Visual Viewshed Simulation: Applying a 3D environment in archaeological research at Faysaliyya (southern Jordan)

Abstract: The shift from presenting and analyzing three-dimensional data in 2D to displaying and analyzing them in a 3D environment is becoming increasingly prevalent in archaeological practice. This approach opens new possibilities, such as a 3D virtual reality, that archaeologists can take advantage of. This paper presents an application of the Visual Viewshed Simulation, a 3D virtual reality tool for (re)constructing the visibility of objects in the field, taking into account factors such as atmospheric and lighting conditions. This approach can provide a new way to research people–place relations and may be particularly useful in landscape archaeology.

Keywords: virtual landscape, 3D in archaeology, simulation, visibility analysis, visibility reconstruction, landscape archaeology, GIS

INTRODUCTION

The use of spatial methods in modern archaeology has become a standard. Despite the ups and downs of the application of methods connected with the Geographic Information System (henceforth GIS) in archaeological

Jacek Karmowski

Jagiellonian University

Polish Archaeology in the Mediterranean 31
Karmowski 2022: 519–535
https://doi.org/10.37343/uw.2083-537X.pam31.04

Acknowledgments
I would like to express my sincere gratitude to Dr. Piotr Kołodziejczyk, the director of the HLC Project, for his unwavering support and guidance throughout the research and writing of this article. I am deeply appreciative of his encouragement to undertake this project and for his valuable contributions, including personally gathered GPS data used in the analysis presented in this paper. I am also grateful to the entire HLC project team for their support and collaboration during my time at the Faysaliyya site. I would also like to extend special thanks to Prof. Michał Choiński for his invaluable assistance in language proofreading of the manuscript.
This research was financed from the National Science Centre, Poland grant UMO-2016/22/E/HS3/00141. The publication has been created with financial support from the Strategic Programme Excellence Initiative at Jagiellonian University, Faculty of History (ID.UJ).

practice from the 1980s, their usefulness in fieldwork is undeniable and they are now recognized as a must-have research tool (Verhagen 2018: 18). GIS can speed up the documentation process, make it more accurate, and allow scientific results to be examined and disseminated in a highly efficient way.

Spatial information in archaeology is examined and presented in a plethora of ways, not just in two but also in three dimensions. Methods like photogrammetry and 3D virtual reconstructions are becoming increasingly available and user-friendly, hence their growing popularity among archaeologists (Forte 2014). The appeal of 3D presentations of scientific results is undeniable, but their potential in solving theoretical research problems is often insufficiently emphasized in many publications (Forte 2010; Campana 2014; Dell'Unto 2014: 56).

Also, thanks to technological advances, GIS and 3D software are becoming more available to a wider range of users. Combining the potential of these two types of software within the archaeological workflow allows for the presentation of data in the form of not only two-dimensional maps and numerical analyses, but also a full 3D view. In archaeological research, there is a gradual shift from presenting and analyzing three-dimensional data in 2D to displaying and analyzing them in a 3D environment, also as a component of fieldwork (Dell'Unto 2014). This kind of approach allows new research angles to be explored.

3D LANDSCAPE RECONSTRUCTION BASED ON PUBLICLY AVAILABLE DEM

Thinking of three-dimensional models in archaeology, one often imagines either small-scale artifacts, like pottery vessels, or large-scale monuments, like architectural buildings, which can be presented/reconstructed and studied (Barceló, Forte, and Sanders 2000). One should keep in mind, however, that 3D models can also represent even larger entities, like entire landscapes. The most common approach to creating a 3D landscape model for further analysis is to base it on a Digital Elevation Model (henceforth DEM). It is a numeric representation of a topographical surface, which specialized algorithms can transform into a reconstruction of the shape of the ground surface in a given location. Measurements for this purpose are taken over a certain area using long range photogrammetry, LiDAR or satellite imagery (Mukherjee et al. 2013: 205). The more accurate data one has, the more accurate the final 3D model can be. Usually, when one wants to use data best suited for a certain purpose, the optimal way to do it is to collect it personally according to one's needs. A rapid evolution of unmanned aerial vehicles (henceforth UAVs) and photogrammetry has made collecting specialized spatial data personally by researchers quite common also in archaeological practice. But there are exceptions when, for example, due to legal restrictions, it is not possible to use drones for photogrammetry on a regular basis. Sadly, it is not so common to have access to measurements from a country-wide project that publicly provides LiDAR data (like, for example, in certain European countries).

Some of these problems can be solved with the help of third-party private companies specialized in providing geospatial services, but many archaeological projects simply cannot afford them. Publicly available geospatial data can be utilized for such purposes and one such source of free DEM is the Shuttle Radar Topography Mission (henceforth SRTM30). It is a project that was carried out jointly by the US National Imagery and Mapping Agency (NIMA), the US National Aeronautics and Space Administration (NASA), the German Aerospace Center (DLR), and the Italian Space Agency (ASI). Its objective was to map nearly the entire globe in 3D by collecting topographic data using space-borne radar interferometry (Van Zyl 2001: 559). Ever since the data from the project were released in 2000, a wide spectrum of disciplines, including earth studies, environmental studies, and social studies have made use of them (Mukul, Srivastava, and Mukul 2016: 909).

WHAT AN ARCHAEOLOGIST CAN GET FROM SRTM30?

In archaeology, SRTM30 data can be used for simple terrain examination, such as visualization of elevation, slope steepness and orientation [*Fig. 1*]. In the early stages of fieldwork, such preliminary studies are useful in helping to understand the terrain and getting a broader perspective for the first time.

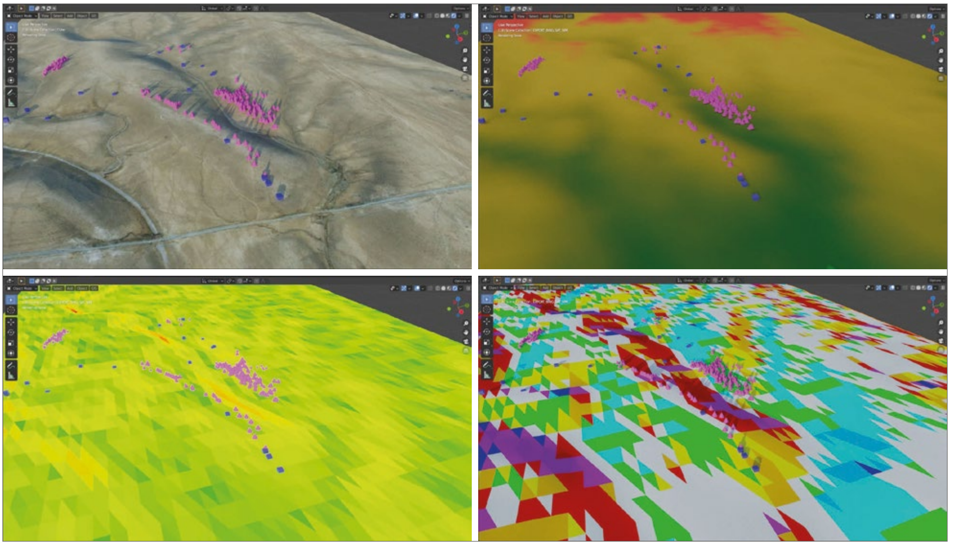

Fig. 1. Examples of DEM presentation and analysis: top left, 3D terrain model with texture based on satellite imagery; top right, 3D terrain model with color indication of height; bottom left, 3D terrain model with color indication of slope steepness; bottom right, 3D terrain model with color indication of slope orientation. All visualizations based on the same 3D model with markers (purple cones and blue cubes) for archaeological structures (Jagiellonian University HLC Project | processing J. Karmowski)

They also help to set the archaeological site in a broader context. SRTM30 data can also be used to draw contour maps of areas with archaeological sites, admittedly not in high resolution (grid resolution of 30 m), making it unsuitable for small-scale landscapes (i.e., individual excavation sites) but successful when applied to bigger ones [*Fig. 2*].

DEM data can also be utilized to perform GIS viewshed analysis and to present archaeological features located in the field. Viewshed analysis is designed to delineate an area or areas that can be seen from a chosen location given the height and taking into consideration the terrain surface (Wheatley 1995). It is suitable for various purposes and is quite popular in archaeology, answering questions such as, for example, visibility from a defensive structure like a tower or city wall. It can also be used to study cultic structures and the visual relations between them, as demonstrated in this case study.

VIEWSHED ANALYSIS VERSUS 3D VIRTUAL LANDSCAPE

In short, viewshed analysis is a computational algorithm using DEM to interpolate a line between the chosen point of observation (a particular pixel) and all other cells that create a given DEM raster. Each pixel contains information

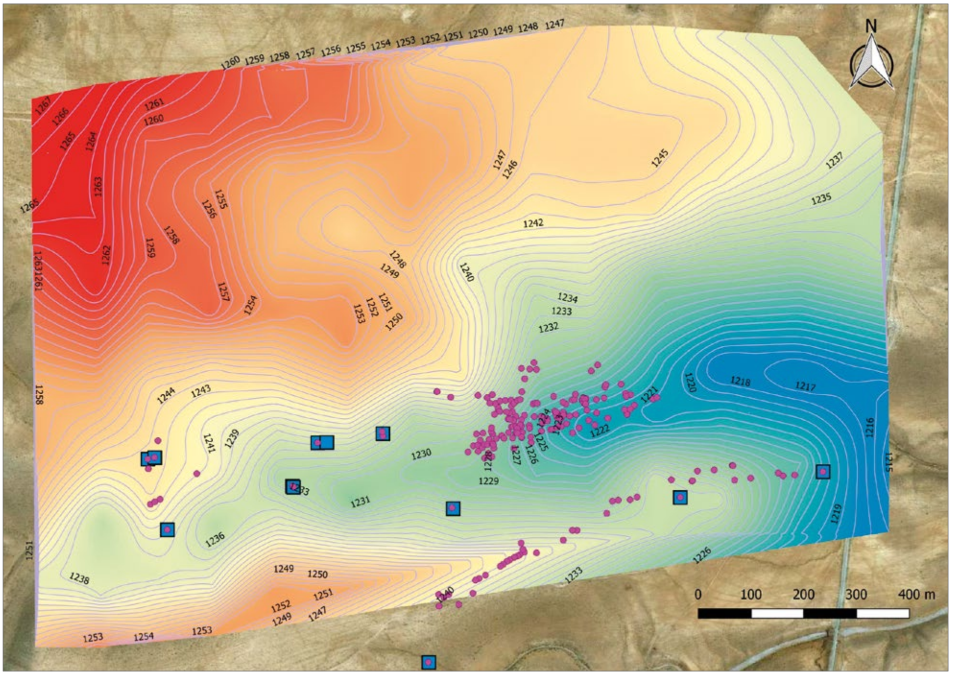

Fig. 2. Contour map of the Faysaliyya site based on DEM obtained from SRTM30. The map is geo-referenced in GIS, allowing it to be superimposed on a satellite image of the area. Archaeological structures marked with purple cones and blue squares (Jagiellonian University HLC Project | processing J. Karmowski)

about its elevation and location. The elevation of all the cells that cross with the interpolated line (so-called line of sight) are checked and evaluated in order to examine whether they are higher or lower than the line. Results are marked in binary fashion for each cell with '0' meaning negative (not visible) and '1' meaning positive (visible). The procedure is conducted for the entire DEM to create a map giving a binary representation of a given area with indication which cells (representing certain locations) should be visible from the point of observation and which would not (Wheatley 1995; Wheatley and Gillings 2002).

The 3D virtual landscape in itself is not an analysis. It is a model of a certain landscape presented in a three-dimensional photorealistic manner. It can be based on numerical data (in this case DEM), geometry (vertices, faces, edges) and texture (colorful raster fitted to the geometry). If based on accurate data, the 3D model gives a unique opportunity to see a given landscape from any point and perspective, including the so-called First Person Perspective (FPP), which aims at a more personal and immersive experience of the observer (FPP is popular, for example, in video games).

It seems that viewshed analysis and 3D virtual landscape both have and both lack something that the other has. Viewshed is a great analytical tool but it uses measurements in pixels to evaluate what is visible and does not take into account environmental, atmospheric or light effects. There are some ways to compute, for example, diminishing vision over distance (Higuchi 1983; Fisher 1992; 1994; Wheatley and Gillings 2000; Ogburn 2006) but mostly GIS methods are not able to include possible visual factors that can obstruct the observer's vision (Richards-Rissetto 2017: 11–16). By contrast, thanks to FPP, the 3D virtual landscape gives one the ability to perceive a given location as it once was almost with one's own eyes. It also allows different visual factors affecting the observer's vision to be considered. Working in a georeferenced 3D scene ensures a more personal approach, coming closer to on-site experience, offering data-based vision simulation. It lacks though the analytical capacity of GIS (Agugiaro 2014). Research presented in this article compares the results yielded by the two methods and explores the potential of the 3D virtual landscape.

CASE STUDY: FAYSALIYYA SITE

The Jagiellonian University HLC archaeological project, carried out since 2016 in cooperation with the Department of Antiquities of the Ministry of Antiquities and Tourism of the Hashemite Kingdom of Jordan, is dedicated to the examination of the archaeological heritage of southern Jordan, focusing on remains from the Early Bronze Age and earlier cultures discovered in this region (Kołodziejczyk, Nowak et al. 2018; Kołodziejczyk, Wasilewski et al. 2018; Kołodziejczyk 2019; Kołodziejczyk et al. 2019). The project has already identified and verified several previously undocumented or poorly documented sites, completing both general field surveys and regular excavations at several sites. For the pedestrian surveys the Project uses GIS software combined with GPS data collected during field research, positioning archaeological features and individual artifacts, and supplementing the cataloging and description (Karmowski 2017).

More than 220 stone cairns were discovered by the HLC research team at the archaeological site of Faysaliyya near the city of Shawbak in southwestern Jordan. The cairns are located both on the slopes of a small periodic river valley and in its higher parts (Kołodziejczyk, Nowak et al. 2018). However, they are difficult to see even at a close distance due to their relatively small size (between roughly 0.50 m and 2.00 m in diameter) [*Fig. 3*]. The cairns could have constituted territorial markers of some kind or else objects of a cultic nature, hence their visibility in relation to one another could have been of significance.

Cairns in general are one of the most common aboveground funerary structures in the Southern Levant (Saidel 2017: 125). Structures like this are dated from the late Neolithic and Chalcolitic through the Early Bronze Age (Avner, Carmi, and Segal 1994; Abu-Azizeh et al. 2014; Saidel and Haiman 2014). They are often located in high places (on hills, ridges, prominent points in the landscape) and, as in Faysaliyya, they can occur in clusters. Cairns come in different shapes: circular, rectangular or square (Haiman 1993; Rowan et al. 2015). They contain primary or secondary burials, but they can also be empty (Saidel 2017: 125). Both of the cairns excavated at Faysaliyya proved to be

Fig. 3. Example of a cairn from the Faysaliyya site (HLC Archeological Project | Jagiellonian University HLC Project | photo J. Karmowski)

empty (Kołodziejczyk, Nowak et al. 2018: 385–386). The remaining 200 could be empty as well. It is clear, however, that they formed a significant visual element of this landscape. Their similar construction and their concentrated grouping might suggest that they were built around the same time. Evidence from the excavation of nearby settlement/pastoral structures set a date at the very end of the Early Bronze Age (Kołodziejczyk et al. 2019: 34). If the cairns and the settlement were contemporary—something not to be assumed outright—they could have served as cultic structures and/or territorial markers of some kind for the pastoral communities inhabiting the place. Hence, assessing the visibility of these structures could be of significance for an analysis of the past landscape.

The first step was to present the Faysaliyya cairns as symbols on a terrain visualization based on DEM and GPS data [see *Fig. 1*]. This displayed them con-

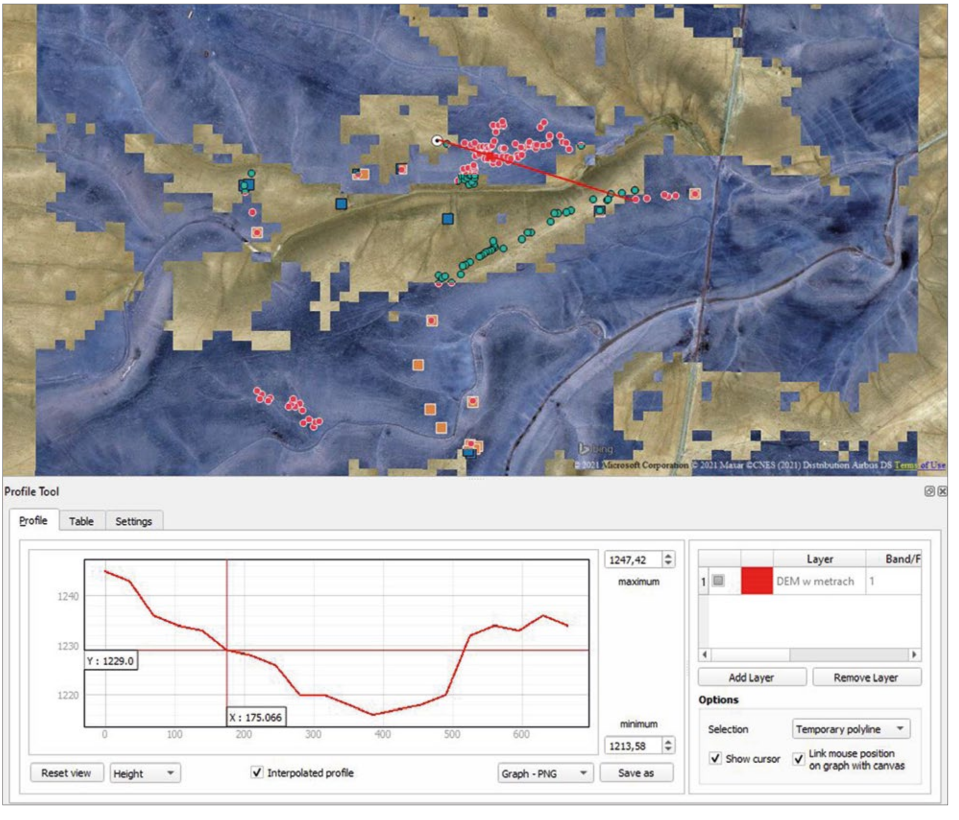

Fig. 4. Result of viewshed analysis. Observation Point (OP) is marked in white. Green dots – cairns visible from OP, red dots – cairns not visible from OP, blue squares – other archaeological structures visible from OP, orange squares – other archaeological structures not visible from OP. Dark color indicates which places are not visible from OP, while regular satellite image texture marks visible areas. Bottom, presentation of interpolated height (Jagiellonian University HLC Project | processing J. Karmowski)

sistently within the landscape in a single visualization. The form of data presentation here displays three-dimensional information in a 3D environment, paralleling the reading of elevation data on any map, described on a terrain model with numerical and color values. The question that this inspired was what would be the outcome of a comparison between a virtual simulation of what could actually be seen in the field with the results of a viewshed analysis.

VISUAL VIEWSHED SIMULATION (VVS) EXPERIMENT

A viewshed analysis was first conducted for a point close to one of the cairns. The underlying assumption was that the observation is carried out from a level of 1.60 m (average observer's height), pointing at objects with a height of 0.50 m, which is the approximate height of most of the cairns. The results clearly show which cairn could be seen from the observer's perspective (points marked in green) [*Fig. 4*]. However, not all of the objects that should have been visible from the observer's eye level simply because of their height and the distance to them, could actually be seen. Several additional factors, like weather conditions, may have obstructed visibility. 3D visualizations could help to resolve this issue because factors of this kind can be simulated to a certain extent in a 3D environment.

For the sake of credibility, the same set of initial data was used to perform both the viewshed analysis and the observations made in a 3D environment. As said above, the DEM was run on publicly available SRTM30 data and the GPS measurements were taken by the HLC team during fieldwork in 2017, using Garmin Etrex 20 and Garmin GPS map 62s devices. The visual 3D representation of the terrain was performed using Blender 2.93 and Twinmotion 2020 software, while the viewshed analysis was performed in QGIS 2.18.

RESULTS

A comparison of results obtained with the two methods broadens the perspective derived from the application of just one method. It becomes clear that a location offering theoretically an advantageous viewpoint did not always ensure visibility of a given feature.

As can be seen in the visualization [*Fig. 5*], cairns located on the opposite slope of the valley, which should be visible according to the results of the view-shed analysis, are not so clearly seen from the observer's eye level in the 3D simulation. They are even less visible when presented in the form of 3D models resembling their real apearance and size [*Fig. 6*].

The application of a 3D environment also makes it possible to illuminate the scene according to the geographical location, time and season—all factors that affect the efficiency of field observations. One can also freely manipulate the weather conditions and, for example, examine visibility during fog, which is common in this region between autumn and spring. In Twinmotion 2020, it is also possible to manipulate the time of day [*Fig. 7*]. Intensity and angle of the lighting are based on GPS location indicated in the software and a specific date and time.

PREDICTIVE AND "PAST CIRCUMSTANCES (RE)CONSTRUCTION" OPTIONS

The Visual Viewshed Simulation method also allows certain environmental or anthropogenic events and objects to be inserted into the 3D reality. Depending on how accurate the data is, it can be used as a stage in the processes of conceptualization and hypothesis testing. In the discussed case study, one can, for exam-

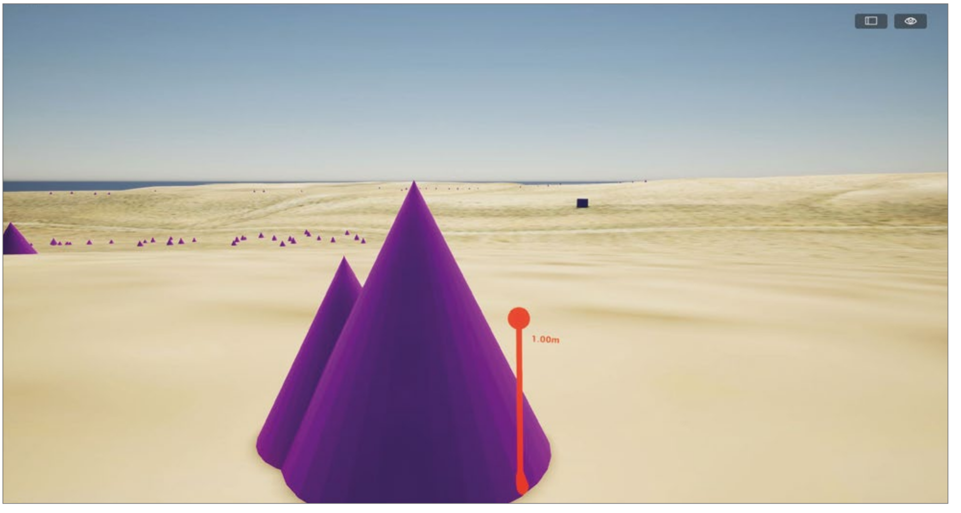

Fig. 5. 3D visualization of the landscape and location of the cairns at the Faysaliyya site. Purple cones represent cairns. The GPS coordinates of the cairn visible in front correspond to the coordinates used as the Observation Point in the GIS viewshed analysis (the same holds for the visualizations in Figs 6–8) (Jagiellonian University HLC Project | processing J. Karmowski)

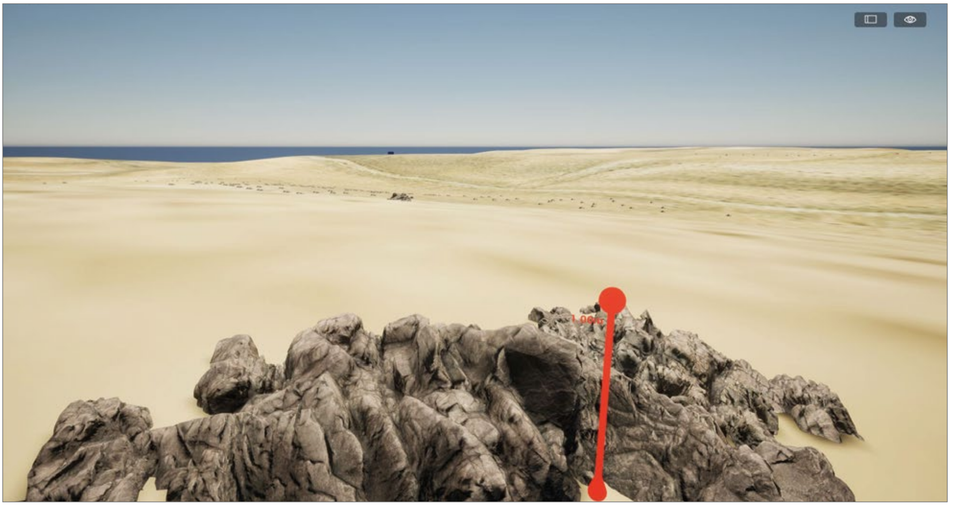

Fig. 6. 3D visualization of the landscape and location of the cairns at the Faysaliyya site with a photorealistic model used for the cairns (Jagiellonian University HLC Project | processing J. Karmowski)

ple, check whether burning fires could have affected the visibility of cairn locations at night and what the effect would be in different lighting conditions at different times of day and in different seasons [*Fig. 8*]. The simulation lets the researcher act out hypothetical scenarios reconstructing past circumstances.

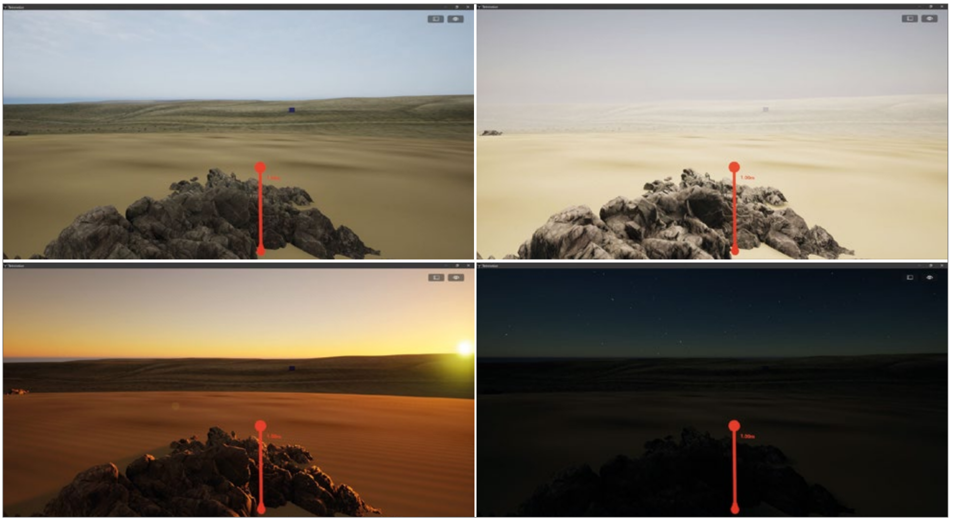

Fig. 7. Weather and lighting condition simulation in the 3D environment of the Faysaliyya site: clockwise from top left, overcast, fog, sunset with clear sky, nighttime with clear sky (Jagiellonian University HLC Project | processing J. Karmowski)

Fig. 8. 3D simulation of hypothetical circumstances in the 3D environment of the Faysaliyya site: top left and right, nighttime without and with fires set up at the cairns on the opposite side of the valley; bottom left, water level higher by 10 m; bottom right, simulated snowfall in the area of the site (Jagiellonian University HLC Project | processing J. Karmowski)

Different natural events can also be simulated in these 3D visualizations based on DEM data. For example, what would the area have looked like if the water level were 10 m higher or if it had snowed [see *Fig. 8*]. These last two examples may not be exactly appropriate in our case study, but they are an indication of the applicability of the method for potential environmental reconstruction/archaeological conceptualization.

DISCUSSION

Visual Viewshed Simulation can be a useful method for archaeologists in conceptualization and an important stage in testing a research hypothesis. The added value of the method is that it helps researchers to understand the personal experience of someone functioning within a certain landscape in the past (Dasgupta 2006; Champion 2011). It could be useful especially in archaeological landscape studies (Knapp and Ashmore 1999).

It is important though to keep in mind that visual methods like VVS are only simulations and are based on a given dataset. They always have to be combined with appropriate analytical tools (in this case GIS viewshed analysis) using the same set of data to ensure that the two methods are comparable. As noted by Philip Verhagen (2018: 13), methods of this kind cannot be introduced to research as a "stand-alone" approach. They always have to be part of what he calls "hybrid archaeological research" and combined with other tools/approaches that enable pluralism of possible answers, indicating which are more and which are less possible and why (Verhagen 2018: 13).

It should be noted that the method discussed in this article uses free software to analyze publicly available data in combination with GPS measurements taken in the field (QGIS and Blender software are entirely free, while Twinmotion can be freely used under an EDU license for non-profit oriented research purposes). Apart from the positive financial aspect, this makes the method easier to apply and develop by anyone with access to a mid-range PC and an Internet connection.

Of course, the presented method is not without its limitations. First, it is only as good as the data: better data means better results. The application of VVS in the way presented in this case study is recommended only for locations where more accurate data cannot be obtained. To answer more specific research questions, a better resolution DEM and GPS RTK measurements (instead of the traditional handheld GPS) are strongly advised.

It should also be said that DEM from SRTM30 actually constitutes what is called 2.5D data (Dell'Unto and Landeschi 2022: 13). 2.5D data comes from raster files that consist of a grid of cells in which the height value is expressed as an attribute (preventing each 'x', 'y' terrain unit from being described by more than one 'z' value). Because of this the data cannot be regarded as true 3D (a 3D model of the landscape is created in the process, based on the grid of values). The experiment presented in this article combines 2.5D and 3D environments. Ideally, the best practice would be to implement only 3D high resolution data, obtained via LiDAR or photogrammetry (3D models based on dense clouds of points). Unfortunately, this method could not be applied in the discussed area because of legal restrictions on the use of drones.

Another issue that might be of concern is that the method itself lacks the analytical value offered by GIS tools. 3D objects and light physics are arbitrary and depend on the software (although the user can manipulate them to some extent). Importantly, in order to use the method, despite its easy accessibility, the user has to proferss a certain knowledge and proficiency in working with GIS data and 3D modelling. It is not a ready-to-use tool and requires some time and practice to apply.

Last but not least, one should bear in mind that VVS. offers only a simulation. It aims at getting the researcher closer to the experience of being in the place, but it is not an actual on-site view. It is crucial to keep these limitations in mind when using this method in order not to confuse the concept of 'vision' with the concept of 'perception' (Richards-Rissetto 2017: 11). People–place relations and dynamics so important in landscape archaeology cannot be reconstructed with the use of simulation alone.

CONCLUSIONS

Introduction of 3D visual solutions in archaeology has given researchers yet another tool to be used in combination with already accepted and commonly applied methods (like viewshed analysis), grounded in a humanistic approach (ideally backed up by tested theories). By bringing to the table a more personal perspective, thanks to photorealism, the Visual Viewshed Simulation technique presented in this paper could constitute an important tool in the conceptualization of research questions. It can also be used to test hypotheses against results obtained with other tools.

VVS can be helpful in understanding the people–place perspective but caution is recommended in its use because it cannot give a direct "vision of the past", no matter how realistic it seems to the user. The "vision" will always be dependent on the data entered, the software used and the users themselves. Like many other GIS tools, 3D visual approaches of the VVS kind should not be treated as a deductive method. It can be part of an inductive process in which many approaches, tools and datasets are dealt with enabling theoretical progress (Maturana and Varela 1980; Richards-Rissetto 2017: 11). In Verhagen's words (2018: 13), the application of this method might be yet another "exercise in (scientific) rhetoric" to help archaeologists create many possible realities and their representations. Two points are vital however: that 1) it is data-driven and can be compared with analytical GIS methods with the help of the same datasets, and that 2) it places emphasis on the personal perspective, thereby combining applied science with a humanistic approach.

The use of 3D visual technologies in archaeology has opened up various paths of research and the method presented here has the same kind of potential. It needs further exploration and development with the help of experts in GIS, 3D modeling and software engineering to gain maximum benefit out of its application and to make it more accurate. This could be achieved by introducing data of higher resolution as well as other kind of data referring to physical properties of certain objects/weather conditions/circumstances and reflecting how they could affect human vision. It would also be beneficial to adapt this method to Virtual Reality systems allowing the use of VR headsets. With a high standard of applied data and immersive VR experience, certain virtual landscapes and their components could be experienced by a statistically chosen sample of individuals. Then, by asking certain questions, it would be possible to investigate matters connected to the landscape itself ([re]constructing human perception, interaction with the landscape). It might also prove of interest to examine what people have to say about the method itself (assessing, for example, its suitability as a tool for the dissemination of research).

Jacek Karmowski
https://orcid.org/0000-0001-8034-0694
Jagiellonian University, Kraków
jacekkarmowski@gmail.com

How to cite this article: Karmowski, J. (2022). Visual Viewshed Simulation: Applying a 3D environment in archaeological research at Faysaliyya (southern Jordan). *Polish Archaeology in the Mediterranean*, 31, 519–535. https://doi.org/10.37343/uw.2083-537X.pam31.04

References

Abu-Azizeh, W., Tarawneh, M., Abudanah, F., Twaissi, S., and Al-Salameen, A. (2014). Variability within consistency: Cairns and funerary practices of the Late Neolithic/Early Chalcolithic in the Al-Thulaythuwat area, southern Jordan. *Levant*, 46(2), 161–185

Agugiaro, G. (2014). 2D GIS vs. 3D GIS theory. In F. Remondino and S. Campana (eds), *3D recording and modelling in archaeology and cultural heritage: Theory and best practices* (=*BAR International Series* 2598) (pp. 103–114). Oxford: Archaeopress

Avner, U., Carmi, I., and Segal, D. (1994). Neolithic to Bronze Age settlement of the Negev and Sinai in light of radiocarbon dating: A view from the Southern Negev. In O. Bar-Yosef and R.S. Kra (eds), *Late Quaternary chronology and paleoclimates of the eastern Mediterranean* (pp. 265–300). Tucson, AZ: RADIOCARBON; American School of Prehistoric Research

Barceló, J.A., Forte, M., and Sanders, D.H. (eds). (2000). *Virtual reality in archaeology* (=*BAR International Series* 843). Oxford: Archaeopress

Campana, S. (2014). 3D modeling in archaeology and cultural heritage – theory and best practice. In F. Remondino and S. Campana (eds), *3D recording and modelling in archaeology and cultural heritage: Theory and best practices* (=*BAR International Series* 2598) (pp. 7–12). Oxford: Archaeopress

Champion, E. (2011). *Playing with the past*. London–New York: Springer

Dasgupta, S. (ed.). (2006). *Encyclopedia of virtual communities and technologies*. Hershey, PA: Idea Group Reference

Dell'Unto, N. (2014). 3D models and archaeological investigation. In I. Huvila (ed.), *Perspectives to archaeological information in the digital society* (=*Meddelanden från Institutionen för ABM vid Uppsala universit* 5) (pp. 55–71). Uppsala: Uppsala Universitet

Dell'Unto, N. and Landeschi, G. (2022). *Archaeological 3D GIS*. Abingdon–New York: Routledge

Fisher, P.F. (1992). First experiments in viewshed uncertainty: Simulating fuzzy viewsheds. *Photogrammetric Engineering and Remote Sensing*, 58(3), 345–352

Fisher, P.F. (1994). Probable and fuzzy models of the viewshed operation. In M.F. Worboys (ed.), *Innovations in GIS 1* (pp. 161–175). London: Taylor & Francis

Forte, M. (ed.). (2010). *Cyber-archaeology* (=*BAR International Series* 2177). Oxford: Archaeopress

Forte, M. (2014). Virtual reality, cyberarchaeology, teleimmersive archaeology. In F. Remondino and S. Campana (eds), *3D recording and modelling in archaeology and cultural heritage: Theory and best practices* (=*BAR International Series* 2598) (pp. 113–127). Oxford: Archaeopress

Haiman, M. (1993). An Early Bronze Age cairn field at Naḥal Mitnan. *'Atiqot*, 22, 49–61

Higuchi, T. (1983). *The visual and spatial structure of landscapes* (C.S. Terry, trans.). Cambridge, MA: MIT Press

Karmowski, J. (2017). Some methodological aspects of documentation in new archaeological survey in at-Tafila District (Jordan) carried out by Jagiellonian University in Cracow (Poland). *Journal of Heritage Conservation*, 50, 44–53

Knapp, A.B. and Ashmore, W. (1999). Archaeological landscapes: Constructed, conceptualized, ideational. In W. Ashmore and A.B. Knapp (eds), *Archaeologies of landscape: Contemporary perspectives* (pp. 1–30). Oxford: Blackwell

Kołodziejczyk, P. (2019). HLC Project 2014–2019: Research activity of Jagiellonian University. In P. Kołodziejczyk (ed.), *Discovering Edom: Polish archaeological activity in Southern Jordan* (pp. 31–50). Kraków: Wydawnictwo Profil-Archeo Magdalena Dzięgielewska; Euclid Foundation for Science Popularization; Institute of Archeology, Jagiellonian University

Kołodziejczyk, P., Nowak, M., Wasilewski, M., Witkowska, B., Karmowski, J., Czarnowicz, M., Brzeska-Zastawna, A., Zakrzeńska, J., Radziwiłko, K., and Kościuk, J. (2018). HLC Project 2017: Jagiellonian University excavations in southern Jordan. *Polish Archaeology in the Mediterranean*, 27/1, 379–416

Kołodziejczyk, P., Nowak, M., Wasilewski, M., Witkowska, B., Karmowski, J., Czarnowicz, M., Zakrzeńska, J., and Brzeska-Zastawna, A. (2019). HLC Project 2018: Jagiellonian University excavations in southern Jordan. *Polish Archaeology in the Mediterranean*, 28/2, 251–286

Kołodziejczyk, P., Wasilewski, M., Czarnowicz, M., Karmowski, J., Kościuk, J., and Węgrzynek, A. (2018). HLC Project. New Polish archaeological activity in At-Tafileh micro-region (south Jordan). In P. Valde-Nowak, K. Sobczyk, M. Nowak, and J. Źrałka (eds), *Multas per gentes et multa per saecula: Amici magistro et collegae suo Ioanni Christopho Kozłowski dedicant* (pp. 567–576). Kraków: Institute of Archeology, Jagiellonian University in Kraków; Alter Publishing House

Maturana, H.R. and Varela, F.J. (1980). *Autopoiesis and cognition: The realization of the living*. Dordrecht: Springer

Mukherjee, S., Joshi, P.K., Mukherjee, S., Ghosh, A., Garg, R.D., and Mukhopadhyay, A. (2013). Evaluation of vertical accuracy of open source Digital Elevation Model (DEM). *International Journal of Applied Earth Observation and Geoinformation*, 21, 205–217

Mukul, M., Srivastava, V., and Mukul, M. (2016). Accuracy analysis of the 2014–2015 Global Shuttle Radar Topography Mission (SRTM) 1 arc-sec C-Band height model using International Global Navigation Satellite System Service (IGS) Network. *Journal of Earth System Science*, 125(5), 909–917

Ogburn, D.E. (2006). Assessing the level of visibility of cultural objects in past landscapes. *Journal of Archaeological Science*, 33(3), 405–413

Richards-Rissetto, H. (2017). What can GIS + 3D mean for landscape archaeology? *Journal of Archaeological Science*, 84, 10–21

Rowan, Y.M., Rollefson, G.O., Wasse, A., Abu-Azizeh, W., Hill, A.C., and Kersel, M.M. (2015). The "land of conjecture:" New late prehistoric discoveries at Maitland's Mesa and Wisad Pools, Jordan. *Journal of Field Archaeology*, 40(2), 176–189

Saidel, B.A. (2017). An alternative date for the Nahal Mitnan cairn field in the Western Negev Highlands: Identifying an Early Timnian tumuli tradition in the Southern Levant. *Paléorient*, 43(1), 125–140

Saidel, B.A. and Haiman, M. (2014). The fieldwork. In B.A. Saidel and M. Haiman (eds), *Excavations in the Western Negev Highlands: Results of the Negev Emergency Survey 1978–89* (=*BAR International Series* 2684) (pp. 7–57). Oxford: Archaeopress

van Zyl, J.J. (2001). The Shuttle Radar Topography Mission (SRTM): A breakthrough in remote sensing of topography. *Acta Astronautica*, 48(5), 559–565

Verhagen, P. (2018). Spatial analysis in archaeology: Moving into new territories. In C. Siart, M. Forbriger, and O. Bubenzer (eds), *Digital geoarchaeology: New techniques for interdisciplinary human-environmental research* (pp. 11–25). Cham: Springer International Publishing

Wheatley, D. (1995). Cumulative viewshed analysis: A GIS-based method for investigating intervisibility, and its archaeological application. In G.R. Lock and Z. Stančič (eds), *Archaeology and geographical information systems: A European perspective* (pp. 171–185). London–Bristol, PA: Taylor & Francis

Wheatley, D. and Gillings, M. (2000). Vision, perception and GIS: Developing enriched approaches to the study of archaeological visibility. In G.R. Lock (ed.), *Beyond the map: Archaeology and spatial technologies* (=*NATO Science Series* 321) (pp. 1–27). Amsterdam: IOS Press

Wheatley, D. and Gillings, M. (2002). *Spatial technology and archaeology: The archeaological applications of GIS*. London: Taylor & Francis