Geodetic work at the archaeological site Tell el-Retaba

Eva Stopková

Institute of Oriental Studies of the Slovak Academy of Sciences, Slovakia
eva.stopkova@gmail.com

Abstract. The paper summarizes the geodetic contribution for the Slovak team within the joint Polish-Slovak archaeological mission at Tell el-Retaba (Egypt), years 2014 – 2017. Surveying work at archaeological excavations is usually influenced by somewhat specific subject of study and extreme conditions, especially at the missions in the developing countries. The case study describes spatial data development according to the archaeological conventions in order to document spatial relationships between the objects in excavated trenches. The long-term sustainability of surveying work at the site has been supported by detailed metadata recording. Besides the trench mapping, Digital Elevation Model has been calculated for the study area and for the north-central part of the site. The comparison of modern spatial data with the map of the site from the beginning of the 20th century has indicated the presence of a temple and a “great house” under the sand heap. In general, topographic mapping together with modern technologies like Spatial Modelling and Remote Sensing provide valuable data sources for spatial and statistical modelling of the sites; and the results offer a different perspective for particular archaeological research.

Keywords: Land surveying; Spatial modelling; Archaeological excavation; Tell el-Retaba.

1. Introduction

Land surveying in archaeology deals with a specific task indeed. The surveyors usually measure and stake out structures that are supposed to become long-lasting, monitor them with millimetre or even submillimetre precision and their work is focused basically on the present or the future. However, an archaeological surveyor documents the current state of the remains of ancient buildings and artifacts aged hundreds or thousands years, many of them to be about decompose in order to continue the research in deeper levels underground.

In general, an archaeological excavation follows the inverse process of the formation of the research objects – artificial layers of ruins and debris that have been accumulated for ages, hiding architectural structures and pieces of ancient ceramics, bones, metals, timber etc. These horizontally stratified layers, that can be thick from metres to even millimetres, are carefully revealed and after the detailed description and recording, most of them must be decomposed to excavate another – deeper and presumably older – layer. Not just the findings but the stratigraphical layers must be well documented, as the composition of the trench provides valuable information on the chronology and reflects the relations between the discovered items.

The variety of methods of the documentation have expanded significantly since the beginning of the 19th century, when the books of Colt Hoare and William Cunnington were released. These publications can be considered as the first attempts at recording the regional archaeology [17]. Drawing, later taking photographs have been accompanied with land surveying, photogrammetric modelling and even laser-scanning; non-destructive methods of field survey like geophysical prospection have been widely incorporated as well. However, the core of archaeological work still remains "destructive", thus requiring fine and careful documentation.

2. State of art

Considering the amount and diversity of archaeological missions world-wide, this chapter has been focused on the brief outline of currently published geodetic work and spatial modelling at Czech and Slovak archaeological missions in the developing countries.

2.1. Land surveying and Geoinformatics at archaeological missions abroad

The papers describing archeological surveying basically mention these types of issues: topographic mapping that has resulted into the contour maps and Digital Elevation Models of the larger sites[1], e.g. the Al-Baharíya oasis [13], Tell Fekheryie [14], or North Sudan [18]; detailed surveying of archaeological excavations in smaller trenches, e.g. at Abusír [7] or Tell Fekheryie [14]; and several specific tasks as well.

Besides traditional surveying methods (including the GNSS technologies with limited use in the developing countries), Satellite Imagery data are successfully applied to the documentation or even detection of the structures in Egypt [5][13], in Sudan [18], or in endangered locations of Mosul [16]; aerial mapping using Unmanned Aerial Vehicles [7] or Kite Aerial Photography [18] as well. Another researches (with Czech and Slovak scientists involved as well) deal with highly effective, but not so widespread methods, as the detection of ruins in the lush vegetation using the LIDAR data in Guatemala [15] or the laser scanning of structures to create high-resolutioned three-dimensional models in Egypt [8], [12].

On the other side, the manuals like [4] and [30] with detailed explanation of basic surveying principles might indicate frequent occurence of the excavations (worldwide) where some provisional mapping may be conducted by absolute beginners.

2.2. Geodesy in Egypt

As summarized in [25], the first geodetic reference frame in Egypt was established in the first half of the 20th century. The scheme of the Egyptian Geodetic Triangulation Network is available e.g. in [2]. In the last decades, a correction model has been being developed using GNSS technologies to fix the distortions of the network [25].

In 1992, two GNSS-based reference frames were established by the Egypt Survey Authority (ESA) – High Accurate Reference Network (HARN) and Notational Agricultural Cadastral Network (NACN) with the stations positioned in Egyptian Mercator grid and modified UTM coordinate system as well [22]. Besides these frames, that should be revised according to the comparison with the results of the *Precise Point Positioning* performed by [22], there are 40 stations of Continuously Operating Reference Stations (CORS) available as well, two of them (ISML and KEBER) [2] quite close to the archaeological site mentioned in the following case study. However, as noted e.g. in [18] as well, import of GNSS receivers and the access to the points of national grids is often confined in the Middle East countries.

[1] An archaeological site (or just *site*) means any place that contains physical evidence of past human activity, and which provides scientific, cultural, or historical evidence relating to the history of that place [19].

2.3. The case study of Tell el-Retaba

Tell el-Retaba, the large artificial mound covering the ruins of the Pharaonic fortress of the New Kingdom, is situated in the eastern Nile Delta in Egypt (Figure 1). Historical knowledge gathered by the long-term archaeological research has been summarized e.g. in [11] or in the reports published in *Aegypten und Levante* [23].

Figure 1: Location of Tell el-Retaba. Satellite image by Google Earth [1]

Although located close to the dynamic rural area, the desert weather and landscape of the *tell* offers quite difficult conditions for surveying work. However, considering the papers cited in previous chapter, the issues related to the control points maintenance (usually in local coordinate system) and limited access to the variety of surveying equipment seem to be typical for the archaeological sites in the Middle East countries.

3. The detailed mapping of archaeological trenches

Since 2007 when the Polish-Slovak mission at Tell el-Retaba started, the surveying work has been focused mainly on the detailed mapping of the stratigraphical layers in the trenches using the local coordinate system[2].

3.1. The concept of surveying work at Tell el-Retaba

Spatial data acquisition naturally follows the methodology of archaeological excavation according to the recommendations of the Museum of London [4]. The main principle is based on the fact that each archaeological site has been formed by a process of stratified deposition and removal [4]. To understand this process, the archaeologists must reconstruct the time periods between the actions according to the positions of remains in the trench. Excavated objects (architectural structures, small items like pottery, bones, coils etc., stratigraphical layers of the fill between them, and much more [4]) are given a reference to the stratigraphical sequence reflecting the immediate physical relationship with its neighbourhood. This spatio-temporal networking, called *Harris matrix* [4], presumes that the lower object (or disrupted by another

[2] In 2014, new Survey Control Network was established [28] in order to recover almost disappeared original local coordinate system after the demolition of provisional control points.

object) the earlier; and requires separate name, database and graphical record for each item in the trench content. The recording system has resulted into the complex and relatively voluminous spatial data that consists of the items with quite a rigid structure (Figure 2). This became an inspiration for the automation of importing raw data into GIS and CAD [27].

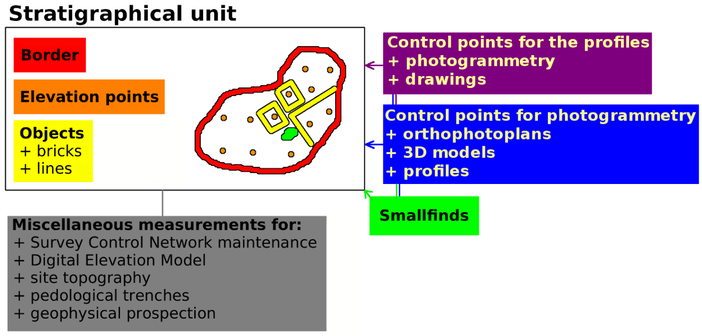

Figure 2: The structure of the archaeological spatial data at Tell el-Retaba.

The complete spatial dataset from the archaeological season contains dozens of stratigraphical units, accompanied with necessary miscellaneous features. Figure 3 shows the number of the objects and points measured daily, classified into broader divisions according to the scheme in Figure 2. The statistics is definitely not meant to evaluate or rank particular seasons; however, it visually summarizes some characteristics of the seasons time schedules.

Most of the layers have been represented by the combination of the border and elevation points within the area, thus the size of the subsamples is nearly equal; the season of 2016 gave extraordinary amount of small finds. Ground control points positioning usually prevails in the end of the season (except for 2015). Grey subsamples refer to various complementary measurements – control points validation, the measurements and stake-outs for geophysical prospection and pedological trenches in 2014 [23], data acquisition for Digital Elevation Model (2015), and topographic mapping of the close surroundings of the site (2016, 2017). In 2017, various unit objects (i.e. any additional, mostly linear elements within the stratigraphical unit, like the foundation lines of the structures) have prevailed significantly.

The daily amount of stratigraphical units may be described using bell-shaped curves. The plot minimum in the middle of the season is usually caused by either difficult, complex situation to be excavated and documented in the trench (that is why the plots should not be considered as any effectiveness evaluation), or the decrease might be caused by the timing – each of the trenches is ready for the measurement at one time and they must wait for each other. It might be presumed that each archaeological excavation would "generate" different, unique track of the measurements, something like fingerprint; depends on the extend of the study area, particular composition of the excavated trenches and surveying methodology following the needs of the research.

3.2. Surveying work sustainability

The dataset consisting of hundreds small vector layers should be accompanied with the detailed metadata that provide the information helpful in the data completion and in the further usage as well.

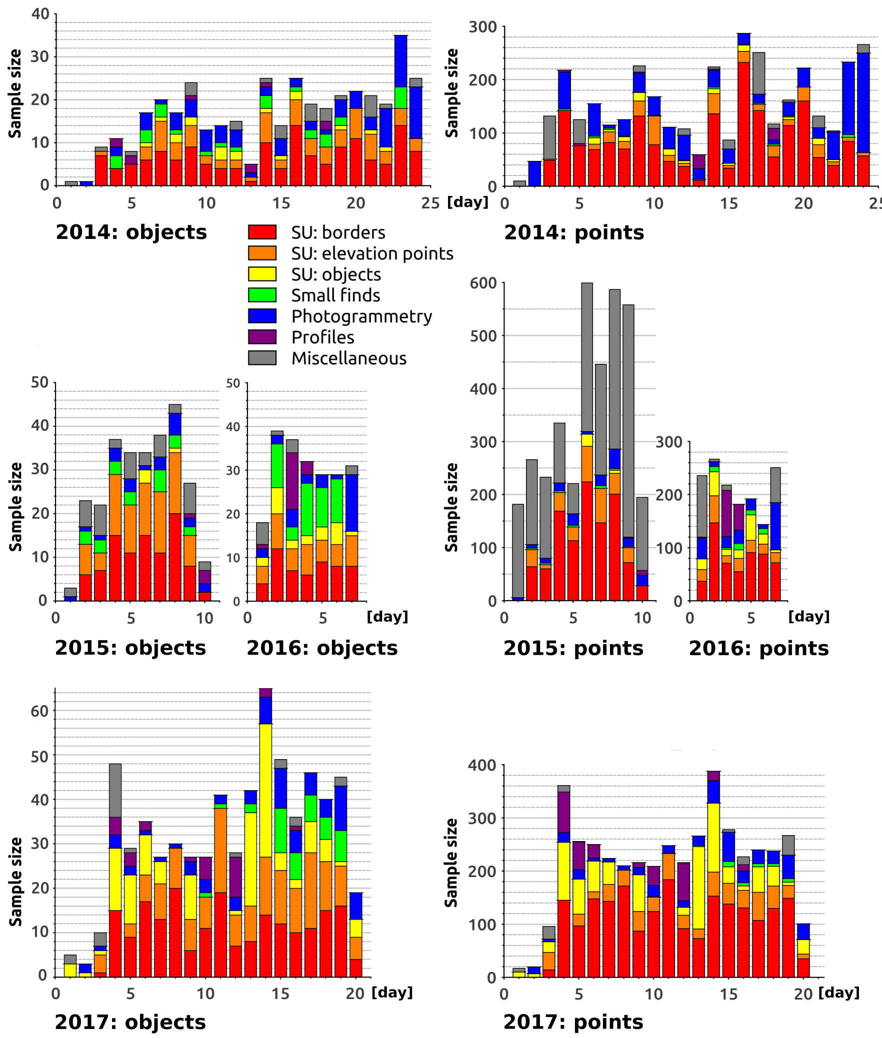

Figure 3: The temporal structure of the land surveying work during the seasons of 2014-2017. The dataset includes spatial data representing just archaeological works done by the Slovak team within the joint Polish-Slovak mission.

The list of measured features with recorded surveying circumstances can be useful after the data acquisition to emerge issues that might happen on the busy site. Dynamic progress of the excavation, revealing new facts and new context, might occasionally require renaming or merging particular stratigraphical units (but original names must be stored as well). The deepening trenches and deteriorating visibility between the surveyor and target operator might despite all the precautions result into the wrong setup of the target height, especially when alternating the object, operator, or surveying a difficult situation. When using only selected target heights, the gaps are obvious immediately; and in case of the mistake, the detailed track of the survey helps to examine all the occurences retrospectively. The surveying journal has not been used often in this sense but when, it used to be extremely effective.

The long-term asset of this recording includes providing a tool for searching all the parts of multiple layers and distinguishing them during the preparation of the plans and figures.

The site has been excavated sequentially within the trenches given by the squares of 25 m^2, thus recorded metadata should be useful in the future to follow the relationships between the layers. Last but not least, they should provide to the surveyors, working at the site in the future, the information on the measurements, methods and achieved goals.

Since 2014, the database of measured objects has been developed in order to track the data flow at the archaeological mission (Figure 4). General information includes geocoded location of the objects (given by the coordinates of the square reference point in local coordinate system) and the daily records of surveying circumstances at the site from the journal – the day of the data acquisition, the trench supervisor (or the chainman), and additional notes, especially modifications of the unit number. Carefully prepared metadata has been really helpful in completing the data and extracting situation plans or various overviews from the CAD drawings that consist of many overlapping, vertically stratified layers (Figure 5).

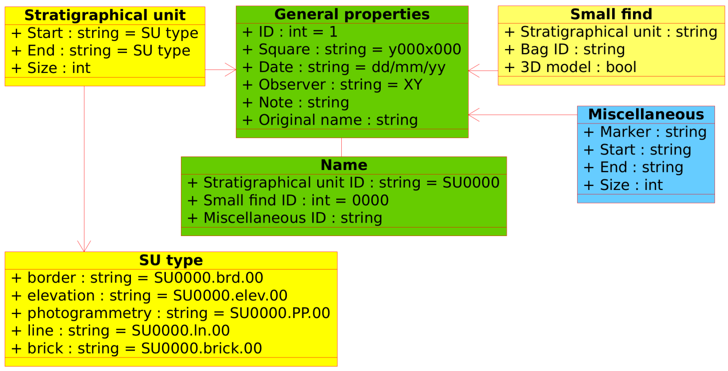

Figure 4: Metadata structure (drawn in Umbrello UML Modeller [3])

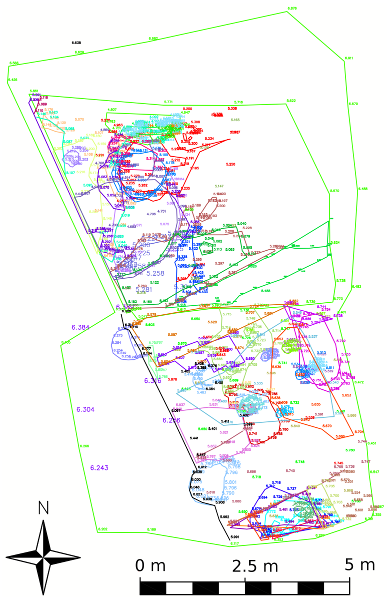

Figure 5: Stratigraphical units in the trench (just borders and elevation labels of the vertices; without elevation points, other labels, and additional measurements). Spatial data (2014) by E. Stopková. Trench supervisor: L. Hulková

4. Topographic mapping and spatial modelling of the *tell*

The main priority of surveying work at Tell el-Retaba has been the detailed, almost continual mapping of excavated objects in the trenches. General contour map from 2007 [24]: *Fig. 1* has covered the whole site but with a focus especially on sparsely preserved remains of ancient structures. In recent years, two Digital Elevation Models (DEM) have been developed for the purposes of more detailed documentation and spatial analysis of the *tell*. Input point datasets in Figure 6 (the study area and the north-central part of site, where the excavations had been performed in the past) were acquired using trigonometric levelling during the season of 2015.

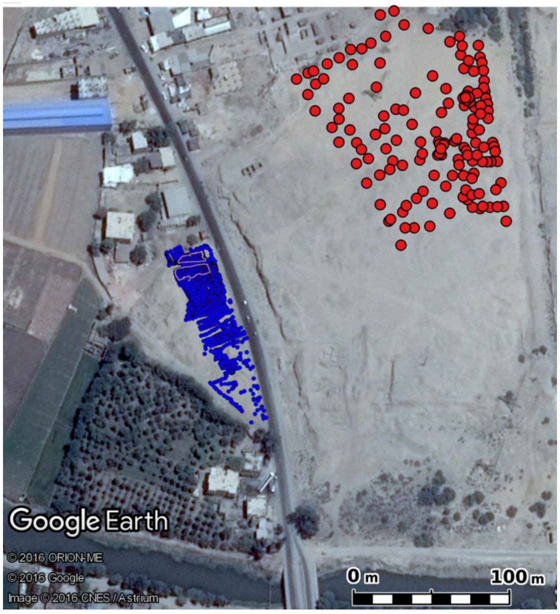

Figure 6: Input points for terrain modelling of the *tell*. Data acquisition by E. Stopková and J. Marko; with M. Černý, E. Fulajtár, L. Kováčik, L. Hulková, R. Rábeková, A. Šefčáková in the study area. Satellite image by Google Earth [1].

Unbalanced distributions of both point samples have been the matter of several practical reasons. Empty spaces over the dataset for the study area represent excavated trenches and the debris, i.e. irrelevant temporary terrain features that disappear after the season refilling the holes with accumulated material. On the other side, these no-data areas should not be excluded from the DEM, as they provide at least an approximate information on the landscape, useful in small scale modelling or for the provisional elevation comparisons of the findings with current terrain. No-data areas in the north-central part of the *tell* dataset represent flat surfaces without significant discontinuities, where just preliminary observations have been performed due to shortage of time (the schedule of the mission and the detailed mapping of the trenches usually require continual presence of the surveyor and surveying equipment at the study area).

4.1. Interpolation of the Digital Elevation Models

DEMs were interpolated using the *Ordinary Kriging* method in an add-on *v.kriging* [29] of the open-source software *GRASS GIS* [9]. Optimal resolutions for each dataset (Table 1) were estimated according to the recommendations in [10] that consider spatial distribution of the input points. Final cell sizes represent a compromise between particular statistical characteristics of the distances between the pairs of the nearest points in the samples: the average of the distances as the coarsest legible resolution (Table 1a) and the finest legible resolution given by their 5% quantile (Table 1b).

The *Nearest Neighbor Analysis* performed in *v.nnstat* [26] indicates that the sample covering the north-central part of the *tell* should be considered as dispersed. However, it is still not distributed in absolutely regular pattern, and thus the same criterion of the average distance of the closest points have been used to estimate the coarsest legible resolution as suggested by [10] in case of random or clustered datasets. Grid resolution might be calculated using the range of the spatial dependence as well, but this approach requires non-linear variogram models; this condition has not been fulfilled by the datasets in this case study.

a) Nearest Neighbor Analysis (in *v.nnstat* [26])	**NE part of the *tell***	**study area**
Sample size	146	1808
Area [m^2]	14804.478352	3157.884467
Density [points per m^2]	0.009862	0.572535
Average real distance r_A between the nearest neighbours [m]	6.070	0.666
Average expected distance r_E between the nearest neighbours [m]	5.035	0.661
The ratio r_A/r_E	1.205549	1.007714
Standard variate of the normal curve	4.751382	0.627500
Null hypothesis: Point set is randomly distributed within the region.	Rejected (dispersed)	Accepted
The coarsest legible cell size ($0.5 \cdot r_A$)	**3 m**	**33 cm**

b) Statistical characteristics of the distances between the nearest points (in *Qtiplot* [31])		
Sample size	146	1810
Minimum [m]	0.55	0.05
Maximum [m]	16.68	6.44
Mean [m]	6.070	0.665
Variance [m^2]	11.256921	0.290556
Standard deviation [m]	3.355	0.539
5% quantile [m]	1.624	0.129
The finest legible cell size	**1.6 m**	**13 cm**
Optimal cell size	**2 m**	**0.20 m**

Table 1: Estimation of the optimal raster resolution following [10]

Linear variogram models were verified using cross-validation based on several points subsamples (Table 2, Figure 7). Statistical characteristics of the residuals have confirmed that the data over the north-central part of the *tell* should be densified to lower the residuals, especially in the sparse areas, and to provide more redundant points for the model validation. Considering this, the final DEM of the *tell* has been calculated using the settings optimal for the dataset with 2% cross-validation points, but using the whole input sample. The dataset for the western part of the *tell* seems to be dense enough. However, there are problematic parts with steep walls of the ruins that require to implement the breaklines modelling into *v.kriging* [29], as indicated by the residuals in 10% cross-validation subsamples. The 15% subsample has been built omitting the points at the edges of the ruins, and the statistical characteristics of the results decreased significantly.

The DEMs based on linear variograms (Figure 9) were calculated using following commands. Parameter *lmax* represents maximum distance for variogram calculation, divided into user-defined number of lags (*lpieces*); further explanation is available in the add-on manual [29].

	sample size	Variogram *lmax* [m]	Variogram lag size [m]	Minimum [cm]	Maximum [cm]	Mean [cm]	Standard deviation [cm]	Quantiles 25% [cm]	Quantiles 50% [cm]	Quantiles 75% [cm]	Quantiles 90% [cm]
NE part of the tell											
2%	**3**	**25.5**	**1.5**	**-1.4**	**8.4**	**3.17**	**4.95**	**1.4**	**2.5**	**2.5**	**8.4**
5%	7	30.0	1.5	-13.8	22.3	2.87	13.01	5.4	10.0	13.8	14.3
10%	15	30.0	1.5	-40.7	65.6	6.59	29.33	15.8	24.5	30.4	40.7
15%	22	22.5	1.5	-60.0	58.5	-0.88	25.17	5.9	18.8	25.0	35.0
study area (western part of the tell)											
2%	36	10.0	0.25	-25.1	36.2	1.36	10.34	1.3	4.5	7.4	13.2
5%	90	7.5	0.25	-31.6	49.4	1.81	14.19	1.5	4.4	10.1	24.6
10%	181	10.0	0.25	-62.7	56.7	-1.42	12.92	1.7	3.8	8.1	15.6
15%	**272**	**15.0**	**0.25**	**-18.0**	**20.5**	**-0.30**	**6.66**	**1.6**	**3.6**	**7.0**	**11.8**

Table 2: Statistical characteristics of the cross-validation over various subsamples; calculated in *v.kriging* [29] and *v.univar* [6]

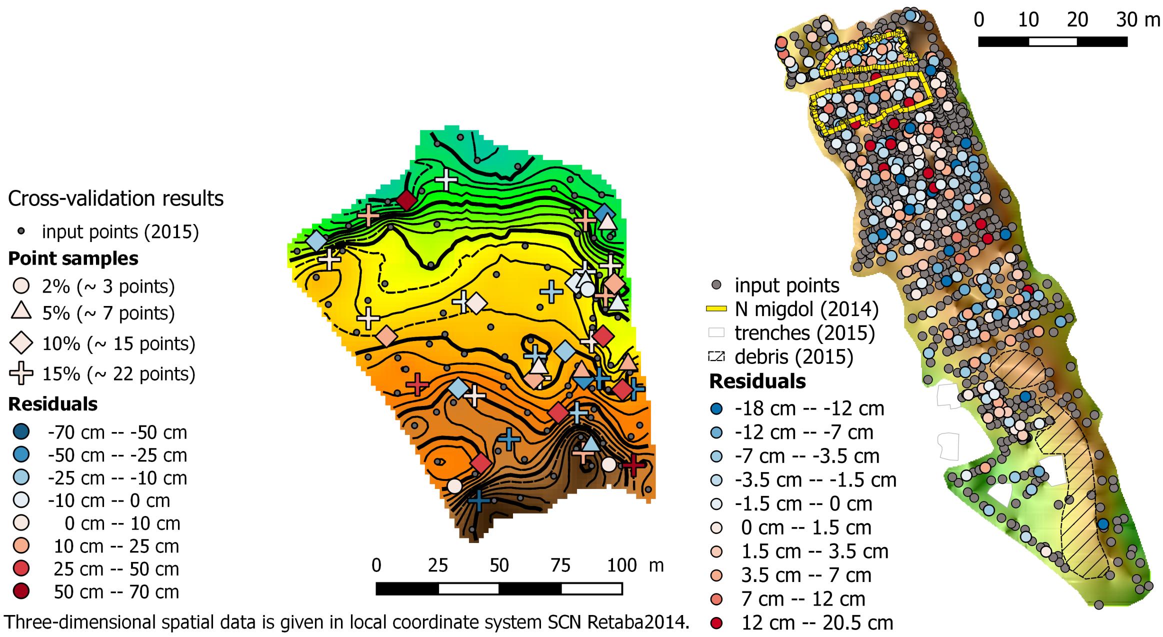

Figure 7: Spatial distribution of the cross-validation results. Positive values refer to the raster cells above the adjacent input point and the negative values vice versa.

```
> v.kriging phase=initial input=dem_site_2d icolumn=elev \
report=dem_site_report_2m_25517_linear.txt lmax=25.5 lpieces=17 -2 -o
> v.kriging input=dem_site_2d icolumn=elev phase=final \
final_function=linear file=png output=dem_site_2m_25517_linear \
crossvalid=dem_site_xval_2m_25517_linear.txt -2 -o

> v.kriging phase=initial input=dem_west_inp272 icolumn=elev \
lmax=15.0 lpieces=60 report=dem_west_20cm_1560_linear.txt -2 -o
> v.kriging input=dem_west_inp272 icolumn=elev phase=final \
final_function=linear file=png out=dem_west_20cm_1560_linear \
crossval=dem_west_xval_20cm_1560_linear.txt -2 -o
```

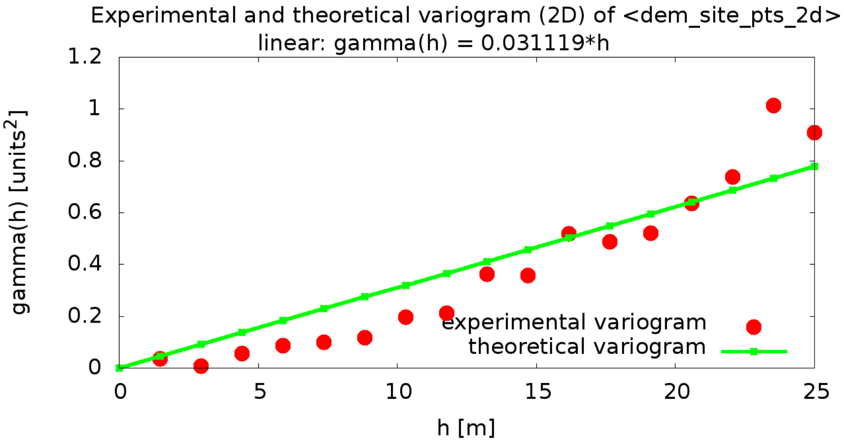

Figure 8: Variogram modelling of the *tell* dataset in *v.kriging* [29]

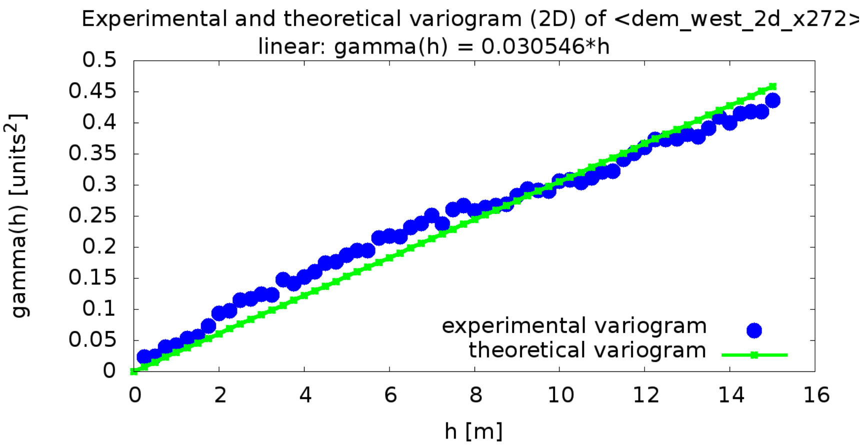

Figure 9: Variogram modelling of the *study area* dataset in *v.kriging* [29]

4.2. Comparison of the Digital Elevation Models with historical map of the site

The contour map of the *tell* from 2007 [24]: *Fig. 1* has presented a general overview of a relatively flat hill, focused especially on the relics of the former fortress scattered sparsely over the area; but nothing more than scant remains of the Ramesside temple among them as noted in [24], comparing the site then and today according to the map from the beginning of the 20th century [20]: *Plate XXXV*. The map has been published in a summary of excavations at Tell el-Retaba by the renowned egyptologist W. F. Petrie (1853 – 1942), unfortunately without mentioning any information on methodology of the surveying work. Current DEMs have been overlaid with this map as well, with quite promising results.

Transformation of the map [20]: *Plate XXXV*, that might be just presumed to use some local coordinate system, into the current local coordinate system *Retaba2014* [28] in georeferencing plugin of *QGIS* [21] has been based on the only object with identical points available (Figure 10) – remains of the northern tower of the former gate (in the Near Eastern Archaeology called *migdol*) in the western part of the site.

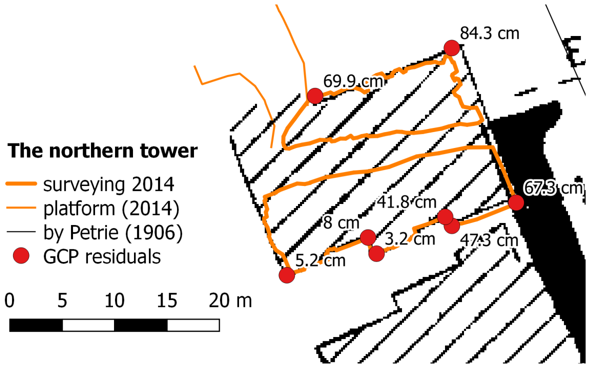

Figure 10: Ground Control Points and the residuals of the transformation of the map from 1906 [20]: *Plate XXXV* (provided by Getty Research Institute, Los Angeles (86-B10322) on the Internet Archive), to the local coordinate system *Retaba2014* [28].

Despite of insufficient sample of identical points and rather high residuals, the comparison of other structures (captured by the DEMs only and thus not providing exact points for the transformation) indicates that the maps match well enough. The detailed DEM of the study area (Figure 11) has provided an overview of the *migdol* and adjacent wall, both of them visible until nowadays and occasionally incorporated into the contemporary landscape, as shown in the aspect map (Figure 11) emphasizing the rectangular depression, built by local shepherds in 2015 along the *wall 3* [20] as a temporary natural sheepfold. A tiny wall (Figure 11; white pointer) as an extension of overlapping walls of two ages[3] fits the historical documentation too.

These structures were documented and positioned before and have provided a valuable verification of the historical map transformation for other, much more vague objects that seem to arise from the ground in central part of the *tell* (Figure 12). Orthogonal elevation lines seem to match the most important buildings in the former fortress and there is a high probability that the sand heap might hide ruins of the *Temple* (even the eastern part, probably not excavated at the beginning of the 20^{th} century) and the *Great House*[4]. In such case, their real shape (and position, as the difference in graphical scale makes 1 m on 30.48 m over this area in the distance of about 300 m from the identical points, but without any other significant distortion, see Figure 12) must be revealed by archaeological excavation or further geophysical prospection[5], and it is worth to continue the detailed mapping over the whole *tell*.

Another structure, a small circular ruin jutting over the terrain just slightly (Figure 12), was measured to test the detection of terrain anomalies that might indicate presence of more objects, possibly hidden underground. However, this analysis requires a dataset of much higher resolution, and the input points should be densified for this purpose in the future.

[3] *Chapter V* [20] has summarized three building epochs of the walls, the *Temple* description and the most significant related findings.

[4] Despite of lower density of elevation lines, the contour map [24]: *Fig. 1* seems to indicate very roughly this connection to the *Temple* as well.

[5] Electrical conductivity map [24]: *Fig. 7* has confirmed the presence of the northern wall, still running underground along the elevation line of 8 m (in three-dimensional local coordinate system *Retaba2014* [28]), as suggested in [20]: *Plate XXXV* as well (Figure 12; yellow arrows).

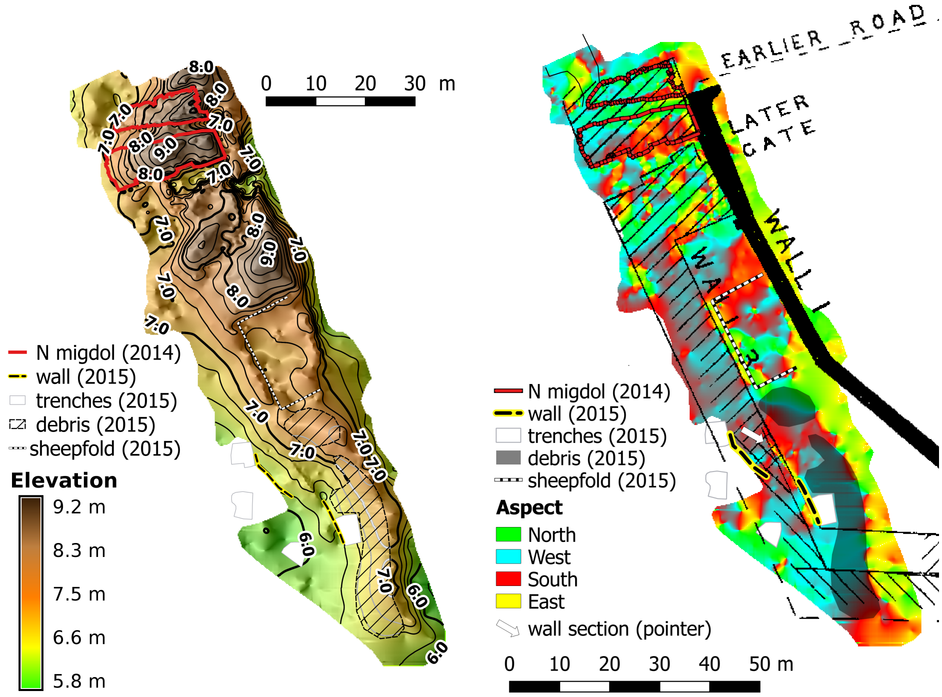

Figure 11: The elevation map of the study area and the comparison of the aspect map with the fortification documented by W. F. Petrie [20]: *Plate XXXV*, provided by Getty Research Institute, Los Angeles (86-B10322) on the Internet Archive.

5. Conclusion

Although the original purpose of cooperation between archaeologists and land surveyors was to map the site and provide exact outputs for the trench documentation, geodetic approach may contribute much more to the reconnaisance of historical and cultural heritage. Carefully acquired spatial data, accompanied with the detailed metadata, provide information on the past recovery and enable clear communication between the surveyors and the missions at the site during the long-term archaeological research over the years or decades. Various ways of the object representation such as three-dimensional models, spatial analyses and satellite imagery offer completely new perspective to the interpretation of archaeological findings.

Spatial modelling at the Tell el-Retaba should continue completing the DEM to document current shape of the site; in relevant areas in more detailed way to perform geomorphological analyses to detect hidden structures or just record interesting objects before they crumble down into the sand. Another branch of the geodetic research will focus on temporal modelling of the site using available current and historical satellite imagery. This would require tracking the borders of the *tell* as soon as possible in order to keep information about current state of the site surrounded by burgeoning agriculture in the rural area.

Acknowledgements

The author would like to thank the members of the Slovak team within the joint Polish-Slovak archaeological mission who have participated on the data acquisition as the survey chainmen,

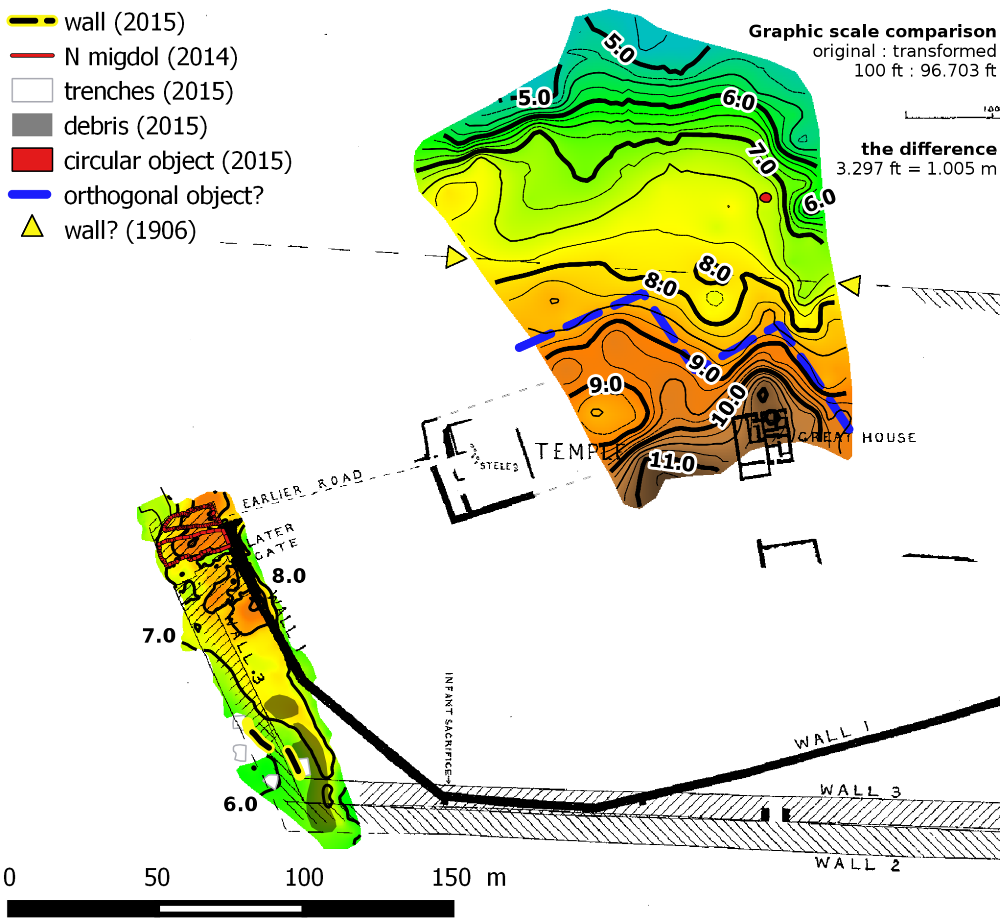

Figure 12: Comparison of the DEMs with the map from 1906 by Petrie [20]: *Plate XXXV*, provided by Getty Research Institute, Los Angeles (86-B10322) on the Internet Archive.

especially M. Černý, S. Štubňová, P. Šútorová, L. Kováčik, M. Lintner, and L. Hulková, V. Dubcová, K. Smoláriková, and M. Odler. Special thanks goes to Ján Marko who participated on the DEM input data acquisition as well and to the other assisting colleagues. Thanks belongs to Getty Research Institute, Los Angeles (86-B10322) and the Internet Archive for sharing digital copy of Petrie's summary of his research at Tell el-Retaba under public domain, and last but not least to the reviewer for the insightful comments that helped to improve the manuscript, including the terrain modelling and the *v.kriging* add-on.

The work has been supported by the Slovak Research and Development Agency (project no. APVV-0579-12).

References

[1] CNES / Astrium 2016. *"Tell el-Retaba". **Google Earth**. June 13, 2016. November 12, 2016.*

[2] Tarek Agag. "VRS (CORS) Network in Egypt". In: *Geomakani 2016. Geospatial Technologies Conference Cairo* (Mar. 2016), p. 18. URL: http://www.un-ggim-as.org/

MeetingAttachments/2ndMeetingFiles/VRS-(CORS)-Network-in-Egypt.aspx?ext=.pdf.

[3] Paul Hensgen et al. *Umbrello UML Modeller*. URL: https://umbrello.kde.org/ (visited on 05/27/2017).

[4] Andrew Westman (ed.) *Archaeological Site Manual*. London: Museum of London Archaeology Service, 1994. ISBN: 0-904818-40-3.

[5] Miroslav Bárta and Vladimír Brůna. *Satellite Atlas of the Pyramids*. London: Dryada, 2007. ISBN: 978-8087025017.

[6] Radim Blazek, Hamish Bowman, and Martin Landa. Available at https://grass.osgeo.org/grass72/manuals/v.univar.html [date accessed 2017-12-18]. GRASS Development Team, 2017.

[7] Vladimír Brůna. "Geoinformatika při archeologickém výzkumu v Egyptě [Geoinformatics in Archaeological Excavation in Egypt]". In: *ArcRevue* 14.2 (2005), pp. 9–12. URL: http://download.arcdata.cz/ArcRevue/2005/2/05-geoinformatika-archeolog-pruzkum.pdf.

[8] Vladimír Brůna, Marcel Brejcha, and Miroslav Bárta. "Laserové skenování Duaptahovy skalní hrobky v jižním Abúsíru [Laser scanning of Duaptah's rock-cut tomb at Abusir South]". In: *Prague Egyptological Studies* XIII (2014), pp. 31–37. URL: http://digitool.is.cuni.cz/R/PC6A4L72LR5DQ1LAP43PS4N423J5I9T9V1D6HQRR2AF4RL32LH-00080?func=dbin-jump-full&object_id=1366313&silo_library=GEN01&pds_handle=GUEST.

[9] GRASS Development Team. *Geographic Resources Analysis Support System (GRASS) Software, Version 7.1. Open Source Geospatial Foundation*. URL: https://grass.osgeo.org/ (visited on 05/25/2017).

[10] Tomislav Hengl. "Finding the right pixel size". In: *Computers & Geosciences* 32.9 (2006), pp. 1283–1298. URL: DOI:%2010.1016/j.cageo.2005.11.008.

[11] Jozef Hudec, Emil Fulajtár, and Eva Stopková. "Historical and Environmental Determinations of the Ancient Egyptian Fortresses in Tell el-Retaba". In: *Asian and African Studies* (2015), pp. 247–283.

[12] Yukinori Kawae et al. "Abusir 3D survey 2015". In: *Prague Egyptological Studies* XVII (2016), pp. 3–11. URL: http://pes.ff.cuni.cz/wp-content/uploads/sites/13/2017/01/yukinori_kawae-yoshihiro_yasumuro-ichiroh_kanaya_3-11.pdf.

[13] Jaromír Kolejka, Lucie Misáková, and Vladimír Brůna. "Application of the Czech Landscape Research Experience in the Desert Environment to Support Archaeological Study". In: *Geografie* 115.3 (2010), pp. 347–360. URL: http://geography.cz/sbornik/wp-content/uploads/2010/12/g10-3-6kolejka.pdf.

[14] Tibor Lieskovský, Drahoslav Hulínek, and Daniel Kendrala. "Geodetic surveys and topography at the Tell Fekheryie location". In: *Archaeology on Three Continents 2006 – 2011* (2015), pp. 59–70.

[15] Tibor Lieskovsky, Milan Kovac, and Tomas Drapela. "Usability of LiDAR data for archaeological survey in the Uaxactun area, North Peten, Guatemala". In: *LiDAR in the Maya Heartland: Results of the 2016 LiDAR survey in Guatemala's Maya Biosphere Reserve* (2017). URL: http://core.tdar.org/document/431295/usability-of-lidar-data-for-archaeological-survey-in-the-uaxactun-area-north-peten-guatemala.

[16] Eva Matoušková et al. "Using Remotely Sensed Data For Documentation of Archaeological Sites in Northeastern Mesopotamia". In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLI-B5 (July 2016), pp. 96–105. DOI: 10.5194/isprsarchives-XLI-B5-335-2016.

[17] Tim Murray. *Milestones in Archaeology: A Chronological Encyclopedia*. Santa Barbara, California: ABC-CLIO, Inc, 2007, p. 166. ISBN: 978-1-85109-645-9.

[18] Jan Pacina. "Geodetic surveying as part of archaeological research in Sudan". In: *Geoinformatics FCE CTU* 14.1 (June 2015), pp. 47–64. DOI: 10.14311/gi.14.1.4.

[19] Chris Park and Michael Allaby. *A Dictionary of Environment and Conservation*. Oxford: Oxford University Press, 2017. ISBN: 9780191826320. DOI: 10.1093/acref/9780191826320.001.0001.

[20] William Matthew Flinders Petrie. *Hyksos and Israelite Cities*. London: School of Archaeology and Bernard Quaritch, 1906.

[21] Quantum GIS Development Team. *Quantum GIS Geographic Information System*. Open Source Geospatial Foundation Project. 2017. URL: https://qgis.org/en/site/ (visited on 05/07/2018).

[22] Mostafa Rabah, Mahmoud Elmewafey, and Magda H. Farahan. "Datum maintenance of the main Egyptian geodetic control networks by utilizing Precise Point Positioning "PPP" technique". In: *{NRIAG} Journal of Astronomy and Geophysics* 5.1 (May 2016), pp. 96–105. DOI: 10.1016/j.nrjag.2016.02.003.

[23] Slawomir Rzepka et al. "From Hyksos Settlers to Ottoman Pipe Smokers. Tell el-Retaba 2014". In: *Aegypten und Levante* XXV (Nov. 2015), p. 98. URL: http://hw.oeaw.ac.at/?arp=0x0032a108.

[24] Slawomir Rzepka et al. "Tell el-Retaba. Season 2007". In: *Polish Archaeology in the Mediterranean* XIX (2007), pp. 143–151. URL: http://www.pcma.uw.edu.pl/en/2018/05/15/pam-19-2/.

[25] Abd-Allah Ahmed Saad and Mona Saad Elsayed. "Simple Model for Improving the Accuracy of the Egyptian Geodetic Triangulation Network". In: *The International Federation of Surveyors* (May 2007), p. 24. URL: https://www.fig.net/resources/proceedings/fig_proceedings/fig2007/papers/ts_1b/ts01b_03_saad_saad_1226.pdf.

[26] Eva Stopková. "Extension of mathematical background for Nearest Neighbour Analysis in three-dimensional space". In: *Geoinformatics FCE CTU* 11.0 (Dec. 2013), pp. 25–36. DOI: 10.14311/gi.11.2.

[27] Eva Stopková. "Open-source tool for automatic import of coded surveying data to multiple vector layers in GIS environment". In: *Geoinformatics FCE CTU* 15.2 (Dec. 2016), pp. 15–26. DOI: 10.14311/gi.15.2.2.

[28] Eva Stopková. "Spatial information recovery in the desert using LMS-based geodetic network adjustment". In: *Survey Review* (2018), p. 11. doi: 10.1080/00396265.2018.1459360.

[29] Eva Stopková. *v.kriging*. url: https://grass.osgeo.org/grass74/manuals/addons/v.kriging.html.

[30] Geoffrey John Tassie and Lawrence Steward Owens. *Standards of Archaeological Excavation; a Fieldguide to the Methodology, Recording Techniques and Conventions*. London: Golden House Publications, 2010, pp. 158–169. isbn: 9781906137175.

[31] Ion Vasilief. *QtiPlot*. url: http://www.qtiplot.com/ (visited on 05/25/2017).