Agnese Kukela, Valdis Seglins
University of Latvia, Latvia

STUDY OF THE HISTORICAL MONUMENTS: FROM THE PHOTOGRAPHY TO THE DIGITAL SPATIAL MODEL

Abstract
The gradual deterioration of historical stone monuments due to weathering and other factors, including the development of tourism is a growing concern. Precise documentation along with historical drawings and photographs of these objects is very important for elaboration of sustainable monument remedy and preservation plan. The integration and correlation of this information is rather complicated. The method elaborated by the authors allows to create 3D model of the object with further possibility to supplement it and integrate into this model various visual and data information and systematically update it. The method is based on the focused selection of the large size digital images and their further integration into digital spatial model created with MicroStation V8i software. This method was developed for the studies of the Step Pyramid of Djoser in Egypt, but it also can be applied for the studies of other historical monuments.
Key words: monuments, material deterioration, digital 3D model, data integration, conservation

Introduction

The elaboration of the reconstruction and conservation strategy plans includes wide range of methods such as documentation of the current conditions of the monument, technical measures of restoration and actions for sustainable preservation of the monument. The specialists of various scientific areas with different professional approach and experience background are involved in each of these steps, thus raising the level of responsibility while choosing particular preservation and reconstruction strategy.

The precise documentation of the monument forms the main basis for elaboration of the conservation strategy. Historical photographs, drawings and sketches are also invaluable. The conjunction and integration of this information is complicated and often also unrealisable process. Traditionally, the preparation of the projects is based on the survey data that forms the graphical background for the technical projects, whereas the assumptions on the possible original look of the particular historical monument are based on experience and creative perception of the artists and architects involved. Thus the documentation on reconstruction of the monument consists of accurate plans and construction projects elaborated by the engineers, visions of the artists and historical photographs or their fragments of different quality.

Detailed photographic documentation of the objects is a widely used method already from the 1880's. Initially these are individual images or their groups. Later diverse methods of photo monitoring were used. Among them - sequential acquisition of the images from the same view point with regular time interval, various methods of photo mosaic and panoramic image development, including the layouts of the facades of the buildings (Groat, Wang 2002: 135-167).

However, aforementioned methods with respect to their technical accomplishment have several substantial drawbacks, where the main one concerns the perspective look and the deformation of the scale of the image. These are the main reasons why these documents are rarely used in the technical projecting.

The aim of this study was to create a certain system for data processing that on the initial stage of the documentation of an object would enable us to integrate numerous images of particular object acquired in different time periods providing further possibilities for focused analysis and detailed elaboration of the preservation strategy plans.

The Step Pyramid of Djoser at Saqqara (Egypt) was chosen as an object of our study. This pyramid along with the other historical monuments of this area in the year 1979 was included in the World Heritage List of UNESCO. Currently the Step Pyramid of Djoser is under vast reconstruction and it is not available for any particular studies except photographic documentation.

Materials and methods

The study was carried out since the year 2005 performing systematic photographic documentation of the Step Pyramid of Djoser as far as the rules and regulations for visitors of this site permitted. The study consists of several stages that are discussed further.

Focused photographic documentation of the pyramid.

The Step Pyramid of Djoser currently has limited availability for documentation and the acquisition of images of both – lower and upper steps of the pyramid could be done only from the ground along the perimeter of the pyramid. Unfortunately, the photography using a tripod is mostly forbidden as well as continuous field observations. Partial reconstruction of the pyramid begun in the year 2009 and envisages replacement of construction blocks of the pyramid and weatherboarding of the facades. This reconstruction process imposed additional constraints to access northern and western façades, while southern and eastern façades were almost completely covered with scaffolding.

Taking into account general requirements of the study, the digital camera for the systematic photo documentation had to meet certain requirements such as: reliability for use in the field (comparatively small weight and size of the camera, ability to function in the temperature above +30°C, resistance against wind with high degree of dust as well as inconsistent intensity of local electricity to charge the camera). Several cameras have complied with these requirements, however the SONY DSC-R1 10.3 Mp camera was chosen as the most appropriate. As a quality control measure part of the facades of the pyramid were photo documented with other cameras (Fuji FinePix S602Zoom and Canon EOS Kiss X2 DSLR). Our experience showed that in such conditions the cameras chosen allowed to obtain images of high quality (at least 2.5 Mb in size) for further processing and interpretation.

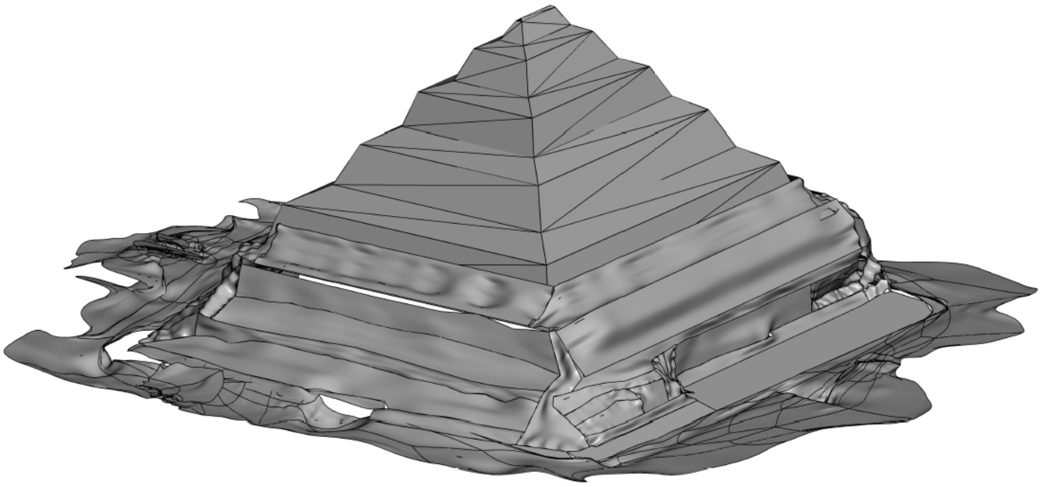
Geospatial model of the pyramid.

At the initial stage of elaboration of the geospatial model of the pyramid possible solutions were analyzed in detail setting certain demands regarding the choice of the software. Comparatively wide use and availability of comprehensive tools to ensure that future results are used by possibly large number of users was one of the first demands. Another requirement was the capability to integrate direct and indirect measurement data compatible also with AutoCad software. Additionally, the software was required to have traditional Geographic Information System (GIS) formats. Analysis of the available software revealed numerous options and advantages of several programs; however all above mentioned features could be realized almost solely by MicroStation software.

For the technical development of the geospatial model of the Step Pyramid of Djoser 3D laser scanner data was used. The 3D laser scanning was performed in the framework of the Latvian Scientific Mission working in Egypt from the year 2005 till the year 2007 that obtained the data on the 1st and 2nd steps of the pyramid (ca. 5 million points). The 3D laser scanner data was further processed by Leica Geosystems generating a model of the surface of the pyramid with 3 cm precision. To design the other four steps of the pyramid Google SketChup model was used (3d-model for GoogleEarth), adjusting it by Djoser's pyramid plan section data. The final stage of elaboration of the 3D model of the pyramid was performed using SmartSurface algorithm of the MicroStation V8i software that requires minimal computer resources for visualization of the surface (Figure 1). This algorithm allows the ortho-images of high resolution to be projected on the planes of the pyramid's surface. Thus this 3D model can be integrated into GIS applications ensuring the possibility for further long-term analysis of the data spatial crossings and thematic maps of different resolution.

The development and application of the specific information layers.

The assessment of the detailed photographic documentation contributes not only to the creation of a high quality geospatial model, but also reflects particular information on the object as such.



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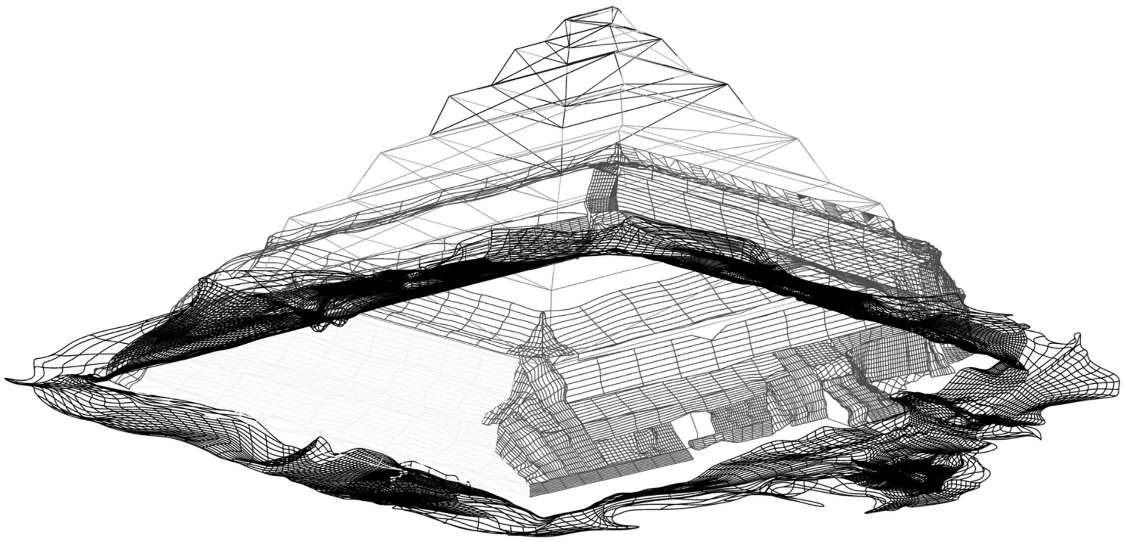

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Figure 1. Simplified visualization of the geospatial model of the Step Pyramid of Djoser.
A: South – west “*Illustration*” display style view of the pyramid; B: South – east “*Wireframe*” display style view of the pyramid.

The Step Pyramid of Djoser is built of the stone construction blocks and one of the major threats is the deterioration of the stone material that threatens the stability of the structure of the pyramid. The assessment of the weathering types and their intensities of the exposed surfaces of the pyramid’s construction blocks were performed manually by applying the method elaborated by the authors (Kukela, Seglins: *in print*). This analysis was carried out with different degree of detailed elaboration in order to determine the best approach for application of such analysis for the whole pyramid in the future.

The study and the results

The study covered completion of several separate tasks that further will be discussed in details as methodological solutions.

1. Creation of the pyramid's digital model.

Creation of the image data base.

All the images (acquired during the time period from the year 2005 till the year 2010, ca. 2100 images in total) included into the image database are classified according to the time of acquisition (the year and the month). Afterwards, attaching the images to the corresponding facades and edges of the pyramid's model, additional data is noted on the size of the image, specifics of the camera and supplementary information on the conditions during acquisition of the image. The classification according to the months and the year of acquisition of an image is set as main criteria since it significantly facilitates the search of particular images. In this case it is very important due to vast reconstruction works of the pyramid's interior and exterior, which have been carried out since the year 2009. During this reconstruction the look of the pyramid's facades changes considerably (the scaffoldings are being moved, the fragments of the facades are being re-built, etc.).

Verification of the quality of the images and their selection for the particular needs of the study.

Originally all the images have been checked and images with impeccable acuity only were included into the data base. Blurry images are excluded from the data base and are kept in the archives. Further verification of the quality of the images is performed taking into account particular purpose of the selection of the images. Since there are several aims in this study, each of them initiated different requirements towards the selection of the images.

The creation of the 3D model of the pyramid.

For this particular part of the research images depicting the panoramic view of the pyramid's façades were selected. The images where the pyramid's façade was partially covered with scaffolding or other extraneous objects were also considered as valid since these images as well are providing information on the dimensions and proportions or the particular façade of the pyramid. The main criteria for the selection of the images necessary for the creation of the 3D model of the pyramid is possibly full depiction of the whole pyramid's façade on the image, including the top, the base line and both sides of the façade.

2. Provision of the pyramid's model with the photographical data.

The creation of the photo mosaic of particular facade for its further integration in to the 3D model.

For this purpose images containing detailed information on particular fragment of the facades were selected. Most suitable are images of at least 2 Mb in size covering several square meters of the façade's fragment, thus allowing identify exact location of this area. In order to create the photo mosaic of the particular façade of the pyramid it is necessary to select as many images, so their totality would completely cover the whole area of the façade (including the inter-step areas) ensuring that the images overlap each other for at least 30%. Fulfilment of this requirement allows further precise combination of the images.

The creation of the photo mosaic of the pyramid's façade.

Each of the images selected from the data base using PTLens 8.7.8 software have been adjusted to correct lens pincushion/barrel distortion, vignetting, chromatic aberration, and perspective. Such an adjustment is necessary to ensure comparability of each image with other images taken in different conditions or time periods. Furthermore, all selected and adjusted images using MicroStation V8i software are placed on the previously elaborated 3D model of pyramid forming a mosaic. The image of the whole façade of the pyramid along with detailed images of the façades fragments are attached to the working 2D file design as raster images. Afterwards raster image "*Warp*" function is used to adjust the size and shape of raster image with a combination of move, scale, rotate and skew options to match raster image to design file elements using several points to match the source and destination points. When all façades of the pyramid's 3D model are completely covered with the photo mosaic, the images are merged to form a homogeneous highly detailed covering.

Detailed steps of creation of the photo mosaic.

Before starting the work process, all selected images necessary to create a photo mosaic of the particular façade are moved into one folder thus facilitating their search. Each of the selected images after their adjustment is geo-referenced by creating the coordinate file with identical file name.

To ensure the object is suitable for its further processing in 3D environment, it has to be defined in the coordinate system with coordinate axis parallel to the planes of the object. This allows to create geo-referenced images with particular coordinates appropriate for their further use in GIS.

Subsequent development of the photo mosaic is performed by the MicroStation V8i software Descartes module that is specially designed to facilitate image transformation, editing, enhancement, mosaicking, and georeferencing (warping). For each step of the pyramid separate file is created. Initially the panoramic view image of the pyramid is attached to the working file as a raster image and then it is georeferenced to the corresponding step of the 2D façade with "*Warp raster*" tool using "*Affine*" method. This method combines move, scale, rotate and skew actions to adjust and match the size and shape of a raster image to the design file elements.

Furthermore, individual images of the fragments of the façade are one by one attached to the design file elements starting from one side of the façade's step. This action is performed with the "*Register dialog*" tool using the "*Projective*" model that projects one plane to another placing at least 4 control point of the image. However, to ensure one pixel match and high compatibility of the projected images with the design file element, the average number of control points should be at least 20 to 30 and they should be placed not only in the corners of the raster image, but also in the other areas proportionally covering whole raster image area. All control points are indicated in the "*Register dialog*" box along with their residual values. The residual of a control point is the difference in location between the position where a control point is pinned on the system as compared to the position where it should be according to the actual model. Residuals are distances. The column X, Y, and XY indicates the X component, the Y component and the magnitude (XY) of this distance. To ensure the high quality of mach, the value of XY should not exceed 0.2000 (ideally it should be 0.000).

After all necessary control points are placed, the control point model should be saved as a separate file assigned with a freely given name in **rgr.* data format. Then "*Resampling dialog*" tool is used to apply a geometric model to an image. The input data is transformed into an output data set that belongs to the base coordinate system, directly compatible with the base vector data that was used to create the mode. The "*Input image*" field displays the name of the input image file (the one that is being matched to the 2D façade's particular step). The "M*odel*" field displays the name of the transformation model file (the model of the control point set). The "*Output image*" field displays the name of the output image file that should be created assigning a freely given name in **tif.* data format. At the file save options a "W*orld file*" should be chosen. It is necessary to attach this image to precise coordinates of the plane. The "*Bilinear interpolation*" algorithms and "S*ame pixel size*" choice ensures the best results of matching of the image. The resampling process is started by clicking "R*un all*" button. The newly created image that was adjusted and transformed is automatically opened and placed in the particular place on the design plane according to the saved control point model.

Furthermore, each of the façade's fragment images is attached to the design file elements in aforementioned way until all the images forming a mosaic are placed on the corresponding design file elements, i.e., fully cover the steps of the particular façade.

However, the joint lines between the images are still visible. To make these joint lines smooth and invisible, the "*Define seam*" tool in a "S*mart*" seam mode is used. It defines the position of the seam between two overlapping image portions of a mosaic.

When all the images are matched and their joint lines corrected, the "*Merge*" tool is used to merge several images contained within a defined area. Through the "*Merge option*" dialog a new image file depicting all the selected merged images is created. It should be assigned with a freely given name in **tif.* data format and at the file save options a "*World file*" should be chosen.

The transfer of the elaborated photo mosaic on the 3D model of the pyramid.

This action is also performed by the MicroStation V8i software Descartes module. All necessary photo mosaic fails are sequentially attached to the working 3D file as raster images. Since the 3D model of the pyramid is formed of the trapezium form rectangles consisting of merged triangles, before integrating the photo mosaic it is necessary to split these figures. It is done by the "*Drop element*" tool that is used to break up elements into simpler components. Further matching of the photo mosaic with a 3D model of the pyramid is done by the "*Texture tools*". First, the photo mosaic image is assigned to a particular area (fragment) of the 3D model of the pyramid. Then using "*Warp to area*" option it is matched with the corresponding fragment of the 3D model by at least 4 points. After all points are pinned, the new photo mosaic texture image should be saved in **tif.* data format. To ensure that newly formed photo mosaic texture images are attached to precise coordinates at the working plane, these images should be also saved in **cot.* data format.

When all the photo mosaic images are matched with the corresponding areas of the 3D model a "*Merge*" tool is used to merge all the attached raster images into one homogenous texture image (Figure 2). The new file also is assigned with a freely given name in **tif.* data format and at the file save options a "*World file*" is chosen.

3. Approbation of the model and data integrated.

The approbation of the study results was preformed in several stages. The assessment of the quality of the photographic documentation was carried out manually by comparing on the pixel level the compatibility of individual images taken with various cameras in the different time periods.

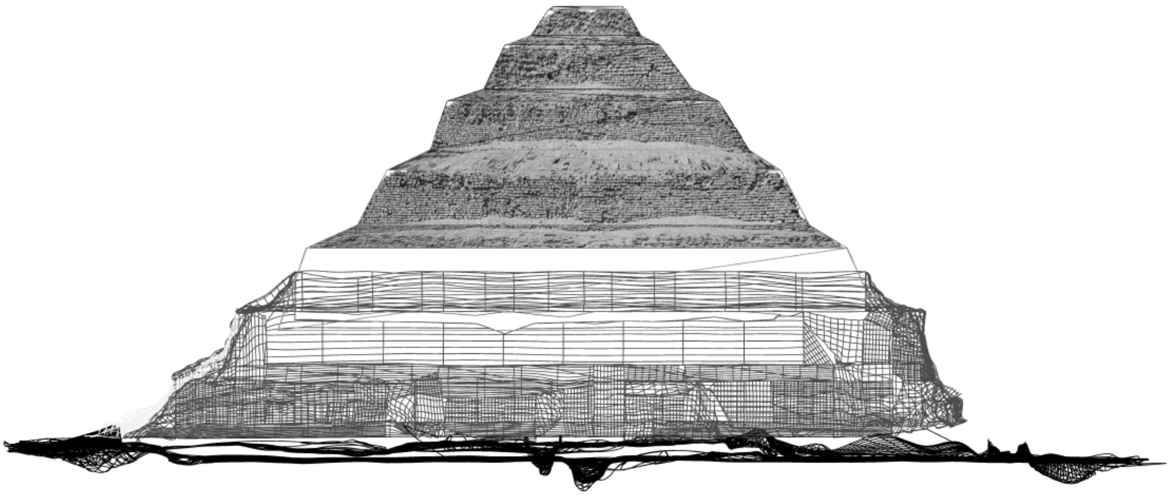


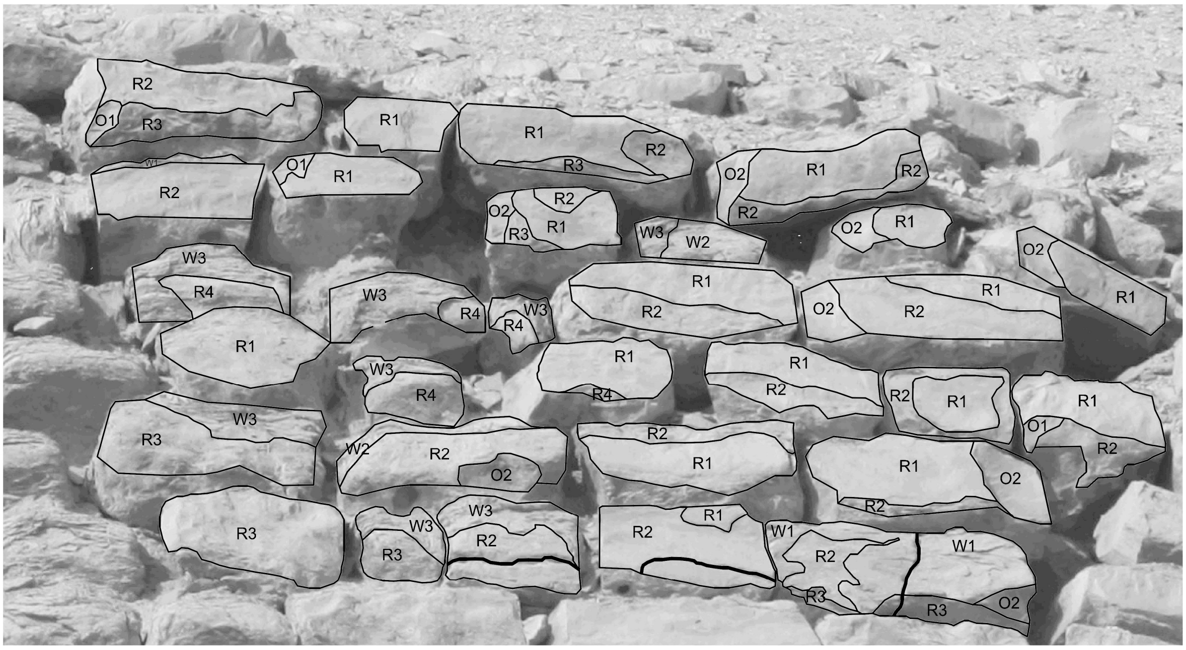
Figure 2. Southern façade of the Step Pyramid of Djoser: photo mosaic integrated onto the geospatial model.

The 3D model elaborated was tested by applying onto it the historical photographs to verify the consistency of the size and shape of the model as well as amending the corrections according to the plans and sections elaborated by J.P.Lauer (Lauer 1962: pl.10).

To approbate the functionality of the model a specific information layer was developed to cover the surface of the pyramid completely. As such specific information layer the degree of deterioration of the pyramid's stone material surface was selected. In order to create this specific information layer each of the stone construction blocks of the pyramid exposed to the surface was analysed in details. The particular weathering type and weathering intensity was determined for each construction block and drawn manually before integrating into the 3D model of the pyramid.

Stone material weathering assessment.

The stone material weathering assessment was carried out applying the method elaborated by the authors (Kukela, Seglins: *in print*) that was approbated on the historical monuments of the proximal sites. In accordance with the methodology systematic processing of the photo documents should be performed: assessment of the quality, georeferencing of the images, diagnostic of the stone material weathering types and development of the weathering intensity estimation scale and its further simplification to ensure correct interpretation of the surface weathering features. Identified stone material surface weathering forms are manually drawn for each individual construction block (Figure 3).



Weathering forms	Weathering intensities
Relief (R)	R1, R2, R3, R4
Back weathering (W)	W1, W2, W3
Break out (O)	O1, O2
Fissure	———

Figure 3. Depiction of the manually drawn stone material surface weathering forms and their intensities. The fragment of the southern façade of the Step Pyramid of Djoser.

This is the most laborious part of the study and we still have not succeeded in easing it without affecting the quality of the research. Similarly all attempts to carry out this work by application of the software of automatic and semi-automatic weathering diagnostics, e.g., Bentley Descartes or GIS software with spatial analysts have turned out to be unsuccessful. However, the attempts to depict identified stone material surface weathering forms and their intensities on the individual areas of the pyramid's geospatial model proved to be successful (Figure 4 A). Similarly, the same conclusion can be made regarding the georeferencing of the historical photographs to the 3D model of the pyramid (Figure 4 B). This allows the comparison of the changes accrued during the long time period as well as evaluation of the intensity of these changes. Nevertheless, the processing of such historical data is a separate study to be carried out in the future since this data is spread in numerous archives and still has not been aggregated.

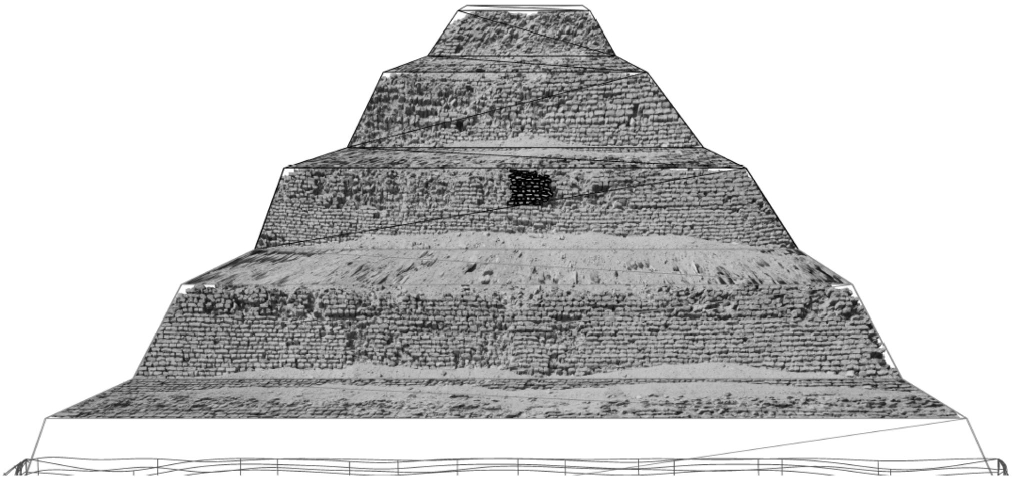


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Figure 4. The model of the Step Pyramid of Djoser with the integrated area of analysed stone material surface weathering (A) depicted in details on the Figure 3 and georeferenced historical photograph (B) taken in the 1930's (Firth, Quibell 1935: Pl.3).

Discussion

The results of the research reveal the possibility to obtain high quality data for the needs of the scientific studies with comparatively simple methods, thus increasing the quality of the documentation of an object. By organizing systematic photographic documentation of the object and recording particular details, the need for documentation was developed into the concept of the 3D model of an object, thus accomplishing certain logical cycle – "from the photography to the digital spatial model".

As a result of the study the 3D model of the Step Pyramid of Djoser was developed relying on the measurements taken *in situ* and LIDAR aerial photographs. This model serves as a reliable geometrical frame for georeferencing various observations, including photographic documentation. The 3D model elaborated is possibly the best solution taking into account limited data available with no option to acquire this data once again due to the extensive reconstruction works currently carried out on the site of the Step Pyramid.

The main advantage of the elaborated 3D model is its suitability for full integration into CAD system ensuring accessibility of the data for the wide-range of users and possibility to integrate it into the WEB GIS applications as a 3D model. In the future even better results could be gained by developing the existing spatial model and applying technologies provided by the photogrammetry or the 3D laser scanner programmes for elaboration of 3D models.

The specific information layer containing the data on the pyramid's façade stone material surface weathering is a particular subject for the discussion. A certain methodology is developed to diagnose, classify and map the weathering features of the exposed stone surfaces. This methodology differs from the ones frequently discussed in the literature (Aboushook, et al. 2009:22, Dorn, Cerveny 2005, Fitzner, Heinrichs 2002: 11-56). The main difference concerns the simplification of the weathering intensity features reducing the number of weathering types and their intensities so they could be identified and mapped not only for the limited area of an object, but for all the façades. In such case an option to integrate the 3D model into the WEB GIS application is also a great advantage providing unlimited possibilities to supplement the research data base in the future even if this addition data will concern just the limited area of the particular façade.

Conclusions

The method developed by the authors allows to create the 3D model of the historical monument with the further possibility to integrate and reflect the investigations carried out in the different time periods (observations, photographic documentation, etc.). Such system enables focused supplementation of the spatial model with the new data and further possibility to its diverse visualization.

Current technical solution envisages targeted selection of the high quality digital images, their adjustment and integration into the digital spatial model developed using MicroStation V8i software. The results obtained by applying this solution prove to be successful.

The method is elaborated during the studies of the Step Pyramid of Djoser in Egypt, but the experience reveals that this method can be applied for the study and documentation of the other cultural heritage monuments as well. However, it should be noted that the system discussed still envisages time-consuming manual work and further development of this system is to be aimed to facilitate it by introducing appropriate technical solutions without reducing the quality of the study results.

Acknowledgements

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References

1. 3d-model for GoogleEarth in Google's 3d-warehouse. http://www.3dhh.de/b/egypt-pyramid-djoser/ [2011.02.03].
2. Aboushook, M.I., Park, H.D., Mazen, S.O., El- Sohby, M.A. (2009) Determination of durability of some Egyptian monument stones using the digital images. In: Chulshaw, M.G., Reeves, H.J., Jefferson, I., Spink T.V. (eds.) Engineering Geology for Tomorrow’s Cities. Geological Society, London, Engineering Geology Special Publications, 22.
3. Dorn, R.I., Cerveny, N.V. (2005) *Atlas of Petroglyph Weathering Forms used in the Rock Art Stability Index (RASI).* http://alliance.la.asu.edu/rockart/stabilityindex/RASIAtlas.html [2009.24.10].
4. Firth, C.M., Quibell, J.E. (1935) *Excavations at Saqqara. The Step Pyramid, vol.2: The Plates.* Cairo : Institut Français d'Archéologie Orientale.
5. Fitzner, B., Heinrichs, K. (2002) Damage diagnosis on stone monuments – weathering forms, damage categories and damage indices. In: Prikryl, R., Viles, H.A. (ed.): Understanding and managing stone decay, Proceedings of the International Conference „Stone weathering and atmospheric pollution network (SWAPNET 2011)”, 11-56, Prague, Czech Republic, The Karolinum Press, Charles University.
6. Groat, L., Wang, D. (2002) *Architectural research methods*. USA: John Wiley & Sons, Inc..
7. Kukela, A., Seglins, V. Simplified Method of Assessment of Weathering on Historical Stone Monuments: An Example of El-Merdani Mosque, Cairo, Egypt. In: Bibliothèque d’Etudes, Institut Français d’archéologie orientale, (in print).
8. Lauer, J.P. (1962) *Histoire Monumentale des Pyramides d'Égypte, vol.1: Les Pyramides à Degrés (IIIe Dynastie).* Cairo : Institut Français d'Archéologie Orientale.