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Seeking a Better View: Using 3D to Investigate Visibility in Historic Landscapes

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Abstract The examination of historic landscapes at complex, multi-phased archaeological sites is hampered by the limitations of traditional two-dimensional (2D) visibility studies in geographic information systems (GISs). This paper argues for integrating three-dimensional (3D), qualitative methods into the study of visibility of monumental architecture at ancient sites. By transforming 2D GIS data into 3D representations of ancient built and natural landscapes, visibility studies can be greatly enhanced, adding into analysis perspective, monument shape, and color, as well as changing levels of visibility across time and space. The ancient Egyptian site of Saqqara (29° 52′ 16.55″ lat./31° 12′ 59.58″ E long.) is one of a number of cult locations with monumental architecture neighboring the administrative capital of Memphis. The Old Kingdom cult site of Saqqara (2670 BCE–2168 BCE) is utilized to demonstrate the potential for 3D visibility studies that better replicate such elements of human perception. This method offers new possibilities for more human-centered studies of past landscapes.

Keywords Visibility · 3D modeling · Geographic information systems · Visualization · Landscape · Egypt

Introduction

The study of ancient ritual landscapes in archaeology offers insights into why certain spaces gained and retained their importance and how people continued to interact with the built spaces of their ancestors, based on personal and cultural memory (Yoffee 2007; Van Dyke and Alcock 2003). An important element of the ritual landscape in many cultures, including ancient Egypt, is the built environment: monuments and their

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integration within the natural world (Ashmore and Knapp 1999; Daróczi 2012; Jeffreys 2012a, p. 8; Dorman and Bryan 2007). The visibility of monuments plays a major role in the construction of "social landscapes," networks of meaning built out of the relationship between multiple buildings across space and time (Llobera 2007, p. 51–52). This article suggests new methodologies for investigating the visual impact of monumental architecture in such ritual landscapes, focusing on the use of emerging 3D GIS technologies.

Early GIS-based visibility analysis focused on binary concepts of visibility—*visible* or *not visible*—based on raster (terrain) elevation values and the addition of an object's height (a single attribute measuring the tallest point). Unsatisfied with the lack of nuance in this analysis, scholars have worked to develop techniques that better replicate real-world vision processes, examining cumulative, directional, and "fuzzy" visibility (these and other techniques are reviewed in Wheatley and Gillings 2000). Most such quantitative studies, however, still fall short of incorporating the qualitative aspects of human perception. Visibility is not single-dimensional but includes aspects like shape,[1] perspective, contrast, color, and reflection. Additionally, the built environment is more complex than single points above a surface (Llobera 2012, p. 502).

More important may be the critique that *vision* is itself less important than human *experience* (Frieman and Gillings 2007, p. 5). Indeed, the changing perception of space through time, as well as human movement through space, has not been sufficiently explored in 2D GIS (Gillings and Wheatley 2001). Researchers involved with visibility studies in archaeology readily admit that new techniques and alternative frameworks are necessary to advance the field and find methods to incorporate visibility into the investigation of human engagement with past environments. A truly "higher level" of analysis than currently available in GIS would include human movement through a landscape, human perception of changing forms during that movement, the appearance of monuments, the identification of focal points, change across time, and the different textures of the natural and built environment (Llobera 2012, p. 499–500). These would more closely align with the experiential and subject-centered approaches to landscape championed by Tilley (1994). This article argues that such "higher" levels of investigation can be broached using GIS data moved into 3D visualization platforms.

Indeed, a small number of researchers have recently begun experimenting with 3D GIS techniques specifically for the analysis of ancient architecture (Paliou 2014; Paliou, Wheatley, and Earl 2011; Papadopoulos and Earl 2014). They demonstrate that the relationship between cultural spaces and visibility is more effectively investigated in 3D environments. This seems especially crucial for monumental architecture, whose meaning and interpretation are not based on a sole concept (such as visibility), but rather on its relationship with the landscape/environment, with surrounding structures, and with the observer (Osborne 2014, p. 4; Paliou 2013, p. 246). Difficulties in integrating GIS datasets with 3D software have hampered the incorporation of 3D modeling techniques into the field of landscape archaeology until now (Verhagen 2012, p. 313), but a 3D GIS study of the site of Saqqara, Egypt demonstrates new potentials.

[1] Pizlo (2008, p. 1–2) argues that shape is a "unique perceptual property" of objects because of its complexity along multiple dimensions. Humans identify objects by their shape group (the family of objects into which a shape falls) and even when the orientation of the eye of the viewer changes in respect to the object, the viewer continues to perceive the object as within that shape group ("shape constancy"). Shape is thus fundamentally linked to human visual identification of objects and their interpretation.

For this project, two-dimensional data created in the ESRI ArcGIS Desktop program was combined with 3D data on monuments and terrain and moved into the 3D city building program CityEngine and the 2.5D visualization environment ArcScene. A workflow from 2D GIS > 3D model environment allows the data to retain the geo-spatial system of a GIS, but with the addition of 3D qualitative information. The 3D environments were then utilized to perform visibility studies that offer new insights on monumental architecture at the site. The methodology demonstrated here allows for a more qualitative approach to landscape visibility studies, providing enhanced visual capabilities for GIS datasets and offering new levels of nuance. Elements such as perspective, monument shape, movement through space, and temporal change are all addressed.

Visibility in the Egyptian Landscape

Ancient Egyptian culture placed great emphasis on sacred landscapes. While studies on the siting and form of buildings and other features have frequently focused on economic and political factors, of equal importance should be the cultural perceptions concerning the existing natural and built landscape of the area (Richards 1999, p. 84; Montserrat and Meskell 1997). Evidence from the urban and funerary sites of Abydos, Amarna, and Thebes suggests that natural and man-made features of great religious significance indeed shaped both tomb/cult structure placement and form and the larger communal perception of sacred space (Richards 1999; O'Connor 2011; Mallinson 1999, p. 72–78; Ockinga 2007, p. 139). One contributing factor to the importance assigned to these places was visibility. This study attempts to examine how monument visibility effected placement and meaning at the cult site of Saqqara.

Case Study: Saqqara

The ancient Egyptian cemetery of Saqqara served as a burial place and cult center for kings, administrators, royal family members, artists, and (less frequently) non-elites over more than 3000 years of intermittant use, 2950 BCE-fourth century CE. Scattered over a 7-km square zone, pyramids, *mastaba* tombs, and huge funerary enclosures still attest to the site's original grandeur. Saqqara is situated on a natural rock escarpment west of the Nile river, and like many Egyptian elite cemeteries in the Nile Valley, it was positioned at the edge of the desert above the alluvial plain, providing a dry location for the preservation of the bodies of the deceased. The natural limestone and marl of the high desert surface were covered with meters of desert sand and gravel blown in from the western desert 6000 to 10,000 years BP (Papa 2003, p. 192–194), with the tombs built atop or cut into these strata. The city of Memphis, which served as a national capital during various historic periods, lay on the alluvial plain below. Royal and elite burials and cult structures from a variety of chronological moments have also been preserved at the neighboring desert edge necropolis of Giza, Abu Sir, Abu Ghurab, Dahshur, and Helwan (Fig. 1). The city of Heliopolis to the northeast, now subsumed by modern Cairo, held the main temple to the solar god Re and served as a major focal point of religious practice throughout the Pharaonic period.

Fig. 1 Satellite imagery with the major ritual sites around Saqqara and observer points in possible locations for ancient Memphis, ESRI imagery

Questions relating to the creation and perpetuation of sacred space at Saqqara have typically been addressed in Egyptology using textual and iconographic sources, and more rarely have archaeological and architectural evidence been utilized. While tomb and cult building location at the Memphite cemeteries is traditionally explained in regard to construction concerns (quality of bedrock and access to natural causeways, harbors, and labor), desire for burial next to high-status individuals, state administrative organization, familial relationships, and in response to changing religious ideas (Roth 1988, p. 201; Lehner 1997, p. 82–163; Bárta 2005; O'Connor 1974, p. 19–22), visibility within the larger sacred landscape has only rarely been considered in descriptions of the cemetery (Jeffreys and Tavares 1994; Jeffreys 1998, 2010). This is surprising, since constructions were monumental in size and possessed conspicuous superstructures.

Admittedly, investigating tomb prominence and lines-of-sight within the greater ritual space at long-lived sites like Saqqara is problematic. Unlike some sites where modern archaeologists can make interpretive observations on visibility questions in the field, the state of the remaining built environment at Saqqara is so degraded that tracing these patterns on site, especially from the earliest periods of occupation, is essentially impossible. Years of ancient and modern change to both the built and natural landscapes make it difficult to re-imagine the interaction between ancient place and environment (see Llobera 2007, p. 53–54, for the difficulty of re-imagining past landscapes). In order to visualize this lost landscape, scholars must grapple with numerous diachronic issues due to major alterations that took place in the cemeteries and city. The first of these are historical and architectural; due to the patchwork nature of the development at Saqqara, lines-of-sight at any given chronological moment have been obscured by later (but still ancient) constructions at the cemetery. One must peel away the layers of later construction in order to replicate historic views. Second, the superstructures of many of the monuments from the cemeteries and contemporary town have collapsed or suffered purposeful destruction. These superstructures, some of them originally many meters in height, do not currently reflect their visual impact at a given time in the past. Third, modern research has demonstrated that the landscape of the surrounding region changed significantly over time. The Nile's course shifted drastically (Jeffreys and Tavares 1994; Lutley and Bunbury 2008; Bunbury and Jeffreys 2011; Jeffreys 2012b), and ancient ground levels in the region have disappeared under the drift of desert sands on the escarpment and the rising alluvial plain (Herbich and Jagodziński 2008; Mathieson and Dittmer 2007; Price 2012; Lehner 2009; Jeffreys 2012b; Alexanian *et al.* 2015). These changes must be acknowledged in any attempt to trace the relationship of the cemetery to the city of Memphis or neighboring sites. Examining the ancient sense of place at Saqqara can only be done, therefore, by modeling a series of now-disappeared environments.

Methodology

This article describes how 2D GIS data from archaeological sites can be imported into 3D visualization environments to perform visibility analyses that add new types of qualitative information to such studies. One major phase at Saqqara was chosen for the analysis, the Old Kingdom (2670–2168 BCE, dynasties 3–8).[2] This is one of the oldest periods of monumental architecture at Saqqara and, in many ways, obscured by later changes at the site.

Creating 2D GIS Data in ArcMap

Archaeological and geological survey and historical map data relating to Saqqara were aggregated into a geographic information system (GIS) database. In the GIS software program ArcMap (10.3), the team prepared footprints outlining the ground plan of each monument to be reconstructed in 3D as 2D polygons. These footprints were selected in

[2] This follows the chronology utilized by the UCLA Encyclopedia of Egyptology (UEE): http://uee.ucla.edu/chronology/.

chronological groups, exported, and imported into the CityEngine program (Fig. 2). Next, we prepared terrain data for the area in ArcMap. Digital contours for areas of specific interest (such as the central Saqqara area) were generated from 1 m topographic lines based on the 1:5000 Ministry of Housing and Reconstruction (MHR) Survey of Egypt series maps, Consortium SFS/IGN France, "Le Caire." The data originates from aerial photos conducted in 1977, at a resolution of 1:15,000.[3] The digital 1 m contour line files of the area of Giza and 5 m contour line files of the area of South Saqqara (H23) were provided by the Ancient Egypt Research Associates and adjusted by that group to reflect modern-day survey data. 3D Saqqara project members hand digitized the other contours at varying intervals.[4] Comparison of the MHR produced terrains and SRTM terrains show the differences between the two (Figs. 3 and 4).[5] Between major areas of archaeological interest, the project digitized contour maps at lower resolution (10 m lines) based on the US Army Corps of Engineers, Army Map Service "Egypt G8300" maps published in 1961, created at a 1:50,000 scale.

The team then adjusted the contour values for Saqqara, South Saqqara, and Memphis to reflect hypothesized "ground horizon" levels at various historic periods, based on published archaeological and geophysical research. This included a general lowering of ASL values in the floodplain and leading up to the escarpment, accounting for the many meters of alluvial silt deposited on the floodplain around Memphis since ancient times. Scholars working in the Memphite area have suggested that the floodplain in the early Old Kingdom stood somewhere around 13–14 m ASL, approximately 6 m lower than in modern times.[6] We lowered topographical lines for the floodplain in Dynasty 0–4 terrains to 13–14 m ASL; those for the later Dynasty 5–6 terrains we lowered in the model to 15–16 m ASL to represent rising ground from alluviation. We also lowered or removed line values around high points on the escarpment that clearly reflects later (both ancient and modern) buildup (Fig. 5). Excavations show that original ground horizon for many areas on the Saqqara plateau stood lower than modern times by a number of meters. For example, pavements in the courtyards of three New Kingdom temple tombs located south of Djoser's step pyramid (which were built over Early Dynastic tombs, presumably destroying their original superstructures located at or slightly lower than these levels) have published elevations ASL between 55.9 and 56.4 m (Raven 2001, pl. 2; Regulski 2011, Fig. 2; Martin 1997, pl. 2; Regulski *et al.* 2010, Fig. 3). Yet the MHR contour lines in this area stand at 58–59 m ASL, suggesting 2–3 m of overburden has accumulated around these monuments (this can be clearly

[3] Maps utilized for this article include F17-18 (Giza), H21-H26 (Abusir to Dahshur), and I22-I23 (the Memphis floodplain).

[4] Abusir and Saqqara (H21, H22) 1 m, South Saqqara (H24) 1 m, Memphis 1 m, and Dahshur (H25, H26) 10 m.

[5] Currently available NASA SRTM data (https://lta.cr.usgs.gov/SRTM1Arc) and ASTER DEMs (https://lpdaac.usgs.gov/dataset_discovery/aster/aster_products_table/astgtm) offer maximum resolution of 30 m (1:50,000 resolution) and thus offer less detail then the MHR maps, so the MHR maps were selected as the basis of the project's terrains.

[6] Geomorphological analysis and archaeological field work has demonstrated that ancient ground level in the entire Memphite area was significantly lower than today, due to the buildup of many meters of sand and alluvial sediment from the late Old Kingdom and after (Alexanian *et al.* 2012; Jeffreys and Tavares 1994, p. 157–158). Lehner offers an in-depth discussion of the evidence for the height of the floodplain in the Old Kingdom (and later) in the Memphite region (Lehner 2009, p. 98–104), estimating a floodplain height of 13–14 m ASL and a peak flood height of 14.5–15 m (Lehner 2009, p. 102).

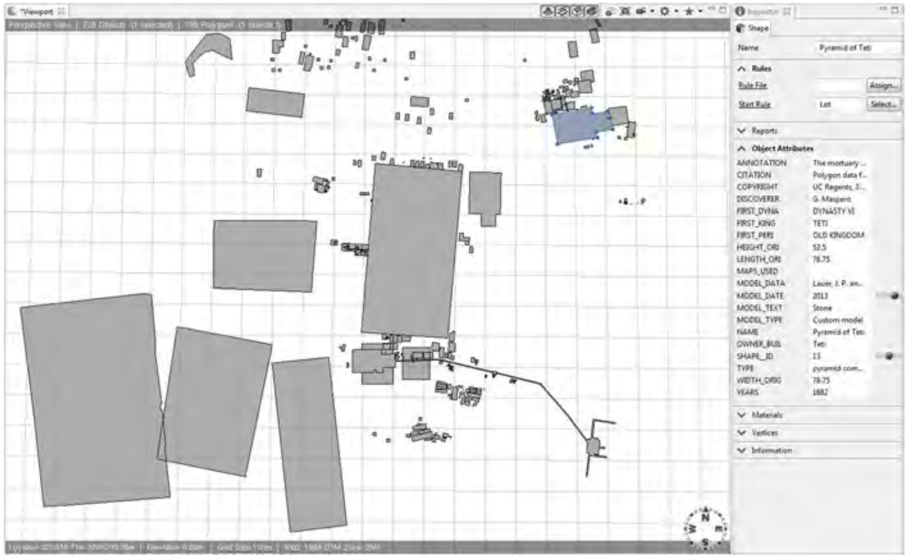

Fig. 2 Shapefiles representing monument footprints imported into the CityEngine platform

seen when visiting the site today). We therefore adjusted contour lines for the area down 2 m to represent the lower ground horizon in the New Kingdom and before. While we made similar adjustments in a number of areas of the site (Fig. 5), because

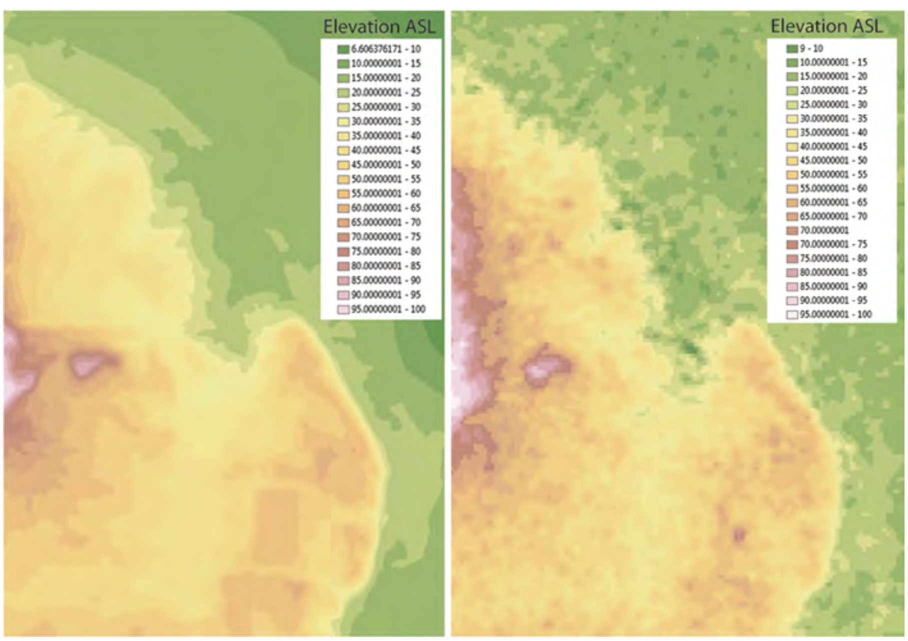

Fig. 3 Comparison of the MHR contour-map produced digital elevation model (*left*) with 30 m SRTM elevation data of the same area (*right*), the MHR contours were adjusted to remove some modern construction; SRTM data 1 Arc-Second Global, ID SRTM1N29E031V3, acquired –February 11, 2000, from the US Geological Survey (USGS)

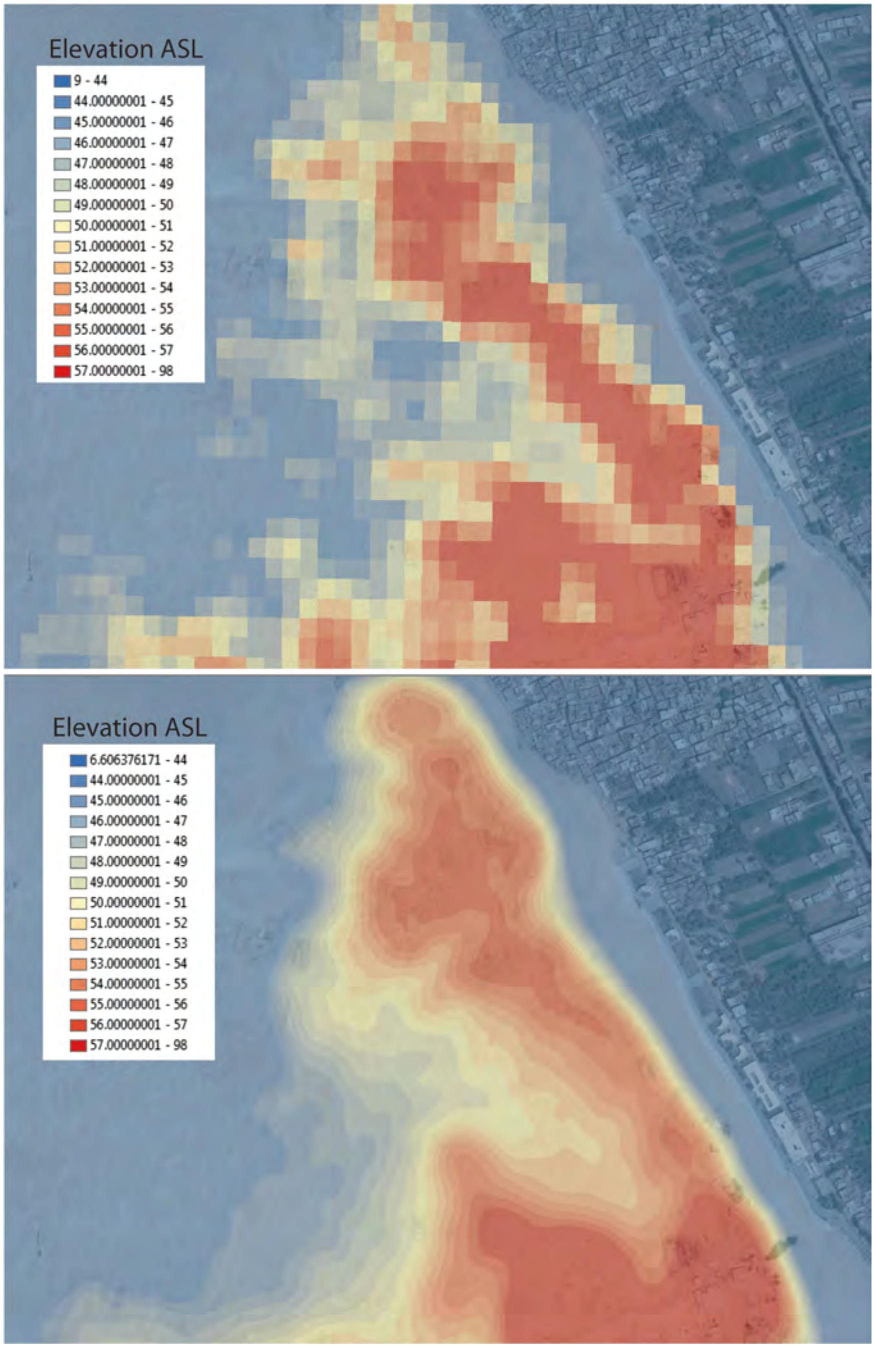

Fig. 4 Close-up of the North Saqqara escarpment showing terrain produced using SRTM 30 m elevation data (*top*) with MHR contour maps (*bottom*) displayed with slight transparency over the same satellite imagery of Saqqara and highlighting elevations between 44 and 57 m above sea level (ASL) with distinct color ramp for detailed comparison between terrains; SRTM data 1 Arc-Second Global, ID SRTM1N29E031V3, acquired February 11, 2000, from the US Geological Survey (USGS); ESRI satellite imagery

early excavators did not publish elevation information (and thus original ground horizon at many areas of the site remains undocumented), we left many areas unadjusted, for lack of quality data. But utilizing this technique, we have been able to create terrains that more closely reflect ancient ground horizons across large sections of the site.[7] To reflect the changing landscape over time,[8] we produced four distinct digital terrain models for the project representing temporal change; two cover the period discussed in this article.[9] Because CityEngine is not compatible with traditional digital elevation model (DEM) formats, we converted the terrain rasters into heightmaps in ArcMap (Saldaña and Johanson 2013, p. 206). Heightmaps are grayscale image rasters that store and display elevation information in TIFF format (Fig. 6).

Moving ArcMap 2D Data into CityEngine

Next, we opened building footprints in the CityEngine program, which maintains the data's geographic coordinates. Each building footprint whose historic ground level was known (from archaeological publications) was then assigned an individual height and moved to its appropriate elevation ASL (Table 1). In CityEngine, this is accomplished by re-positioning each of the polygon's vertices (Fig. 7).[10] We also produced individual polygon footprints that reflect hypothetical locations for major natural features no longer in their historic positions, including the lake of Abusir and the Nile river. The terrain heightmaps were then opened in CityEngine for integration with the polygon footprints (Fig. 8). For those buildings or features whose historic heights cannot be based on published archaeological data,[11] elevation ASL was assigned based on the adjusted terrain data. Those polygon footprints can be selected, and using CityEngine's "adjust polygons to terrain" function, these snap directly on the custom terrains.[12] This capability allows the researcher to utilize well-documented elevations when they are

[7] Many of the areas adjusted of terrain adjusted (Fig. 5) are particularly relevant to the conclusions in this article, as they focus on the eastern-most high points of the Saqqara escarpment, potentially the most prominent areas from the floodplain.

[8] While the floodplain changed most dramatically due to rising ground level and the shifting position of the Nile, areas of the escarpment also changed. In a number of places, Egyptians constructed tombs directly above the collapsed superstructures of earlier burials, now filled in with sand and trash. At the Dynasty 6 cemetery surrounding the Teti pyramid, for example, the excavator found one New Kingdom tomb chapel floor level at 4 m above the floor of the Old Kingdom *mastaba* tomb below it. The excavator suggested that the entire area was leveled to a similar height during the New Kingdom, significantly above that of the Old Kingdom level (Ockinga *et al.* 2004, p. 122–123).

[9] All the terrains were produced using ArcGIS's Spatial Analysts *Topo to Raster* tool, which interpolates "hydrologically correct digital elevation models" from topographic contours or point data: http://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-topo-to-raster-works.htm.

[10] This methodology was developed by Dr. Marie Saldaña, described in her unpublished tutorial: "ArcGIS > CityEngine > Unity Pipeline Tutorial."

[11] It is important to note that elevations for many monuments at Saqqara have not been published, especially structures excavated before modern field survey techniques developed. In Table 1, the base height of some monuments was estimated based on the MHR contour data. Because of the lack of general elevation data at Saqqara, base heights for some monuments are based on elevations for any part of the structure with information on "ground horizon," such as the interior court height of a pyramid's memorial temple or the floor level of the start of the pyramid causeway. It is assumed for this project that these represent a ground horizon, although they may differ slightly from the original monument "base."

[12] This methodology was developed by Dr. Marie Saldaña, described in her unpublished tutorial"ArcGIS > CityEngine > Unity Pipeline Tutorial."

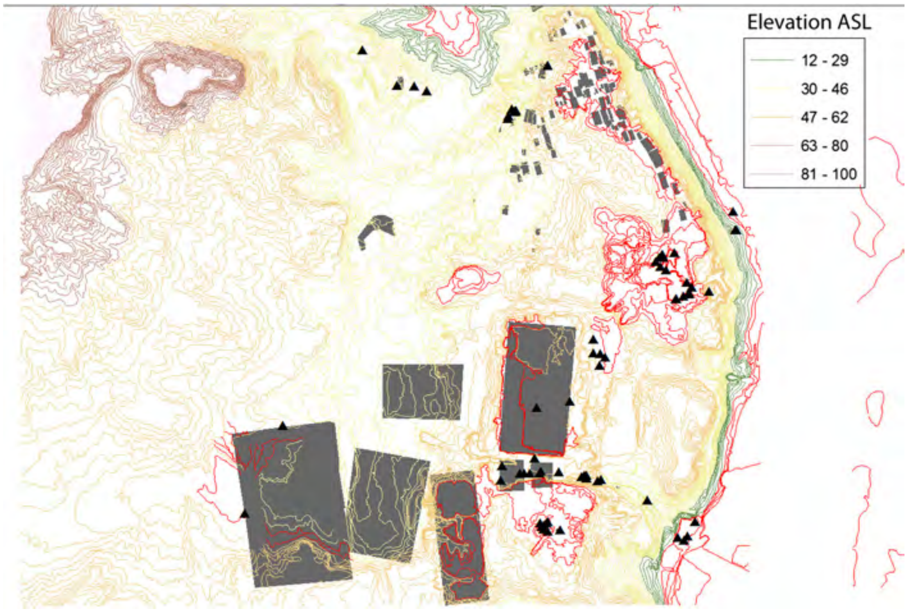

Fig. 5 Digitized contour line maps of terrain elevations with red lines marking contours lowered to reflect ancient ground horizons or to eliminate areas of modern overburden and black triangles representing points with known elevations related to ancient ground level

available (moving the footprints manually to exact heights) and more estimated elevation data when individual building ground levels are not known.

Incorporation of 3D Models

For this project, 3D massing models of well-documented monuments were created in the program Trimble SketchUp. The models were designed based

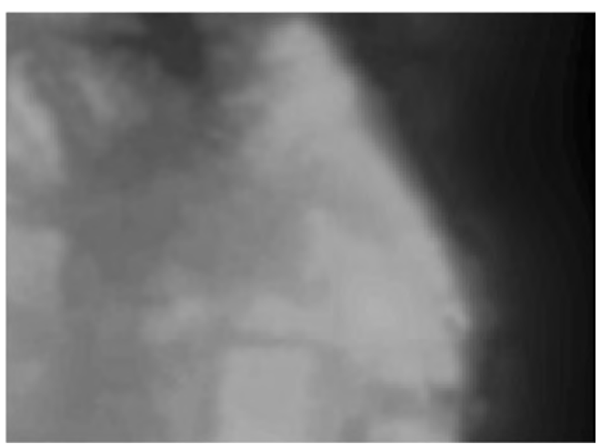

Fig. 6 Close-up of the North Saqqara escarpment showing heightmap raster created from digital elevation model based on MHR contour data

Table 1 Base elevation and height for major monuments at Saqqara discussed in this article with source data

Site	Monument owner	Base height ASL (m)	Source	Model pyramid height (m)	Source
Dahshur	Sneferu, Bent pyramid	57	Estimated based on topographic line data	105	Lehner (1997)
Dahshur	Sneferu, North pyramid	59	Estimated based on topographic line data	105	Lehner (1997)
South Saqqara	Pepy II	50	Estimated based on topographic line data	52.5	Lehner (1997)
South Saqqara	Pepy I	42.7	Labrousse and Albouy (1999, p. 122, 133)	52.5	Lehner (1997)
South Saqqara	Djedkare Isesi	45	Estimated based on topographic line data	52	Verner (2001)
South Saqqara	Merenre	46.5	Estimated based on topographic line data	52.5	Lehner (1997)
Central Saqqara	Unas	55.4	Labrousse and Lauer (1977, Fig. 38)	43	Lehner (1997)
Central Saqqara	Djoser	55.6	Lauer 1936: 24 and pl. XIX	60	Lehner (1997)
Central Saqqara	Userkaf	48	Labrousse and Lauer (2000, Figs. 342 and 344)	49	Lehner (1997)
Central Saqqara	Teti	57	Jeffreys, Smith, and Price (1988)	52.5	Lehner (1997)
Central Saqqara	Menkauhor?	53	Estimated based on topographic line data	35 original height unknown	Estimated based on base size
Abusir	Neferirkare	50.5	Based on a memorial temple floor height of 31.49 m above the zero point of the Sahure valley temple floor (Borchardt 1910, blatt 2) with the zero point at the Sahure valley temple at ~19 m, following Seidlmayer (2001, p. 48)	72	Lehner (1997)
Abusir	Niuserre	47.5	Based on a memorial temple floor height of 28.61 m above the zero point of the Sahure valley temple (Borchardt 1910, blatt 2) with the zero point at the Sahure valley temple at ~19 m, following Seidlmayer (2001, p. 48); also, Borchardt (1907, blatt 5) states that the valley temple's portico pavement is 28.28 m lower than the memorial temple floor, and Krejčí (2011, p. 522) cites an internal chapel	51.68	Lehner (1997)

Table 1 (continued)

Site	Monument owner	Base height ASL (m)	Source	Model pyramid height (m)	Source
			in the valley temple portico as standing at 18.72 m, equaling 47 m.		
Abusir	Sahure	37	Krejčí (2010, p. 27); based on a memorial temple floor height of 17.82 m above the valley temple floor (Borchardt 1910, blatt 2), with the zero point at ~19 m, following Seidlmayer (2001, p. 48)	47	Lehner (1997)
Abusir	Khentkaus	50	Verner, Posener-Kriéger, and Jánosi (1995, Fig. 73)	17 (estimated)	Verner, Posener-Kriéger, and Jánosi (1995)
Abusir	Niuserre solar temple	35 (courtyard/base of obelisk pedestal)	Jeffreys (1998), Table 2	56 (from base of pedestal to obelisk tip)	Lehner (1997)
Giza	Menkaure	75.3	Digital data courtesy of Ancient Egypt Research Associates 2013	65	Lehner (1997)
Giza	Khafre	69.9	Digital data courtesy of AERA 2013	143.5	Lehner (1997)
Giza	Khufu	59.9	Digital data courtesy of AERA 2013	146.6	Lehner (1997)

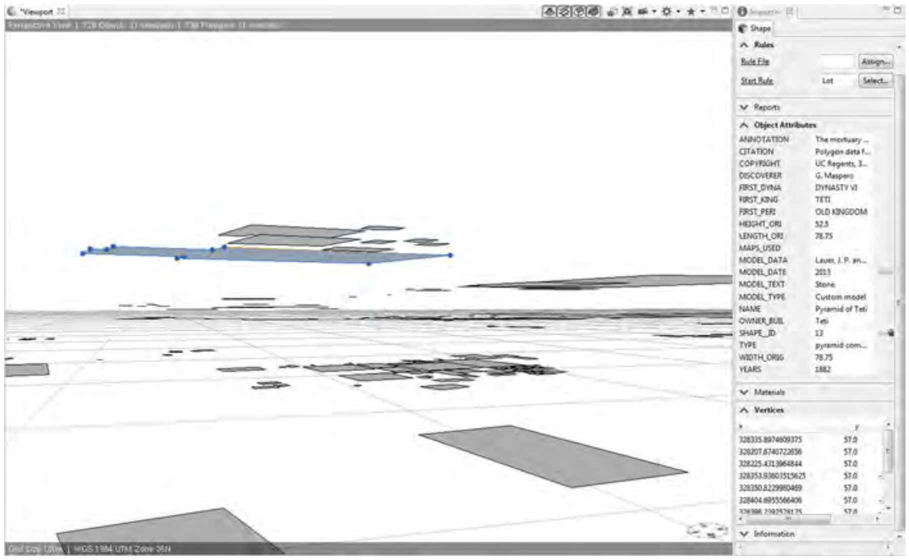

Fig. 7 Adjusting polygon vertices of footprints to reflect historic ground level in CityEngine

on published archaeological plans and axial drawings. Only exterior areas were modeled in detail, as interior spaces are unrelated to the research question. We added to each model color and texture based on original building materials in an attempt to approximate the historic appearance of the monument (Fig. 9). Exported as .OBJ files (a common 3D model file type), we then imported them

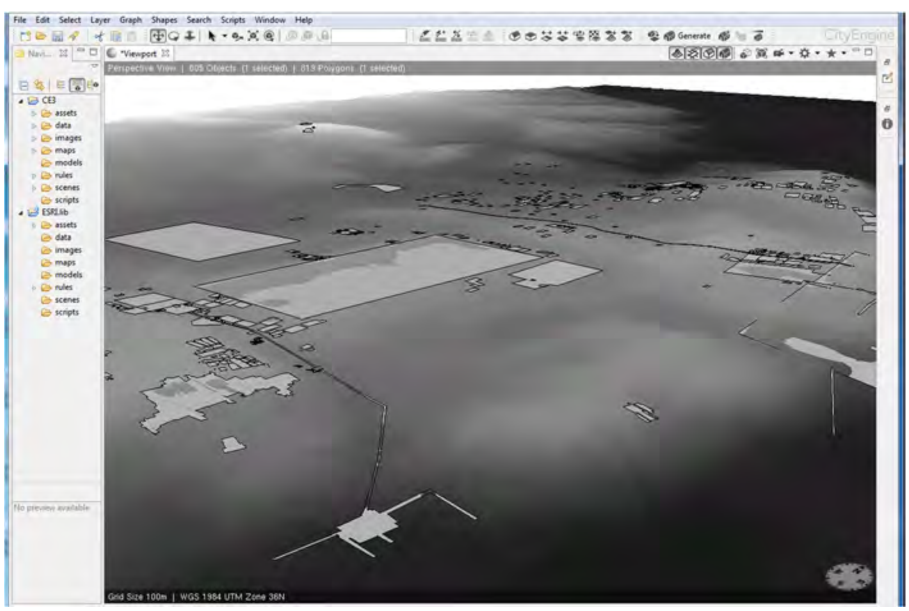

Fig. 8 Adjusted monument footprints with the terrain heightmaps added to CityEngine

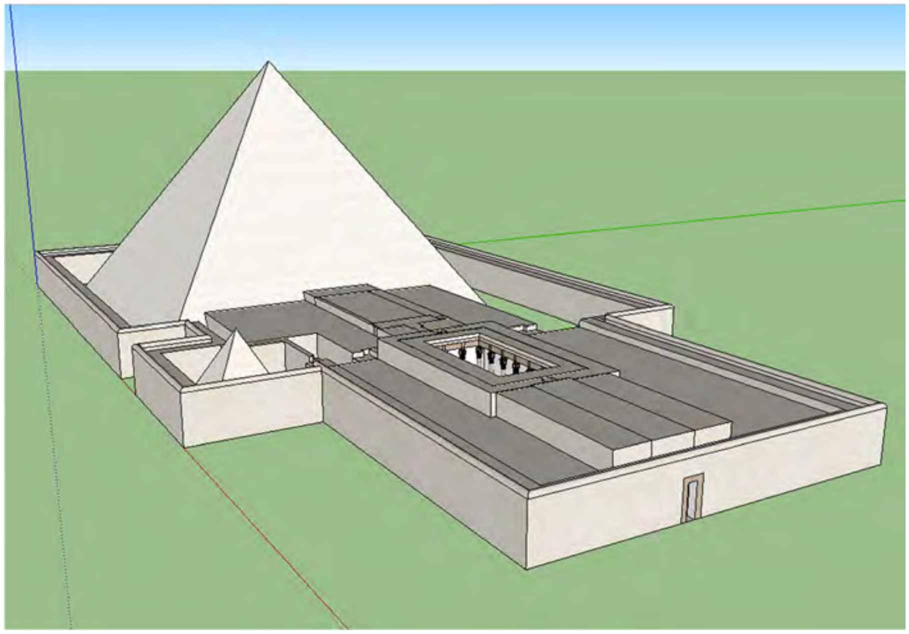

Fig. 9 3D model of the pyramid of Unas created in Trimble SketchUp Pro

into CityEngine and then individually oriented them on the correct polygon footprint (Fig. 10). Dense clusters of rectangular *mastaba* tombs at Saqqara were excavated during the early 1900s, and although basic plans of these exist, little or no detailed information was published on the superstructure of the monuments. Including these smaller tombs in any visualization is vital, as they were part of the ancient landscape, but modeling them each individually would be time consuming and still inexact.[13] CityEngine facilitates the efficient modeling of such structures using procedural modeling techniques (Saldaña and Johanson 2013, p. 206). We based the height of the Saqqara *mastabas* on simple scripting rules using each polygon footprint's size (length and width), and we designed their basic form (flat versus rounded shapes, presence of niches, *etc.*) according to general architectural trends documented for various chronological periods in Egypt. *Mastabas* excavated more recently, whose ground plans are well established, were procedurally modeled following the same rules. All of these structures' presence could have impacted visibility and visual impact of the monumental constructions nearby. In total, over 250 procedurally generated *mastaba* tombs at Saqqara and Abusir were included in the model. We left the models left highly schematic (without detailed textures) to help the viewer distinguish the procedurally modeled monuments from the buildings with better superstructure documentation (Fig. 11).

[13] As 3D archaeological reconstruction projects expand out from highly detailed models of individual buildings to larger sites and landscape visualizations, scholars are experimenting with new techniques for "scaling up" these projects, which demand the production of more schematic, "type-based" models. *Giza 3D* is one project focusing on an Egyptian site experimenting with this type of representation (Der Manuelian 2017, p. 209–210).

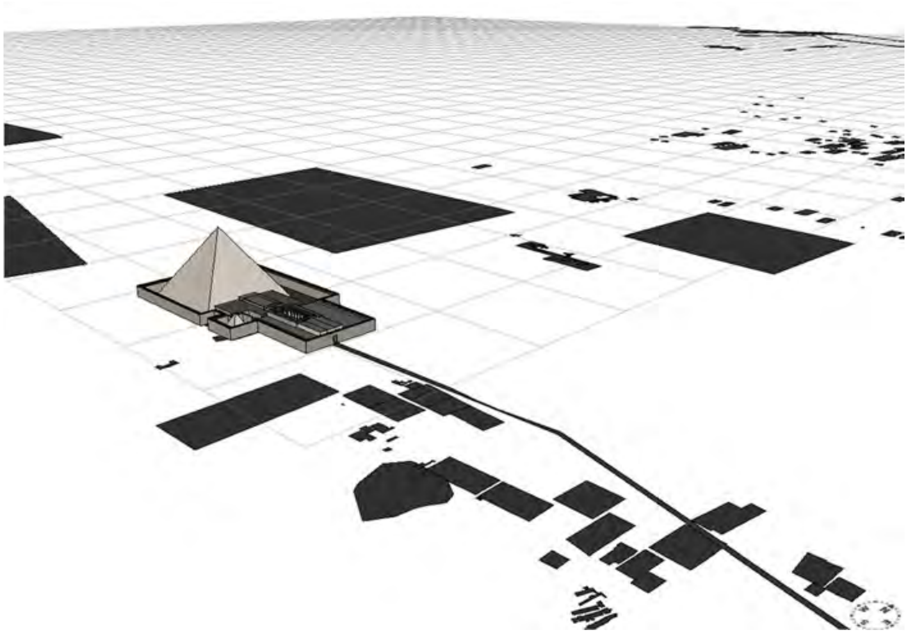

Fig. 10 3D model of the Unas pyramid complex imported into CityEngine and oriented on the polygon footprint

Viewing the Reconstructed Landscape in CityEngine

Within the CityEngine viewer, one could at this point fully interact with the created landscape in 360° space. Monument size, volume, color, and textures were apparent. We added in sky domes and terrain coloring in order to re-create environmental contrast that would have affected visibility.[14] We did not add vegetation to the scene, as the proliferation of "high-rise" vegetation (palm and other types of trees that would potentially block visibility) that typify this area today are possibly a modern phenomenon tied to the rising water levels fueled by the Aswan dam (Jeffreys 2009, p. 261). To set specific locations for viewing or movement, we imported observer points created in ArcMap into the viewer. Heights for the area of the Early Dynastic city are suggested to have been at least 1.5 m above that of the flood plain (at least 15.5 m ASL).[15] We therefore tested observer locations (Table 2) at a height of 15.5 m for Dynasty 4 and 16 m for Dynasty 6 to reflect the presumably higher ground of settlement later. Observer point 3, located on the *Kom Rabia* mound, was placed at a higher elevation to reflect that this area may have always stood significantly above the floodplain levels. Suggested heights of later occupation in this area (west of the Ptah temple) range from 18.5 in the late Middle Kingdom to 20–22 m ASL in the New Kingdom (Giddy 2012, p. 15; Jeffreys 2006, p. 20, 43, 135; Jeffreys, Malek, and Smith 1986, p. 4–5; Jeffreys and Smith 1986, Fig. 4).[16]

[14] Dennis Ogburn describes a number of factors that would have affected the level of visibility of objects in historic landscapes, including object size, color contrast with surroundings, shape, and intentional placement to be seen against the sky (Ogburn 2006, p. 407).

[15] Lehner (2009, p. 102) estimated a floodplain height of 13–14 m ASL and peak flood of 14.5–15 m. Settlement would logically be placed at a height above the highest maximum inundation level.

[16] Note that the EES elevations are frequently given off their local datum height of 100 m, equivalent to 22.3 m ASL, according to Jeffreys, Malek, and Smith (1986, p. 2).

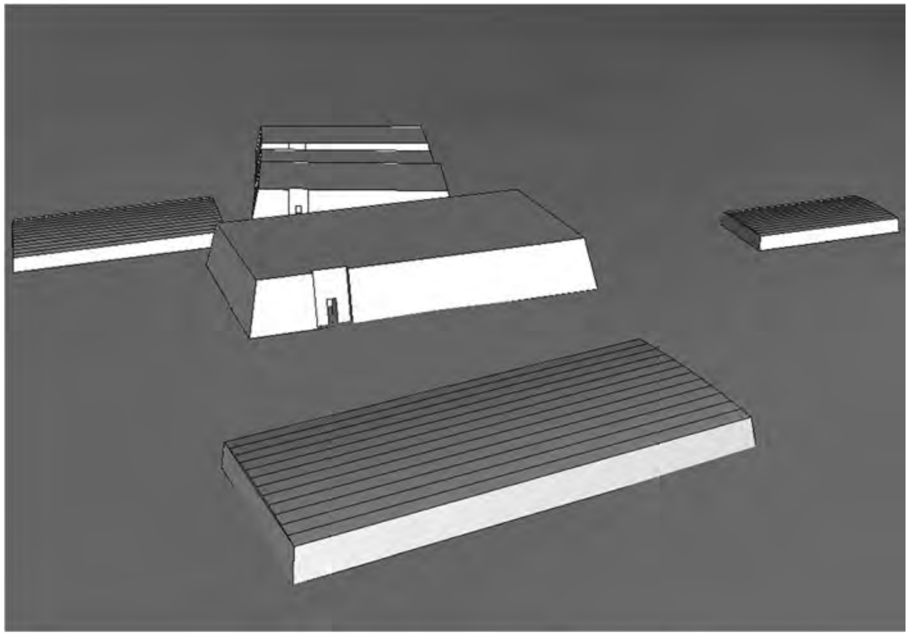

Fig. 11 Models of *mastaba* tombs procedurally generated using the CityEngine program

Virtually "standing" in the re-envisioned landscape, we could then test sight lines and panoramas of interest in the viewer in a way that more closely mimics human sight (Fig. 12). CityEngine does not include calculations for curvature of the earth, so any long-distance views created within the program had to be checked in ArcScene (below).

Moving CityEngine Data into ArcScene

While CityEngine offers solely qualitative visibility opportunities, viewing data in the 3D ArcScene environment provides quantitative possibilities, as the program is capable of performing 3D analytics. In order to move the 3D monuments out from CityEngine, we exported all the monuments as Collada files (.DAE) and then imported them into ArcScene. The heightmap terrains created for CityEngine cannot be utilized in ArcScene, so we produced Triangulated Irregular Network (TIN) files in ArcMap (for 2.5D visualization of data) and raster digital terrain models (for analysis) from the original contour data. The raster terrain model can be adjusted so that curvature of the Earth and refraction correction is included in calculations for line of sight analysis.

Analytics in ArcScene

To run line of sight analysis in ArcScene,[17] we created separate feature classes for observer points and target features. The former designates the point from which views originate, and the individual points created in the feature class were given exact elevation heights to reflect

[17] A step-by-step guide to this process will be published in winter 2017 as a white paper to the National Endowment for Humanities Office of Digital Humanities website: http://www.neh.gov/divisions/odh.

Table 2 Observer location information

Observer point	Time period	Suggested ground level for settlement (m)
(1) Hypothesized location of Early Dynastic city	Dynasty 4	15.5
(1) Hypothesized location of Early Dynastic city	Dynasty 6	16
(2) Later Memphis *Mennefer*	Dynasty 6	16
(3) Later Memphis: modern Mit Rahina	Dynasty 6	19.75

historic environments (adjusted to 1.5 m above the terrain in order to replicate human eye level). In order to capitalize on the 2.5D abilities of ArcScene, target features were designed as lines and polygons (instead of points). This technique allows the researcher to investigate the visibility of an entire face of a monument or a specific volume of interest. The *Construct Sight Lines* and *Line of Sight* tools were employed in ArcScene, utilizing the raster terrain model for analysis and the TIN to visually display the data in a 2.5D environment. Groups of monuments were selected as the "input features" for the *Line of Sight* tool, causing any 3D monument that broke the line of sight from the observer to the target to be recognized in the GIS, showing an obstruction. With this technique, how much of a monument was visible from any given point (or a series of points) could be quantified and compared across time and space.

Results and Discussion

A number of questions relating to the significance of visibility in the Memphite region can be addressed with these techniques.

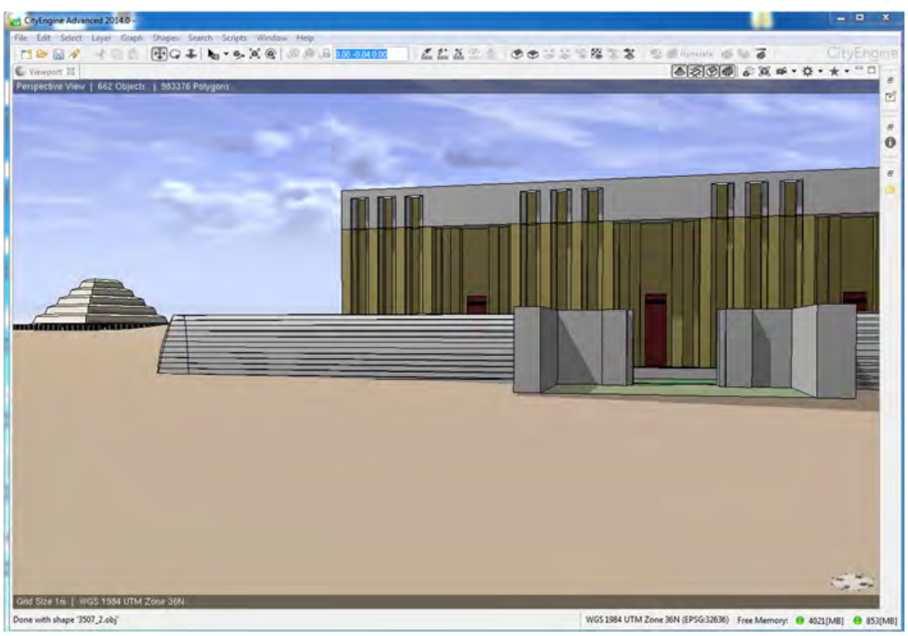

Fig. 12 3D visualization of monuments in the Saqqara necropolis in CityEngine with color and textures added; viewpoint ~1.5 m above the terrain

The Pyramids as "Scale Models"?

Egyptologist David Jeffreys has suggested that Egyptian builders may have deliberately controlled the height and volume of the major royal pyramids in the Memphite region in order that these monuments would have appeared as "roughly identical in size" from the city of Memphis (Jeffreys 2009, p. 263). Jeffreys proposed that from a theoretical location for the core of the early town (located further to the northwest of the later New Kingdom city; see Fig. 1 observer point 1), an optical illusion would have operated to make the closer structures (the smaller pyramids at nearby Saqqara, 60 m, and Abusir, 47–72 m) appear similar in size to larger structures (the massive pyramids at Giza, 144–147 m, and Dahshur, 105 m) further away (Jeffreys 2009). Such a strategy would suggest that the visual relationship of these monuments to the early city was a major factor in siting and size of construction already during Dynasty 4. When viewing the built landscape at the end of Dynasty 4 from Jeffrey's proposed town location in the model, however, the impact of proximity on the prominence[18] of the step pyramid at Saqqara versus the larger (but more distant) pyramids is clear (Fig. 13). As well, despite the pyramids at Giza and Dahshur being sited on plateaus at higher elevation than that of the step pyramid, the early towns' proximity to the Saqqara pyramid gave that monument the appearance of substantially greater height (Fig. 14). This suggests that in the 4th Dynasty pyramid construction, location and design choices were *not* based on situating the pyramids of Dahshur and Giza to appear "to scale" with the step pyramid at Saqqara from the town. It is possible that maintaining the visual dominance of the 3rd Dynasty step pyramid was even a factor in the siting and size of the later 4th Dynasty pyramids—that the later kings *intentionally* retained its prominence from the core Memphite area.[19]

However, the scale of new royal pyramid construction at Abusir and South Saqqara in Dynasty 5 and early Dynasty 6 suggests that appearance of scale from the town on the floodplain may have been an important consideration at *that* time (Fig. 15). From Jeffrey's proposed town site, the 5th Dynasty pyramid of Djedkare Isesi and the 6th Dynasty pyramid of Pepy I at South Saqqara (each approximately 52 m tall) appear approximately the same size (and even slightly taller) than the 105 m tall pyramids of Dahshur. Pepi's predecessor, Teti, constructed his 52.5 m tall pyramid on a spot at the far east of the Saqqara escarpment, so it appears similar in size (and even slightly taller) than that of the step pyramid, which stood 60 m tall but further (west) from the escarpment edge.[20] The three major 5th Dynasty pyramids at Abusir (Neferirkare (72 m),[21] Niuserre (52 m), and Sahure

[18] Monument prominence in this work refers specifically to "local prominence," defined by Bernardini *et al.* (2013, p. 3947) as the "visual significance from a particular human observation location."

[19] I would like to thank one of the anonymous reviewers of the draft of this article for pointing this out.

[20] The pyramid immediately east of Teti's, designated Lepsius 29, has been most recently dated to dynasty 5 by Hawass (2010), although other scholars have assigned it a date to dynasties 9–10 (Lehner 1997, p. 165). Its original height is unknown; we assigned it a height of 35 m in the model as an estimate, but whether it would have originally appeared taller than the step pyramid cannot be determined without more information. It is included in the model to show its possible presence in Dynasty 5, but I am leaving it out of the discussion due to the uncertainties in date and form.

[21] This pyramid was never completed, and thus, the stepped core was never covered with a smoothed limestone facing. The 3D model here shows it complete, at the fully anticipated height, to suggest the intended appearance of the builders.

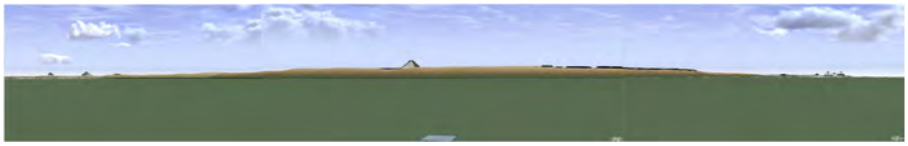

Fig. 13 Visualization in CityEngine of Dahshur (*far left*), Saqqara (*center*), and Giza (*far right*) during Dynasty 4 from the from the proposed core early town site (observer point 1) showing the prominence of the Step Pyramid at central Saqqara

(47 m)) closely resemble the size of the (huge) Giza pyramids from this view, despite the much greater size of the monuments of Khufu (147 m) and Khafre (144 m) (see Table 1 for all monument heights). As Jeffreys noted, Egyptologists debate the reasons for the dramatic decrease in size of the 5th and 6th Dynasty pyramids, suggesting causes based on contracting resources or, on the contrary, a shift in focus from sheer size to quality and decoration (Jeffreys 2009, p. 258). The model suggests that their pyramids (although significantly smaller) were constructed just large enough that the inhabitants of Memphis on the floodplain would have *perceived* them to be as grand (and even slightly taller) than the neighboring monumental 4th Dynasty pyramids. The 5th Dynasty and early 6th Dynasty pharaohs had the best of both worlds—the small size of the pyramids allowed for more resources to be used on embellishment of the overall complex, but their visual impact from the Memphite floodplain compared to that of the larger pyramids. These kings may have purposefully combined choice in siting and overall size of these monuments to capitalize on the optical illusion produced from the city. That such factors that were not a consideration in the earlier (Dynasty 4) decision-making practices do not preclude their use at later moments.

The Movement of Memphis and Its Impact on Monument Siting

Temporal changes in the location of urban occupation may have had further impact on pyramid siting during the late Old Kingdom (Jeffreys 2009, p. 263–264). The pyramid and associated town of early 6th Dynasty king Pepy I was called *Men-nfr* (rendered by the Greeks as Memphis), the name that came to later designate the city and capital itself (Gardiner 1947, p. 122; Love 2003, p. 71). The most likely location for this town is on the floodplain surrounding the

Fig. 14 Visualization in CityEngine of Dahshur, Saqqara, and Giza during Dynasty 4 from the from the proposed core early town site (observer point 1) with *scale bars* approximating the height of the Step Pyramid placed beside the Dahshur and Giza pyramids and a *line* approximating the height of the Step Pyramid along the *horizon line*

Fig. 15 Visualization in CityEngine of *Dahshur* (*far left*), *South Saqqara*, *Saqqara*, *Abusir/Abu Ghorab*, and *Giza* during early Dynasty 6 (reign of Pepy I) from the proposed core early town site (observer point 1) showing the prominence of the pyramids of Djedkare Isesi and Pepy I in South Saqqara compared to the pyramids of Dahshur; the prominence of the pyramid of Teti I at *central Saqqara* compared to the *Step Pyramid*; and the prominence of the pyramids of Neferirkare, Niuserre, and Sahure at Abusir compared to the pyramids of Giza

pyramid's now-disappeared valley complex (Stadelmann 1981, p. 73).[22] If significant habitation shifted during Dynasty 6 to this area or further east as suggested by a number of archaeologists (Jeffreys 2009, p. 263–264; Giddy 1994; Love 2003, p. 78), concern for orientation to the earlier town location would have eventually diminished. Indeed, views of the later 6th Dynasty pyramids of Merenra and Pepy II were significantly blocked from the proposed early town site, suggesting that this viewpoint lost its importance[23] (Figs. 16 and 17).

From the proposed new occupation area at *Men-nfr* (see Fig. 1, observer point 2), Abusir (whose last royal construction was built in Dynasty 5) is completely obscured by the Saqqara escarpment (Figs. 18 and 19), which would—if visibility to the capital city played a major role in choosing pyramid locations—explain the complete lack of Dynasty 6 royal construction at the site.[24] From both the suggested Dynasty 6 occupation areas, all four of the 6th Dynasty pyramid complexes (Teti, Pepy I, Merenre, and Pepy II) are visible, with the latter three at South Saqqara very prominent (Fig. 18).

From the more eastern proposed location for Memphis (near the area of modern Mit Rahina, the confirmed site of the New Kingdom city) (see Fig. 1, observer point 3), sections of the tips of the two tallest Abusir pyramids are still visible, although the solar temple is completely obscured (Fig. 20).[25] Even from this point (at an elevation almost 4 m higher than observer point 2), there

[22] The valley temple and surrounding pyramid town of Pepy I have not been excavated nor have the posited pyramid towns of Merenre, Djedkare Isesi, or Pepy II, which are all suspected to be located east of the escarpment under the alluvium, following a pattern recognized at other extant sites (Lehner 1997, p. 158, 162; Stadelmann 1981). Pyramid towns are also documented in textual sources.

[23] Note that the view of these pyramids was obstructed by the already existing structures of Pepy I (the immediate predecessor of Merenra and Pepy II) and Djedkare Isesi (Dynasty 5), meaning that the later complexes would have been constructed with full knowledge that they would not have prominence from the early town site.

[24] Certainly crowding at the Abusir area would have been a major factor, as kings ran out of room to construct huge pyramid complexes between existing structures.

[25] Because the height of the pyramid designated Lepsius 29 is unknown, that pyramid was not included in the model during this analysis. Views in CityEngine suggest its position would not have impacted sight lines to Neferirkare, but depending on its height, it may have further obscured the Niuserre pyramid.

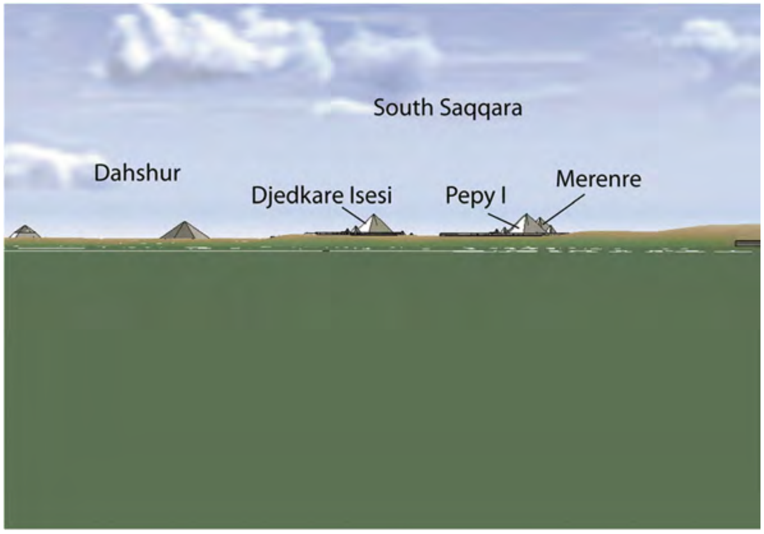

Fig. 16 Visualization in CityEngine of South Saqqara from the proposed core early town site (observer point 1) showing the pyramid of Pepy II obscured from view by the pyramid of Djedkare Isesi and the pyramid of Merenre partly obscured by the pyramids in the complex of Pepy I

is significant loss of prominence of the major three monuments (compare the differing prominence in Fig. 20 with Fig. 15).

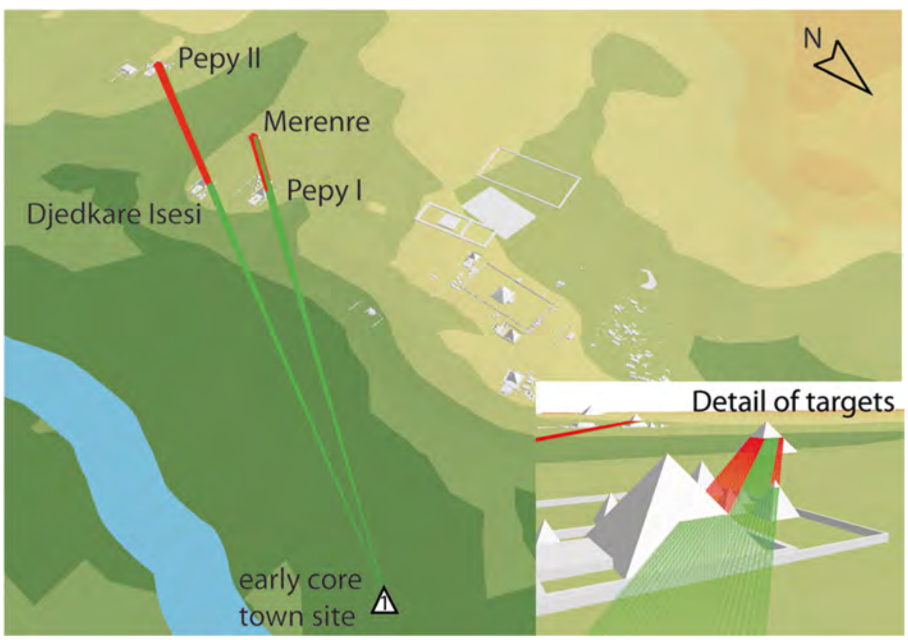

Fig. 17 ArcScene line of sight analysis from the proposed core early town site (observer point 1) to the pyramids of Pepy II and Merenre; target polygons are situated horizontally; *green* signifies "visible" and *red* identifies areas where the view of the target polygon is blocked; *inset* shows a close-up of the Merenre pyramid and the points where visibility is blocked by the Pepy I structures (color figure online)

Fig. 18 Visualization in CityEngine of the Saqqara area from the proposed later city of Memphis (observer point 2) showing Abusir entirely obscured behind the hill of central Saqqara, the prominence of the three later 6th Dynasty pyramids (*Pepy I*, *Merenre*, and *Pepy II*), the earliest 6th Dynasty pyramid (*Teti*) partly visible, and the pyramids of the last two kings of Dynasty 5 (*Djedkare Isesi* and *Unas*) visible/partly visible

Significance for the Study of Egyptian Ritual Landscapes

In both cases highlighted in this study, results suggest that over the course of a few hundred years, the landscape took on new meanings. Royal patrons actively reinterpreted the significance of the built environment.[26] They capitalized on elements of human vision and the shifting site of the city of Memphis to give their smaller constructions the prominence of larger (and earlier) monuments. Their new monuments obscured past views, presumably as such views lost importance as areas of occupation migrated from the early town site. That in the present, we have interpreted that Egyptian monumental landscapes as possessing "eternal" or timeless meanings is a consequence of our own lack of temporal imagination. Landscape meaning was fluid and could be changed as the kings (with the power and economic ability to build on the monumental scale) ascribed new importance to existing places. This investigation also suggests that the context of viewing[27] was a key element in creating meaning—views could be intentionally manipulated for access from the (shifting) city of Memphis, the administrative center, and a major population hub. While this study cannot confirm that the visual impact of the monument was a primary factor influencing its location or form (such decisions must have involved a number of factors, including available space and rock quality), it does suggest that visibility played either a role in siting or in the subsequent size of construction of late Old Kingdom monuments in the Memphite necropolis. Such 3D temporal visualizations of monumental landscapes allow us to examine ancient places with a fresh perspective, identifying patterns or points of significance obscured on site today.

This article refers specifically to the monumental landscape as designed and interpreted by the king (the sponsor of the construction) and the high elites residing in Memphis. It is likely that people in other social groups (the non-elites, non-Egyptians, *etc.*) would have understood and interpreted the landscape in completely different ways.[28] While from the floodplain/town locations investigated here, all

[26] As James Osborne has noted, the meaning of monuments and those who view and interpret them are in a constant and shifting relationship over time (Osborne 2014, p. 3–4).

[27] Bernardini *et al.* (2013, p. 3947) describe the context of viewing as one of the "overlooked social aspects of 'viewship' that affect how meaning is assigned to parts of the landscape by viewers." That the context for the views of the Egyptian pyramids centered on the capital city, where the royal palace and many elite residences would have been located, is critical to interpretation of the meaning and intentionality of these constructions.

[28] Thomas (2001, p. 176) discusses how different group identities (including gender, status, ethnicity, sexuality, etc.) would impact an individual's understanding of place. This type of investigation has not yet been attempted at Saqqara to the author's knowledge, presumably due to the lack of textual material ascribed to anyone besides elite males and royal wives and daughters, especially from the earliest phases at the site discussed here.

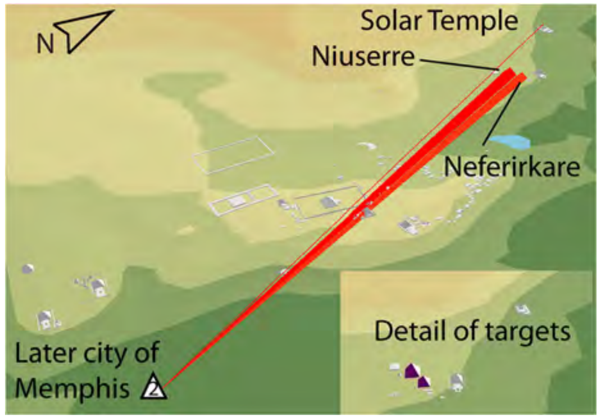

Fig. 19 ArcScene line of sight analysis from the proposed later city of Memphis (observer point 2) to three monuments of Abusir showing visibility fully obscured by the hill of central Saqqara; target polygons trace two faces of the pyramids (from base to pyramidion) of Niuserre and Neferirkare and the tip of the obelisk of the solar temple of Niuserre (all shown *purple* in *inset*); *red lines* indicate the target feature is blocked at some point along the view path; note that the "Lepsius 29" pyramid is not included in this analysis (color figure online)

elements of Egyptian society would have been able to view the escarpment monuments, it is clear that some parts of the Memphite population would have also visited the site and experienced the monuments from up close. Certainly, Egyptian cemeteries were active places, and Saqqara was the location of ongoing royal funerary cults staffed by priests, as well as construction grounds for royal and private monuments (necessitating the presence of stone cutters, builders, and other craftsmen). Family members of the Old Kingdom Memphite elite would have visited the tombs of their ancestors to leave offerings at their open chapels. Graffiti documented at Saqqara in the New Kingdom (also a very active period at the cemetery) show that at that period at least, the cemetery was accessible to "visitors," many of them self-described as "scribe," who visited to admire the (then quite ancient) step pyramid of Djoser.[29] Whether such "tourism"[30] would have been common in the Old and Middle Kingdom is unclear, as there are no graffiti as yet discovered dated to those periods (Navrátilová 2007). But anyone visiting the necropolis in person would realize that Djoser's pyramid stood taller than the others at the site; anyone visiting Giza would know that Khufu and Khafre' pyramids dwarf all those at Saqqara. Prior experience up close with these monuments certainly must have impacted the perception of those viewing them from the floodplain, and personal experience and memory must have mixed in ways that impacted interpretation for different individuals.

Archaeological exploration at Saqqara will soon be in its 200th year, and hundreds of monuments at the site have been examined and published, making it one of the best-documented ancient sites in Egypt (Buongarzone 2003). Yet, new discoveries are still

[29] While literate 'scribes' certainly fall into the social category of elites in Egypt, additional New Kingdom graffiti found in the temple-tombs south of the Unas causeway include many figural examples. These may document illiterate Egyptians interacting with the tomb, and could suggest a wider audience in the necropolis, at least in the later New Kingdom (van Pelt and Staring 2016).

[30] In one inscription, a scribe of the treasury named Hednakhte writes on a chapel of Djoser that he came to "make a stroll and amuse/invigorate himself in the West of Memphis" (Navrátilová 2007, p. 110–111).

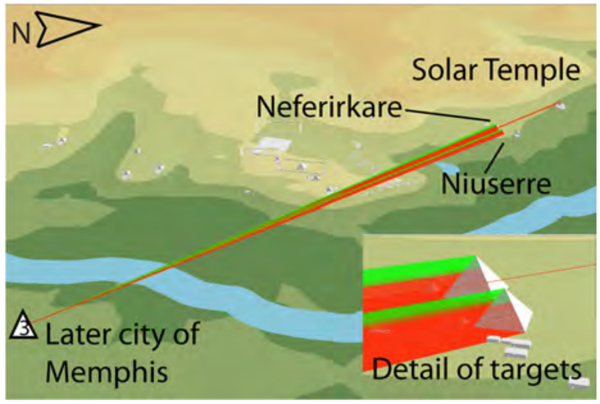

Fig. 20 ArcScene line of sight analysis from the proposed later city of Memphis (observer point 3) to three monuments of Abusir; target polygons trace two faces of the pyramids (from base to pyramidion) of Neferirkare and Niuserre and the tip of the obelisk of the solar temple of Niuserre; *green* signifies "visible" from the observer point, and *red* indicates that the target feature is blocked at some point along the view path; *inset* shows a detail of the two pyramids showing which specific areas of the pyramids were visible and which were blocked; note the "Lepsius 29" pyramid is not included in this analysis

ongoing, and scholarly understanding of many elements of the landscape hypothesized here—including the location of early settlements of Memphis—may change in light of new information. The methodology described in this article is consciously designed to test out landscape spaces with uncertainties, gaps, ambiguities, and different resolutions of data. Many archaeological sites, including well-explored sites like Saqqara, still present us with significant challenges of interpretation, both spatial and chronological. Expansion out to large-scale landscapes or regional studies inject additional complications. The model utilized in this study attempts to engage with 200 years of existing data from Saqqara and surrounding sites (spanning a 20-km zone), despite its incompleteness, to investigate patterns of visibility in monumental construction. A 3D model cannot purport to approximate the complexity of reality (as any model is a data abstraction), or fully represent past times, which are lost to us forever. I suggest here that, instead, the 3D Saqqara model functions to create new access points into the examination of visual landscapes that are unavailable for our consideration in the present.

Conclusions

This paper argues that new forms of 3D GIS incorporating modeled representations of the built and natural environment offer innovative methods for studies of past landscapes. By moving GIS datasets into 3D urban simulation programs like CityEngine, the limitations of binary visibility analysis are overcome. Qualitative aspects of human vision can be more closely approximated, including perspective, appearance, color, and prominence. Elements of the 3D built environment connected with meaning and purpose can more effectively be investigated.[31] While less useful for qualitative studies

[31] Paliou (2013, p. 252) suggests that "built environments are redolent with visual cues that embody messages of power, status, and identity…These cues are encoded in a 3D environment and on many occasions cannot be examine effectively or at all with 2D analytical approaches."

(because of its crude graphics), 2.5D programs like ArcScene allow for enhanced quantitative studies; for example, researchers can identify how much/which parts of a structure was obscured by later construction at a site, incorporating a monument's volume and shape into visibility analysis. While traditional 3D modeling programs offer more impressive photo-realistic capabilities, the process described here allows archaeologists to maintain datasets in a geospatial coordinate system, affording important analysis opportunities.

These techniques are not offered as a replacement for traditional quantitative visibility analyses such as viewsheds, as GIS programs cannot yet run similarly complex calculations in fully 3D-aware space. They are instead argued here to be complementary to traditional studies and can be conducted to investigate specific questions raised by preliminary examinations in 2D GIS. The suggested techniques do not provide the broad coverage of traditional 2D GIS viewsheds, quantifying all "visible" and "non-visible" elements; instead, the 3D models provide another, more culturally situated analysis, focusing on the examination of questions that can be better approached from a more "human" perspective.

While the sense of sight is still privileged here (see Frieman and Gillings 2007, p. 4–5 for a critique of the isolating vision to the exclusion of other sensory stimuli), this study explicitly addresses the impact of visibility on the siting and long-term influence of monumental architecture in Egyptian society. As is clear from other Egyptian sites, visibility was an important element of the creation and perpetuation of ritual space. The changing smells and sounds at the necropolis over hundreds of years are not aspects of the landscape controlled (or necessarily anticipated) by the original constructors/sponsors of each monument, and while such sensory investigations would make for fascinating study of human experience within the space over time, they would not necessarily address issues regarding intentionality of construction. Indeed, many of the views dealt with for this project cover long distances, for which other sensory experiences like sound, touch, and smell become negligible (Wheatley 2014, p. 126–127). Nevertheless, I argue that the addition of 3D data allows for *more* (if still imperfect) contextualization than traditional 2D GIS. Although the visual is placed front and center, 3D GIS allows for the incorporation of a sense of human scale and movement within investigated spaces. This comes closer to the goal of human embodiment expressed in subject-centered critiques of GIS, concerned with understanding human perception and the experience of being present in a specific place. Indeed, feminist scholars have criticized the 2D, top-down, disembodied view used in GIS mapping for its detached and distancing qualities (see McLafferty 2005, p. 38–39, for a discussion of these issues). Visibility studies in GIS have been subject to further critique for privileging the western and modern perspective of the overhead map (Thomas 2009). The integration of 3D qualitative information into GIS studies offers alternative experiences that move away from the "view-from-above" and instead embed the researcher within the landscape at human scale, offering new levels of contextualization that are missing from traditional 2D studies. This is all done while maintaining the geospatial coordinate system and analysis opportunities that are the hallmark of GIS research. The affordances of 3D are especially useful at multi-phased, long-lived sites like Saqqara, where changes in landscape and hundreds of years of continuous monument construction and destruction means that many of the original spatial and visual linkages and their meanings are lost to us today. This paper demonstrates how such meanings and elements of human perception can be approached and investigated in new ways that more closely replicate the human interpretive experience.

Acknowledgements Vital technical assistance to the project in moving the data into CityEngine was provided by Marie Saldaña, then UCLA graduate student. UCSC undergraduate student Max Van Rensselaer and Center for Integrated Spatial Research staff member Aaron Cole were instrumental in developing the methodology for moving CityEngine data into ArcScene. Additional important data and workflow contributions in GIS at the initial project stages were made by then UCLA graduate student Eric Fries. UCLA undergraduate student Aria Klucewicz provided valuable assistance with digitizing topographic line data, procedural modeling in CityEngine and contributing 3D models. Victoria Schniedewind, UC Berkeley undergraduate, contributed 3D models for the project.

Digital topographic line data and survey information for the Memphite region and Giza were generously shared with the project by Dr. Mark Lehner and the Ancient Egypt Research Associates (AERA). 2D GIS monument data for the entire area of North and Central Saqqara was shared with the project by Dr. Emanuele Brienza, the University of Kore, Enna, Sicily and the University of Pisa. Ana Tavares (AERA) shared crucial high-resolution topographic line maps of the Memphite region.

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