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Modelling the Seventies: Image-Based Modelling to Investigate Landscape Change in a Mediterranean Mountain Area

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Abstract –
Historical aerial imagery can be used to investigate geomorphological change over time, which can inform research about the preservation and visibility of the archaeological record, as well as heritage management. This paper presents a composite Image-Based Modelling workflow to generate 3D models, historical orthophotos, and historical digital elevation models from images from the 1970s. The main challenge was the lack of high-resolution recent digital elevation models and ground control points. Therefore, spatial data from various sources had to be combined. To assess the accuracy of the final 3D model, the RMSE was calculated. While the workflow appears effective, the low accuracy of the initial data limits the usefulness of the model for the study of geomorphological change. However, it can be implemented to aid sample area selection when preparing archaeological fieldwork, or, when working with different survey datasets, signal areas with a high bias risk resulting from post-depositional processes.

I. INTRODUCTION

Pedestrian field survey currently faces paradoxical developments. In the rapidly deteriorating archaeological landscapes of the Mediterranean as well as elsewhere, archaeologists are becoming ever more reliant on field survey data, especially those collected in earlier times with relatively good quality surface finds (so-called legacy datasets). At the same time, over the past decades there has been increasing attention for the various biases that may occur when sampling the archaeological record by pedestrian survey. Initially, much research has targeted methodological biases, amongst others to correct for the varying visibility of archaeological surface material during the surveys. This has led to a well-developed rigour in field survey practices documenting the present field conditions as systematic and well as possible [1-12]. In this paper, we focus on one particular factor, which is the geomorphological change over time. Erosion and depositional processes, as well as incisive anthropic actions such as mining, all influence the location and preservation of the archaeological record. Understanding geomorphological change can help to better assess the value of surface distributions of archaeological finds retrieved during field work, and at least in theory also to assess the reliability of legacy survey datasets.

Historical aerial images have since long been valued for helping in identifying archaeological features that in the meantime have been obscured or obliterated by more recent anthropic manipulations and/or natural events. More specifically, historical aerial photographs now also allow us to generate historical digital elevation models (hDEMs), historical orthophotos and 3D models of areas that have often been subjected to significant landscape change over the years. This can be done by using Image-Based Modelling (IBM) techniques. When a recent digital elevation model (DEM) is subtracted from an earlier one, a map of the occurred geomorphological change can be extracted, thereby generating useful new data. The generation of hDEMs from historical aerial images is not always straightforward. Common problems with the generation of hDEMs consist of poor or lacking metadata, low image resolutions, and the absence of contemporary GPS ground control points (GCPs). These factors can complicate generating new data from historical photographs. Additionally, the comparison of data with different coverages, resolutions, and levels of precision can cause problems, which makes estimating the difference between two DEMs in order to investigate geomorphological change challenging.

Issues concerning hDEM generation are often resolved by using GPS GCPs on locations that are visible in both historical and recent remote sensing data, or by creating new GCPs from accurate (and often more recent) maps in

GIS and using those in the IBM software. An alternative is to co-register the created DEMs to ones that are currently available, as demonstrated by Sevara et al. [13]. Common workflows use ground control points that were recorded in the field with a GPS, therefore establishing deviations of less than 10 cm [14-18] or use highly accurate recent DEMs for co-registration [19-22]. These resources were not available in the region under investigation, therefore the objective of this study was to assess the feasibility of a composite workflow using legacy data that was lacking any physical GCPs. One potential source of error is the manual placement of the control points, in both GIS and IBM software, since this mostly relies on the resolution of the images and the accuracy of the user. Furthermore, the quality of the final result largely depends on the quality of the initial data. As previously mentioned, in the case of this research no GCPs or high-resolution DEM were available, which significantly complicated the IBM procedure. Therefore, its usefulness for further research and analysis was investigated by assessing its accuracy after several improvements.

The research presented in this paper was carried out using data provided by the *Aesernia* Colonial Landscape Project, which was started in 2011 by Dr. T.D. Stek as an EU Marie Curie Fellowship at Glasgow University, and subsequently, in 2013, continued in the larger framework of the Landscapes of Early Roman Colonization (LERC) project, a collaboration between Leiden University and the Royal Netherlands Institute in Rome (KNIR), funded by the Netherlands Organisation for Scientific Research (NWO) [23]. The LERC project investigates the early Roman colonisation process in Italy, mainly by pedestrian surveys and remote sensing [24]. This paper focuses on the landscape surrounding the Latin colony of *Aesernia* (263 BCE), around the modern town of Isernia, situated in the Molise region in south-central Italy (Fig. 1).

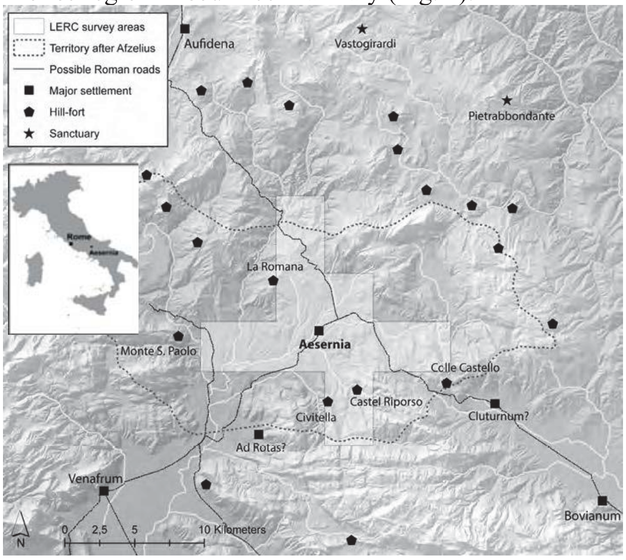

Fig. 1. LERC research area around Aesernia [3, 24].

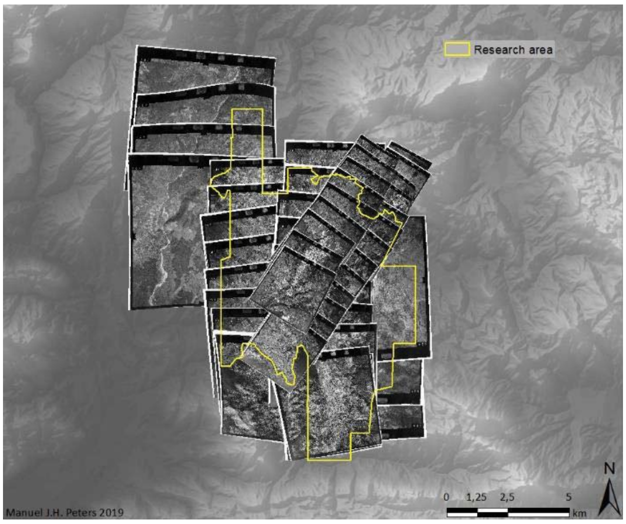

Fig. 2. Aerial image coverage for 1970-71 around Isernia.

II. DATA

For our present analysis, we used 53 aerial photographs from the Isernia area (Fig. 2) which were produced in 1970-71 for cartographic purposes by the Società per Azioni Rilevamenti Aerofotogrammetrici (SARA) [25]. Additionally, a regional orthophoto of the Isernia area from 2007 was provided by the geoportal of the regione Molise (using the AutoGR tool developed by Dr. Gianluca Cantoro). The TINITALY/01 DEM released by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in 2007 was used as control DEM. This is a composite DEM that is commonly used in recent archaeological research [26]. In Molise, the RMSE of the TINITALY DEM (modern DEM or mDEM) is 3.76 m in the non-urban areas, and 4.51 m in the urban areas [27, 28]. A hillshade visualisation of this DEM was used as base map for several figures (1, 2, 4, 8) in this paper.

Agisoft Metashape Professional 1.5.2 build 7838 was used to create the various models using Structure from Motion (SfM), CloudCompare 2.10.2 was used for modifying and co-registering the point clouds. ArcMap 10.4.0.5524 was used to run the GIS procedure, and ArcScene 10.4.0.5524 to visualise the data in 3D. All data was processed in the EPSG:32633, WGS84 / UTM 33N coordinate system.

III. METHODS

A composite workflow involving SfM, point cloud processing software, and GIS was used. First, a preliminary model using 53 images from 1970-71 was built using SfM. Next, GCPs were placed in a GIS environment on the resulting orthophoto. This was done by using features that appeared unchanged and were easily recognisable on the 1970-71 and 2007 orthophotos, such as corners of buildings and intersections of roads. The XY coordinates were obtained based on the 2007 orthophoto, and the elevation values were extracted from the mDEM.

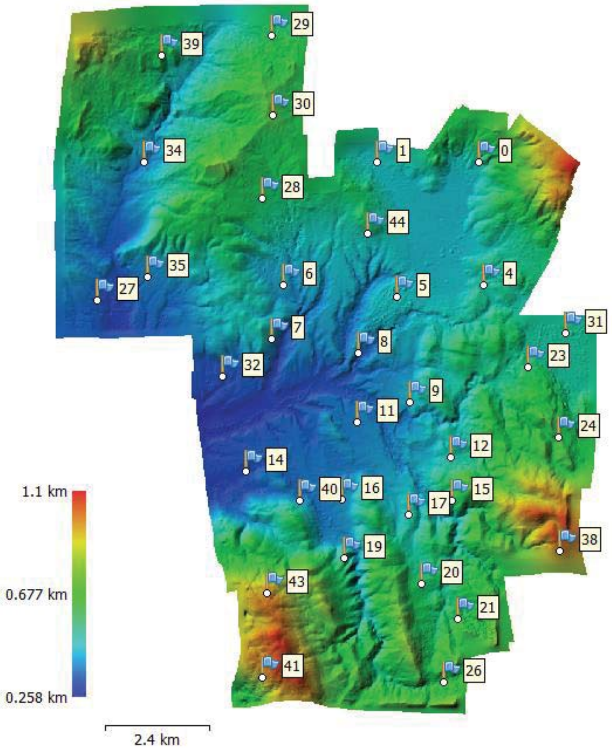

Fig. 3. hDEM after cleaning, including GCP locations.

This data was then imported into the SfM software, where the GCP locations had to be modified manually by keeping the SfM and GIS software side by side. Once the GCPs were added, a more conventional workflow was followed; the images were aligned, a sparse point cloud was created, camera alignment was optimised, and points with high projection error (above 0.25 m), high reconstruction uncertainty (above 10 m), or low projection accuracy (below 2.5 m) were removed. The filtered point cloud was then used to create a dense point cloud. A preliminary hDEM was then built (Fig. 3), and an orthomosaic was generated.

Ground points were classified using a 15 degrees maximum angle, 2 m maximum distance, and 25 m cell size. The ground point cloud (hDEM) was then further modified in CloudCompare. An additional filtering step was carried out using Statistical Outlier Removal, using 10 points for the mean distance estimation and 1.00 as the standard deviation multiplier threshold. Duplicate points were removed as well, and the point cloud was downsampled to a 2.5 m resolution to speed up processing. Then, the hDEM was co-registered to the mDEM using an iterative closest point (ICP) algorithm. This co-registration procedure corrected the hDEM, decreasing the tilt and modifying the scale to better fit the mDEM. This resulted in a decrease in RMSE on the whole hDEM area from 13.95 m to 7.48 m.

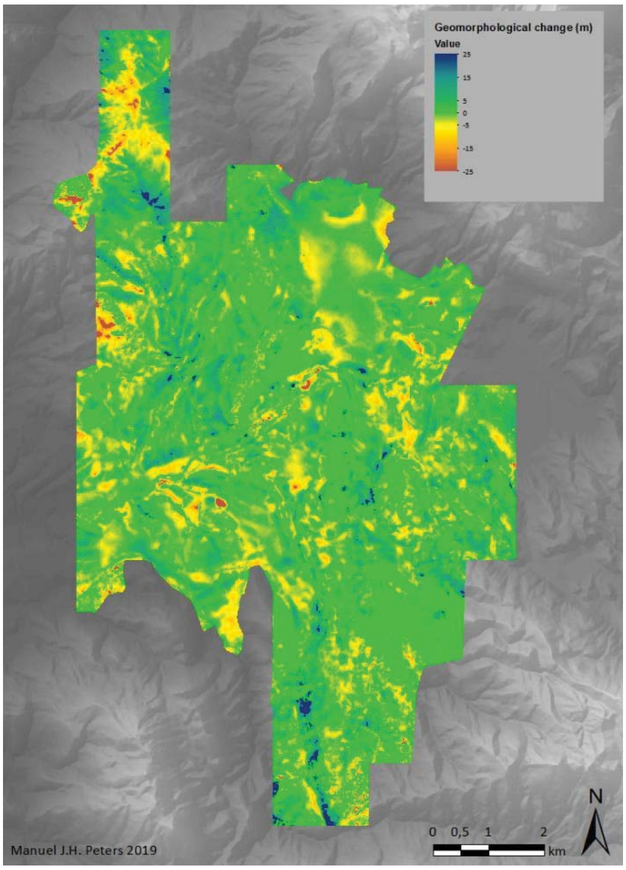

Fig. 4. Geomorphological change (erosion and sedimentation).

The hDEM was then rasterised to a grid size of 10 metres in order to be comparable with the mDEM. An additional compensation was carried out by measuring the deviation of the hDEM in 101 new GCPs in supposedly stable areas, interpolating these values using Kriging, and subtracting the resulting deviation map from the hDEM. The mDEM was subtracted from the compensated hDEM, showing the geomorphological change in the area. In order to exclude areas with vegetation or buildings from the geomorphological change model, these were masked by a combination of automated classification based on the grey values of the historical orthophoto and manual adjustments of the mask. The resulting model shows both the positive (presumably sedimentation) and negative (presumably erosion) change in the landscape (Fig. 4).

IV. RESULTS

The 3D model generated by the SfM procedure was sufficient for a visual study of the landscape surrounding Isernia (Fig. 5). In order to determine its suitability for the determination of geomorphological change, an accuracy assessment was carried out.

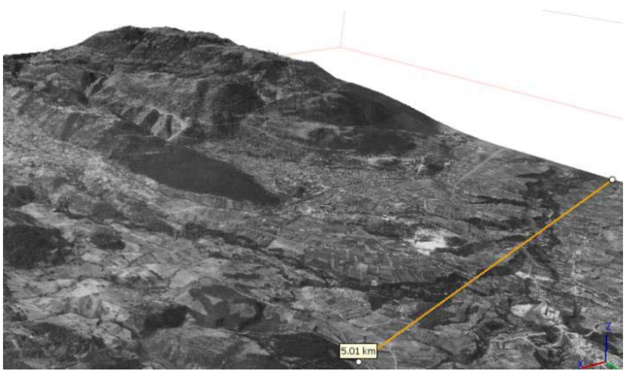

Fig. 5. Detail of 1970-71 3D model. Orange line representing 5 km.

The north-south and east-west profiles of the various DEMs were compared (Fig. 6-7), showing that the co-registration resolved a significant amount of tilt both in the north-south and east-west planes. The additional compensation using the deviation surface obtained with Kriging resulted in another improvement.

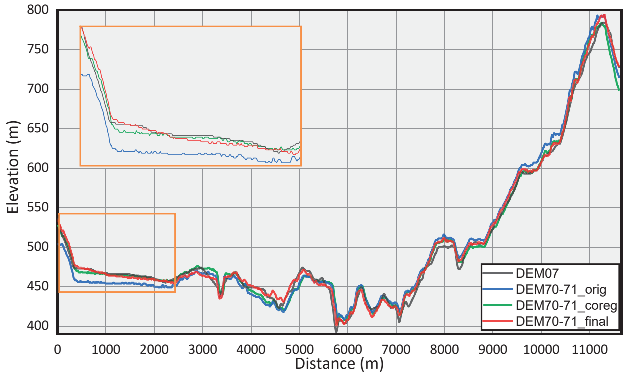

Fig. 6. Profile comparison between elevation models in north-south direction.

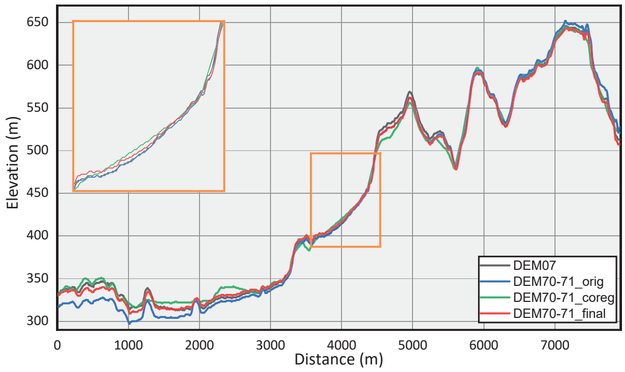

Fig. 7. Profile comparison between elevation models in east-west direction.

The RMSE of the hDEM relative to the mDEM was calculated, and the total RMSE was calculated using the relative and the mDEM RMSE (Formulas 1-2; Table 1).

The final hDEM had an RMSE of 5.87 m. Although this is a significant possible error when dealing with landscape change, this is mostly due to the original data quality. Considering the fact that the original 2007 DEM has an RMSE between 3.76 m and 4.51 m in the Molise region, and a resolution of 10 m, the 5.87 m RMSE of the final hDEM was considered an acceptable result.

$$RMSE_{rel} = \sqrt{\frac{\sum_{i=1}^{n}(hDEM-mDEM)^2}{n}} \qquad (1)$$

$$RMSE_{tot} = \sqrt{RMSE_{rel}^2 + RMSE_{mDEM}^2} \qquad (2)$$

Table 1. RMSE values.

	Relative RMSE	Total RMSE
Before compensation	6.48 m	7.49 m
After compensation	4.51 m	5.87 m

Even though there are limits due to the RMSE of the final hDEM, the resulting geomorphological change map obtained by subtracting the mDEM from the hDEM serves as a useful indication of the changes around Isernia. The resolution is not high enough to allow detection of more subtle changes; however, especially since in this procedure no GCPs are necessary, it may be used to better select the sample areas during the planning of archaeological fieldwork. Additionally, its results can assist the interpretation of the data collected by the pedestrian surveys. As such, it can help improve existing archaeological models, for example about site distribution, in a way not dissimilar to the soil map analysis by Casarotto et al. [29]. A good example of the changing landscape in the area can be found south of the town of Isernia, where a quarry has expanded dramatically in a few decades, leaving a lasting effect on the landscape (Fig. 8).

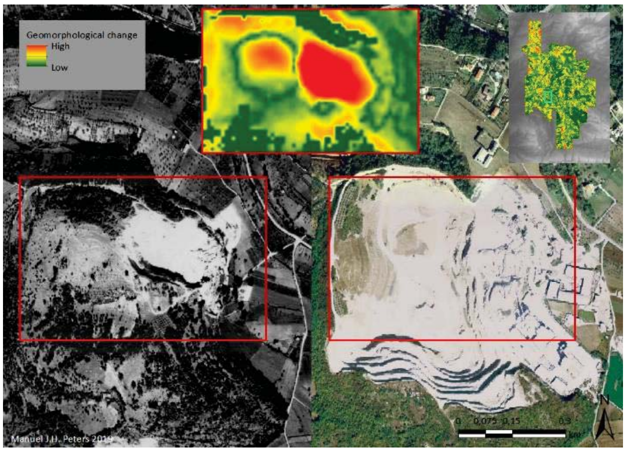

Fig. 8. Geomorphological change due to mining activities.

V. CONCLUSIONS

The main goal of this research was the creation of a composite IBM workflow to build historical landscape models from historical aerial photographs using SfM, and extracting information about geomorphological change. By applying data from other sources such as a more recent orthophoto and DEM to obtain ground control points in GIS that could then be entered in the SfM software, it was possible to create historical orthophotos and hDEMs. The hDEM for 1970-71 was further filtered and co-registered to the mDEM from 2007. Subsequently, it was corrected by applying interpolation to create a vertical deviation surface from other GCPs, which resulted in a compensated hDEM that was then subtracted from a modern DEM in order to observe geomorphological change, ignoring areas with buildings or vegetation.

Although there are severe limitations resulting from the quality of the initial data in our example, the proposed composite workflow appears effective for the creation of more accurate historical 3D models and geomorphological change maps of rapidly evolving landscapes. Although geomorphological change has an inherent duality, both positively (uncovering) and negatively (displacing/covering/destroying) influencing the visibility of the archaeological record, geomorphological change maps can be used to provide feedback for planning pedestrian surveys and interpret their data critically, possibly assisting in the assessment of its accuracy and the improvement of archaeological models.

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REFERENCES

[1] P.Attema, “Two Challenges for Landscape Archaeology”, in P.Attema, G.J.Burgers, E.van Joolen, M.van Leusen and B.Mater (eds), New Developments in Italian Landscape Archaeology. Theory and methodology of field survey. Land evaluation and landscape perception. Pottery production and distribution, University of Groningen, April 13-15, 2000, BAR International Series, vol.1091, 2002, pp.18-27.

[2] J.Bintliff, P.Howard and A.Snodgrass, “The Hidden Landscape of Prehistoric Greece”, Journal of Mediterranean Archaeology, vol.12, No.2, 1999, pp.139-168.

[3] A.Casarotto, “Spatial patterns in landscape archaeology. A GIS procedure to study settlement organization in early Roman colonial territories”, Leiden: Leiden University Press, 2018.

[4] R.C.Dunnell, “The Notion Site”, in J.Rossignol and L.Wandsnider (eds), Space, Time, and Archaeological Landscapes, New York: Plenum Press, 1992, pp.21-41.

[5] H.Feiken, “Dealing with biases: three geo-archaeological approaches to the hidden landscapes of Italy”, Groningen: Barkhuis, 2014.

[6] R.Francovich, and H.Patterson, “Extracting meaning from ploughsoil assemblages”, Oxford: Oxbow Books, 2000.

[7] J.García Sánchez, “Method Matters. Some Comments on the Influence on Theory and Methodologies in Survey Based Research in Italy”, in R.Cascino, F.De Stefano, A.Lepone and C.M.Marchetti (eds), TRAC 2016, Proceedings of the Twenty-Sixth Theoretical Roman Archaeology Conference, Sapienza University of Rome, 16th-19th March 2016, Rome: Edizioni Quasar, 2017, pp.151-164.

[8] C.Haselgrove, “Inference from Ploughsoil Artefact Samples”, in C.Haselgrove, M.Millet and I.Smith (eds), Archaeology from the Ploughsoil Studies in the Collection and Interpretation of Field Survey Data, Sheffield: University of Sheffield, 1985, pp.7-29.

[9] J.Lloyd, and G.Barker, “Rural settlement in Roman Molise. Problems of archaeological survey”, in G.Barker and R.Hodges (eds), Archaeology and Italian Society, Oxford: BAR International Series, vol.102, 1981, pp.289-304.

[10] M.B.Schiffer, A.P.Sullivan and T.C.Klinger, “The design of archaeological surveys”, World Archaeology, vol.10, No.1, 1978, pp.1-28.

[11] N.Terrenato, “The visibility of sites and the interpretation of field survey results: towards an analysis of incomplete distributions”, in R.Francovich, H.Patterson and G.Barker (eds), Extracting meaning from ploughsoil assemblages. Oxford: Oxbow Books, 2000, pp.60-71.

[12] P.M.V.van Leusen, “Pattern to process: methodological investigations into the formation and interpretation of spatial patterns in archaeological landscapes”, Groningen: Rijksuniversiteit Groningen, 2002.

[13] C.Sevara, G.Verhoeven, M.Doneus, E.Draganits, “Surfaces from the Visual Past: Recovering High-Resolution Terrain Data from Historic Aerial Imagery for Multitemporal Landscape Analysis”, Journal of Archaeological Method and Theory, vol.25, 2018, pp.611-642.

[14] Y.C.Hsieh, Y.C.Chan and J.C.Hu, “Digital Elevation Model Differencing and Error Estimation from Multiple Sources: A Case Study from the Meiyuan Shan Landslide in Taiwan”, Remote Sensing, vol.8,

No.3, 2016, pp.199-220.

[15] S.Ishiguro, H.Yamano and H.Oguma, “Evaluation of DSMs generated from multi-temporal aerial photographs using emerging structure from motion–multi-view stereo technology”, Geomorphology, vol.268, 2016, pp.64-71.

[16] C.Sevara, “Top Secret Topographies: Recovering Two and Three-Dimensional Archaeological Information from Historic Reconnaissance Datasets Using Image-Based Modelling Techniques”, International Journal of Heritage in the Digital Era, vol.2, No.3, 2013, pp.395-418.

[17] C.Sevara, “Capturing the Past for the Future: an Evaluation of the Effect of Geometric Scan Deformities on the Performance of Aerial Archival Media in Image-based Modelling Environments”, Archaeological Prospection, vol.23, No.4, 2016, pp.325-334.

[18] J.Vaze, J.Teng and G.Spencer, “Impact of DEM accuracy and resolution on topographic indices”, Environmental Modeling & Software, vol.25, No.10, 2010, pp.1086-1098.

[19] G.Verhoeven, D.Taelman and F.Vermeulen, “Computer Vision-Based Orthophoto Mapping Of Complex Archaeological Sites: The Ancient Quarry Of Pitaranha (Portugal-Spain)”, Archaeometry, vol.54, No.6, 2012, pp.1114-1129.

[20] G.Verhoeven and F.Vermeulen, “Engaging with the Canopy - Multi-Dimensional Vegetation Mark Visualisation Using Archived Aerial Images”, Remote Sensing vol.8, No.9, 2016, pp.752-769.

[21] G.Verhoeven, M.Doneus, Ch.Briese and F.Vermeulen, “Mapping by matching: a computer vision-based approach to fast and accurate georeferencing of archaeological aerial photographs”, Journal of Archaeological Science, vol.39, No. 7, 2012, pp.2060-2070.

[22] F.J.Aguilar, M.A.Aguilar, I.Fernández, J.G.Negreiros, J.Delgado and J.L.Pérez, “A New Two-Step Robust Surface Matching Approach for Three-Dimensional Georeferencing of Historical Digital Elevation Models’, IEEE Geoscience and Remote Sensing Letters, vol.9, No.4, 2012, pp.589-593.

[23] T.D.Stek and J.Pelgrom, “Landscapes of Early Roman Colonization: Non-urban settlement organization and Roman expansion in the Roman Republic (4th-1st centuries BC)”, TMA, vol.50, 2013, pp.87.

[24] T.D.Stek, E.B.Modrall, R.A.A.Kalkers, R.H.van Otterloo, J.Sevink, “An early Roman colonial landscape in the Apennine mountains: landscape archaeological research in the territory of Aesernia (Central-Southern Italy)”, in S.De Vincenzo (ed), Analysis Archaeologica vol.1, Edizioni Quasar, Rome, Italy, 2015, pp.229-291.

[25] http://www.saranistri.com, accessed on 13 April 2019.

[26] S.Tarquini, and L.Nannipieri, “The 10 m-resolution TINITALY DEM as a trans-disciplinary basis for the analysis of the Italian territory: Current trends and new perspectives”, Geomorphology, vol.281, 2017, pp.108-115.

[27] S.Tarquini, I.Isola, M.Favalli, F.Mazzarini, M.Bisson, M.T.Pareschi and E.Boschi, “TINITALY/01: a new Triangular Irregular Network of Italy”, Annals of Geophysics, vol.50, No.3, 2007, pp.407-425.

[28] S.Tarquini, S.Vinci, M.Favalli, F.Doumaz, A.Fornaciai and L.Nannipieri, “Release of a 10-m-resolution DEM for the Italian territory: Comparison with global-coverage DEMs and anaglyph-mode exploration via the web”, Computers & Geosciences, vol.38, No.1, 2012, pp.168-170.

[29] A.Casarotto, T.D.Stek, J.Pelgrom, R.H.van Otterloo and J. Sevink, “Assessing visibility and geomorphological biases in regional field surveys: The case of Roman Aesernia”, Geoarchaeology, vol.33, No.2, 2017, pp.177-192.

[30] M.J.H.Peters, “Bypassing the Bias. Applying lmage-Based Modelling and GIS to Assess the Effect of Geomorphological Change, Topography, and Visibility on Survey Data from the Early Roman Colony of Aesernia, ltaly”, Leiden: Universiteit Leiden, 2019.