized contour lines*, we could be accepted that the both are approximately well matched (Figure 10); that means the DTM posting can be categorized as good, therefore it was possible to use it in orthophotos creation.

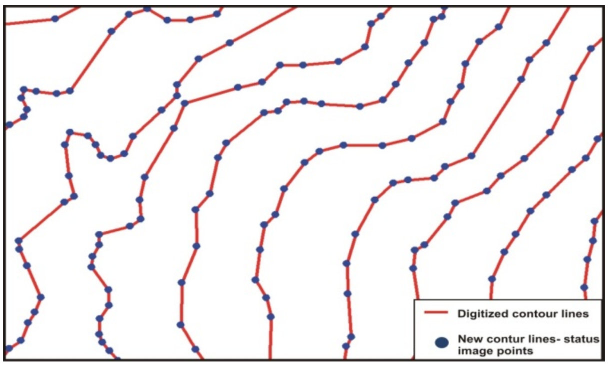

Fig. 10: Comparing between digitized contour lines and the new one created using the DTM-status image points

4.2. Baalbek's orthophotos check

The quality of the differential rectification could be discussed based on the following aspects (Kraus, 2003):

- Input data (e.g. image resolution, control points accuracy)
- Image distortion (radial and decentring distortions)
- The approximation of the surface curvature in the DTM grid
- Interior and exterior orientation parameters, etc.

An important criterion concerning the orthophoto quality is the *position error* Δr in the orthophoto, which is given based on the *position error* ΔR in the reality as following (Kraus, 2003):

$$\Delta r = \frac{1}{m_0} \cdot \Delta R = \frac{1}{m_0} \cdot \frac{\Delta Z}{\frac{c_k}{r} + tan\alpha \cdot cos\beta} \qquad (7)$$

m_0 image scale number (it is 4000 in our project)
c_k camera focal length (ca. 200 mm)
r the distance in orthophoto between the both footprints for object point P_i and the Nadir point
α the angle of terrain slope
β the horizontal angle between the line of greatest slope and the optic axis passing through the object point P_i
ΔZ the error of the height; which is defined as a treble of the precision related to the contour lines in the raster image. It can be given as:

$$\Delta Z = 3(0.00015h) \qquad (8)$$

An object point associated with the image radius ca. 95 mm in orthophotos was checked. With respect that the flying height $h = 800$ m, the terrain curvature is ca. $tan\,\alpha = 10\%$ and $\beta = 50$ gon; the *position error* Δr will be ca. 0.04 mm

4.3. Evaluation of 3D feature acquisition

"CityGML supports different Levels of Detail (LODs) by them we can represent different data collections. Basically, there are five LODs. LOD0 is essentially a 2.5D DTM. LOD1 is the well-known blocks model of the buildings with flat roofs structures. Additionally, LOD2 has more details about the roofs' structures. LOD3 denotes architectural models with detailed walls and roofs. The last type is LOD4 which represents the interior structures of the objects" (Kolbe, 2009).

The quality of 3D object points extracted should be checked to know in which LODs the applicable object points can be modelled. According to (Gröger et al., 2008), the 3D feature accuracy for CityGML is described as standard deviation of the absolute 3D points. In LOD1 the positional and height accuracy of the 3D points should be 5m or less. In contrast, by LOD2 the positional and height precision of object points should be 2m or better. In our project, the achievable accuracy of the applicable 3D object points based on the oriented model of the images is smaller than 2/2 m (for the position and height); therefore, it will be possible to use the 3D features derived to create a 3D city model of Baalbek in LOD2. This model provides on one hand an important document for the city and on the other hand to understand the historical development of Baalbek's buildings remains from the prehistoric date until 20th century.

5. CONCLUSION

3D re-construction process of object points was achieved based on oriented historical images of Baalbek. The 1st step of this process is a creation of Baalbek orthophotos using the oriented images (in this step a DTM of the studied area was necessary). 2D object points depending on the created mosaic were derived. The 3rd dimension (Z) of measured 2D points was integrated using oblique and terrestrial photos as well as the stereoscopic analysis. 3D object points extracted have to be modelled, so that a classification of applicable points can be enforced to know from which camera a point is taken, moreover, from which image this point will be optimal recorded. The achievable accuracy of 3D features acquired allows using them to create a 3D CityGML model of Baalbek in LOD2 which includes geometric and semantic data. This step is considered as a further task of this work.

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