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Title: Multi-scaler 3D modelling to reconstruct an experimental landscape: An example from a worker's cottage at Mount Dutton Bay, South Australia

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New advances in 3D GIS provide the opportunity to create and interact with spatial datasets that are both empirical and experiential, thus bridging the historical divide between cartography and phenomenology. Survey and photogrammetry data from the colonial-era woolshed and port of Mount Dutton Bay in South Australia are used to create a visually realistic 3D landscape model. Viewshed analysis provided important information about the use of space and construction techniques for the shearers' cottage on this site. The results demonstrate that rigorous quantitative analysis is not incompatible with understanding the human experience of an archaeological site, and therefore open up exciting new avenues of archaeological enquiry.

Introduction

Human interaction with landscape can be investigated from both empirical and experiential perspectives, with each providing unique archaeological information (Ashmore and Knapp, 1999; Fleming, 2006; Tilley, 1994, 2010). Whilst both approaches are useful, research that has placed human perspectives in the study foreground have found such experiences difficult to quantify and have been accused of producing conclusions that are difficult to scientifically validate or reproduce (Barrett and Ko, 2009; Fleming, 2006; Forbes, 2007). On the other hand, phenomenology suggests that empirical approaches ignore the impact (such as sights, sounds and shades) of a landscape on human actors (Tilley, 1994, 2010). Traditional mapping is an excellent example of this failing as it typically projects complex 3D structures and topography onto a two-dimensional plane with which the researcher interacts in a way that is completely alien to how a landscape would normally be experienced.

Modern technological advancements have changed the nature of the data that can be captured and allow complex 3D data to be visualised in ways that may significantly reduce distortion and perspective bias. Recent landscape archaeology investigations have pursued analysis through more-complex forms of data visualisation such as virtual and augmented reality (Eve, 2012; Pierdicca et al., 2015). This approach aims to generate telepresence: the feeling of being present within an environment despite engaging with it via a communication medium (Richards-Rissetto et al., 2012; Steuer, 1992). Although this does not replace the experiences of true 'presence' within a landscape, it does begin to allow new questions to be formulated that relate to the human experiences of a landscape. In order to take advantage of these benefits, a new data collection methodology is required as these methods require rich, 3D data that can

capture as close to a true representation of a landscape as possible (Frischer and Dakouri-Hild, 2008; Wüst et al., 2004). There are a variety of data collection methods that capture data in three dimensions, but photogrammetry stands out for its ease of use, low cost and its ability to create photorealistic 3D models with accurate scaling (McCarthy and Benjamin, 2014).

The capture and visualisation of these data only addresses part of the challenge for landscape archaeology, which still requires structured organisation to allow geostatistical analysis. A structured framework that can organise both detailed and visually engaging data in a way that allows comprehensive geostatistical approaches is necessary to ask questions relating to the deeper human experience of a landscape. Geographic Information Systems (GIS) allow the organisation and analysis of complex spatial data which addresses many landscape archaeology challenges, however 3D visualisation has not been at the focus of these systems for the majority of their history. The modern generation of GIS platforms (such as ArcGIS Pro) allows 3D data to be treated much the same as two-dimensional data, enabling integration and spatial analysis along with visualisation (Richards-Rissetto et al., 2012; Wüst et al., 2004).

This article will demonstrate research conducted on a historical coastal landscape on the Eyre Peninsula, South Australia. This research demonstrates the combined use of 3D landscape scale modeling and the detailed modeling of individual features such as buildings, to create a model which can be experienced at an intuitive as well as geostatistical level. This combined approach has the potential to bridge the gap between empirical and empathic approaches afforded by modern survey and data visualisation techniques.

Site location and historical background

Mount Dutton Bay is located about 750 km west of Adelaide on the Eyre Peninsula to the north of Coffin Bay (Figure 1).

Figure 1. Mount Dutton Bay, Eyre Peninsula of South Australia

This area was first explored by Charles Christian Dutton who settled there in the 1840s (Shefi, 2007). The area quickly became a major part of the fishing industry with a focus on the oyster beds which were abundant in the bay (Colvin, 2011). The surrounding pastoral lands, ideal

grazing for sheep and cattle, developed wool as a major product of the region (Colvin, 2011; Khan, 2006). The two separate industries connected in around 1875 when a woolshed was constructed on the coast of Mount Dutton Bay. Construction of the jetty at the bay was completed by 1881 and soon become the major port connecting this region to the colony. Built within a few metres of the woolshed, both structures were designed to be operated closely together with a rail connecting them. Whilst the jetty was used primarily for wool exports from the adjacent pastoral lands it also played a role in the fishing industry servicing the prolific oyster cutters which made the bay famous (Colvin, 2011; Khan, 2006). The wild oyster population eventually ran low due to unsustainable fishing practices and the industry went into decline by 1920 (Shefi, 2007). By the 1930s the railway made the jetty obsolete. Today the woolshed has been converted into a museum and the jetty is now converted for recreational use after a long period of closure and disrepair (Khan, 2006).

During their heyday the Mount Dutton woolshed and jetty were a significant regional focus of activity. Sitting at the union of maritime and terrestrial culture, this site provides unique insights into colonial views towards coastal space. Despite this, only limited archaeological research has been conducted at the site, which have focused exclusively on the maritime activities of the region and neglected the coastal connection to the terrestrial colonial settler cultures that surround the bay (Khan, 2006).

Methods and results

This study aimed to survey all surface features within the Mount Dutton complex. To unify multiple sources of data into a singular GIS, a total station survey was used to measure points around the base of the buildings, surface features such as fence lines, roads and walkways and additionally to record surface elevation and ground control markers visible with aerial photography. The purpose of this data is to record the spatial layout of the site as well as to provide tie points for data integration and for georeferencing photogrammetric models. Figure 2 shows a site plan derived from the total station data.

Photogrammetry

The photogrammetric survey method (see Remondino and El-Hakim, 2006; McCarthy, 2014) utilises multiple digital photographic images of a subject, taken from multiple angles with overlapping coverage, to generate an accurate 3D model of the subject (De Reu et al., 2013). Photogrammetry is particularly suited to analysis of complex features as it is a detailed survey method that records the spatial extent of the features in an accurate and comparable way to traditional twodimensional recordings (De Reu et al., 2013). Photogrammetry recording allows individual site features to be recorded in the detail required to capture useful multi-focal archaeological information. With site features which have many important details on different scales, such as the spatial layout and style of the structure as well as the makers' marks on the bricks, photogrammetry allows the capture of visual and spatial data in one unified methodology. Photogrammetry also records the appearance of the features as well as their spatial characteristics. This allows intrinsically integrated interpretation of these separate components. The choice of this method strengthens data integration, allows for a more holistic interpretation of individual site features within their connected extended landscape systems, and minimises interpretive disconnect between data and reality (Bourdier et al., 2015; Frischer and Dakouri-Hild, 2008; Hermon, 2008). Other suitable approaches to 3D data collection such as laser scanning exist (see Haddad, 2011 for a review) however we believe that

photogrammetry undertaken from a variety of platforms provided the most appropriate balance between resolution, site coverage and cost effectiveness in this case.

The structures present on the landscape, woolshed, well, cottage and jetty, were individually recorded for photogrammetric modeling. The terrain itself was also recorded for photogrammetric modeling using aerial photography. The photography was taken with a Nikon D300 SLR camera, using a wide-angle lens with focal lengths between 18mm and 55 mm. Photographs were taken with at least 30% overlap of each adjacent image, and images taken with a minimum aperture of f/16 to maximise the depth of field, whilst exposure was controlled using ISO and shutter speed. A fast shutter speed, never less than 1/ 100 s, avoids any motion blur in the images. Exposure is stabilised between images to account for changes in lighting conditions from different angles of view. Figure 3 shows the models produced which represent the cottage (Figure 3a), woolshed (Figure 3b) and a small island associated with the site (Figure 3c).

The terrain and landscape around the woolshed complex was recorded using aerial photography. The photography was captured using a DJI Phantom remotely piloted radio-controlled aircraft (drone). The DJI Phantom Vision 2+ drone has an integrated 12-megapixel camera on a gimbal which works to keep the camera facing 90 degrees to the ground regardless of the orientation of the drone. The small unnamed island near the end of the jetty was also recorded with aerial photography using the DJI phantom drone.

3D photogrammetry models were created using Agisoft Photoscan Professional (Agisoft, 2013) and then the completed models were exported as 3D models in the COLLADA file type for further GIS integration. These models covered a total area of ~86,483m² and had a cell size of 1.04m². Models were exported with local coordinate systems as well as exported in a GDA 94 projected coordinate system. Orthophotos (photomosaics), were generated from different orthographic perspectives, are two dimensional images that represent the features of the geometry as viewed from one fixed orthographic perspective (projection). Exported with georeferenced data for further data integration orthophotos are produced as a function of Agisoft Photoscan.

Elevation models

A digital elevation model (DEM) was generated from the elevation data of each point of the total station survey using the kriging surface interpolation method. Kriging is an interpolation method that makes estimates of values for unknown areas based on a set of known points. Kriging was selected as it has been found to be the most accurate interpolation method for elevation data (Arun, 2013). The ‘ordinary kriging’ method in Arc GIS was used which makes no assumptions of trends in the data and will produce an unbiased result (Oliver, 1990). The generated surface had a total area of ~85,377m² and used a cell size of 0.00028m².

The sampling of the total station survey was very extensive on the property, however, the site of the old homestead was inaccessible, leaving a gap in the survey data for that area. The kriging surface produced values for this section, although these are less reliable than the more detailed data obtained from other areas of the site. Therefore, a second DEM was generated from the photogrammetric modeling of the aerial photography which had good coverage of this area. Photoscan software was used to export this DEM. Figure 4 shows the DEM produced from the total station data (Figure 4a) and aerial photography (Figure 4b).

A comparative analysis was conducted to assess the accuracy of the DEM produced using photogrammetry compared to the DEM produced from the total station survey data. The cell sizes of both raster (pixel/ cell based) images were the same and the images were clipped so that they covered the same area. The raster calculator tool from the spatial analyst toolbox in ArcMap was used to subtract the photogrammetry surface from the total station surface cell by cell. The resulting surface shows values close to zero where the two DEMs are similar and then values that are greater or less than zero show disagreement between the models. Figure 5 shows this comparison.

Figure 2. Site plan developed from the 2016 total station survey.

Data integration and visualisation

All gathered data was integrated into a central GIS for combined management and analysis. ArcGIS Pro software was selected to integrate the data as it allows the integration of both two-dimensional and 3D datasets as well as the ability for detailed visualisation of the landscape. Figure 6 shows several combinations of the datasets available viewed in a 3D scene.

Integration of the 3D model was achieved using the Import 3D tool available in the ArcGIS Pro software. This tool takes a COLLADA file and converts it into a multipatch feature. The multipatch feature class is a 3D feature class developed by ESRI for representation of 3D data in a GIS which can represent textured geometry within geographic space and retain links with associated attributes tables (ESRI, 2012). The Multipatch geometry type has been demonstrated as useful to archaeological representation of 3D features as it allows databasing, spatial analysis

and querying of archaeological data whilst retaining a detailed visualisation of the data (Dell'Unto et al., 2015; Katsianis et al., 2008; Landeschi et al., 2016). The separate datasets were imported into a 3D scene and viewed together in their correct geographic position.

The organisation of data in this way allows highly intuitive visualisations, where the landscape can be viewed in an almost photorealistic way. It also facilitates the inclusion of more-abstract data such as historical maps, which hold information that is not inherently visible to ground based landscape inspection. This combination and visualisation of data reveals otherwise hidden information about the arrangement of the structures at the woolshed complex, most notably the position of the shearers' cottage. Located at the northern end of the site, the shearers' cottage has large front windows facing inland and away from both the ocean and the woolshed. It is further shielded from the woolshed and ocean by its placement behind a hill, upon which another building has subsequently been constructed. This placement occludes a view of the ocean, however ground-based inspection cannot determine if the ocean view was originally impeded by the hill or by the subsequent placement of the contemporary building. To better understand the placement of the structures at the site, a 'visibility' analysis was conducted from the rear windows of the shearers' cottage. Visibility has been identified as a useful factor in understanding archaeological sites (Richards-Rissetto et al., 2012; Spencer, 2007) as Grguric (2007, 2008) demonstrates in his application of basic visibility analysis on interpreting the defensive application of windows on colonial frontier stations.

To analyse the placement of the shearers' cottage, the visibility analysis tool in ArcGIS Pro was selected which combines point data representing observer locations and a DEM and then returns raster images showing which areas of the DEM have a ground surface visible from the input observer points. Visible points are given a 1 and invisible points are given a 0. These raster visibility surfaces were generated using the DEM interpolated from the total station survey and points representing the cottage windows. The DEM produced from the total station data was used for the visibility analysis as this does not include the built structures. Figure 7 shows the results of the visibility analysis, displaying green for areas visible from the location of the cottage front windows and red for those areas that are not visible. This analysis only includes occlusions from the terrain relief. Figure 7 clearly demonstrates that neither the woolshed nor the ocean are visible from the windows of the shearers' cottage.

A notable observation of the initial inspection of the shearers' cottage is the height of the small windows in the rear wall of the cottage. These windows are a modification to the typical European design of the time, similar to those noted in previous archaeological research conducted in the region (Grguric, 2007, 2008). At 'Central Outstation' on the north-west coast of the Eyre Peninsular a similarly designed cottage has been hypothesised to have windows of this kind as defensive features to aid fortification against Indigenous raids (Grguric, 2007, 2008).

(a) Photogrammetry model of the cottage viewed looking south west

(b) Photogrammetry model of the woolshed and holding yard looking north east

(c) Photogrammetry model of the island near the Mount Dutton Bay Jetty viewed looking north east

Figure 3. Photogrammetry of built heritage and landscape features in Mount Dutton Bay.

The windows allowed a vantage for defenders to fire rifles whilst remaining defended themselves. The windows in the cottage at Central Outstation are positioned to have a view of the sheep holding pens which Grguric argues to be the likely target of Indigenous raids on the station (2007: 76). The Central Outstation was leased and developed in 1856 by Price Maurice, the same man who later built the Mount Dutton Bay woolshed. The major difference between the windows recorded at Central Outstation and those at Mount Dutton Bay however, is a marked discrepancy in their height above ground level, with the men's hut at Central Outstation recording a height of 1.4m whilst the shearers' cottage windows are measured at 2.3m high. Figure 8 shows the difference in window placement between the two stations.

Although the visibility analysis shows the surface of the ground visibility, it is limited as it does not show features that stand on top of the surface which may only be partly occluded by the terrain. An 'Above Ground Level' (AGL) visibility analysis produces a raster surface of values showing how much the ground surface at each point would have to be raised before it was visible to the location of the rear windows of the shearers' cottage. Figure 9 shows the results of the AGL analysis, with colourised classes for increments the ground surface would need to be raised to be visible from the shearers' cottage. These increments can also be thought of as the height an object must be in order to be visible from the shearers' cottage.

To explore these differences a hypothetical AGL visibility analysis was conducted from window heights of 1.4m which matched those recorded at the Central Outstation and the true height observed at Mount Dutton Bay. This analysis was conducted to determine the effective differences to the visibility of these windows at their raised heights. Figure 9 shows the results of these analysis.

To better understand the difference in visibility between these two window heights, the second surface was subtracted from the first to show the differences between the two surfaces. Figure 10 shows the difference in the visibilities, with larger numbers describing the superior vision of the raised window heights.

(a) Digital elevation model interpolated from total station measured surface elevations

(b) Digital elevation model interpolated from photogrammetry modeling of aerial photography

Figure 4. The two different elevation surfaces produced from total station, and aerial photography survey.

Spatial arrangement

The spatial arrangement of structures at the Mount Dutton Bay Complex suggests three interpretations of colonial attitudes towards this coastal space. The first relates to the separation of the location of the original homestead and the shearers' cottage. Although the building is no longer standing, the homestead's original location is shown in Figs. 9 and 10. Photographs of the original structure show that the homestead's front windows faced towards the water, whilst visibility analysis shows the shearers' cottage to have no view of the ocean. These two living spaces are therefore face away from one another. This may indicate some pursuit of privacy in the design of this layout. The homestead appears to be larger than the shearers' cottage and faces towards the bay with an uninterrupted view of the water. This suggests that an ocean view and the size of the dwelling were both indicators of status.

As Maurice had control of a large parcel of land, many locations could have been chosen for the site of the shearers' cottage that have ocean views and afford the same privacy from the homestead. The choice to place the shearers' cottage on the far side of a hill in one of the only locations to have no view of the water must therefore be considered deliberate.

A second possible interpretation for the placement of the structures is related to working space. The shearers' cottage clearly had no view of the woolshed, despite this being the primary working location for any occupants residing at this location. This may indicate a deliberate separation of living and working space. This interpretation can perhaps be extended to the lack of visibility of the ocean from the shearers' cottage, given that the woolshed, jetty and ocean are designed as an integrated workspace. In that case, the shearers' may have felt themselves to have maritime occupations at this coastal node reinforcing the notion that in coastal landscapes terrestrial and maritime cultures are inherently intertwined (Ford, 2011a, b; Westerdahl, 2011).

One final interpretation of the layout of the site comes from Grguric's (2007, 2008) interpretation of the windows as defensive fortifications. This can be individually assessed for the shearers' cottage at Mount Dutton Bay. Grguric argued that the placement of the structure was to provide visibility cover the sheep yards which he identified as the primary target of any raids on the Central Outstation property. The visibility analysis (Figs. 9 and 10) shows that the only asset in view of the rear windows of the shearers' cottage at Mount Dutton Bay was the original homestead. If Grguric's defensive interpretation is accurate this would suggest that the homestead was viewed as the primary target of raids on this property. This is a significantly different feature to the sheep yards that were being defended at the Central Outstation, however no similar structure to the homestead was present at Central Outstation. Food would only be stored in the homestead and shearers' cottage and the sheep population at the woolshed was transient. In this regard a valuation of the homestead as a primary target is consistent with a defensive interpretation for the site layout. The AGL visibility analysis of the shearers' cottage rear windows shows that they had a good coverage of the rear of the homestead. The AGL surface shows that a person could be visible when standing at three of the four sides of the homestead. Interestingly when the same AGL was conducted from a height of 1.4m to match the windows at the Central Outstation site this coverage was notably reduced. This strongly supports the defensive interpretation as the Central Outstation site was on flat ground and had no need to raise the windows for the same coverage, whereas the Mount Dutton Bay shearers' cottage would be defending a structure on top of a hill and benefits greatly from the raised windows as a result.

Grguric included as counter argument for a defensive interpretation, the 1856 date of the Central Outstation, which is late in the narrative of frontier conflict and likely past the point of major attacks. This is even more true for the Mount Dutton Bay site which was constructed in 1875, a further twenty years later. If the defensive interpretation holds true, this indicates that a mindset of defense, fortification and fear were much longer lasting than previously thought. It is possible that a tradition was established to setting up new sites where defense was a built-in consideration. Given the long history of conflict in the region and the personal experiences of Price Maurice, which did stretch back to the time of frontier conflict, a long-lasting defensive strategy in consequent site and structure plans seems plausible.

Figure 5. Surface showing difference between Interpolated DEM and Photogrammetry DEM.

Figure 6. Many arrangements of different datasets viewed together in a unified 3D scene.

Figure 7. Visibility analysis results. Red signifies areas not visible and green signifies areas at ground level that are visible from the windows of the shearers' cottage.

Figure 8. Rear windows of Central Outstation Men's Hut (left) (Grguric, 2007:149) and 3D model of Mount Dutton Bay shearers' cottage (right) created using photogrammetry.

Figure 9. Height Above Ground Level (AGL) visibility from the shearers' cottage with windows at a hypothetical height of 1.4m (as observed at Central Outstation) and at the true height of 2.3m (as observed at the Mt. Dutton Bay shearers' cottage).

Discussion: review of approach

This research has taken a modern digital approach to the task of archaeological landscape analysis, producing and analysing 3D data that represent the site in a very intuitive way. This addresses the call within the field of landscape analysis to reduce the abstractions of data and engage with it in a more natural way, whilst maintaining the empiricism needed to draw reliable conclusions (Bourdier et al., 2015; Frischer and Dakouri Hild, 2008; Hermon, 2008; Wüst et al., 2004). In this regard this approach has been a success, creating a spatially accurate digital reconstruction of the site as well as facilitating investigation of more experiential questions about the landscape. Similar approaches have been applied to largely urban environments such as the cities of Pompeii (Dell'Unto et al., 2015) and Copan (Richards-Rissetto et al., 2012). These flagship studies have demonstrated the strengths of a 3D approach to understanding large, complex and visually complicated environments. In contrast, Mount Dutton Bay is a relatively simple site with only a few structures surrounded by water and pastoral fields. Such a setting may appear to provide limited opportunities for this approach; however this research has demonstrated that representing this site in 3D still offers new perspectives.

The assessments of visibility made during this research exceed what is possible with a ground-based inspection of the site. Features such as trees or contemporary residential structures added to the site since the era in question are easily removed in GIS, allowing the visibility analysis to address the landscape in a much closer form to that which would have been present in the 1870s. Conversely features that were once present and since removed can be speculatively added to the scene. For example, based on historic photographs, the homestead was added to the scene, providing an opportunity to inspect the visual landscape with the additional presence of this structure. Newer approaches to vector-based visibility analysis in archaeology in a fully 3D environment have recently been undertaken with impressive results (Landeschi et al., 2016). Unfortunately the lack of built structures at the Mt. Dutton Bay site mean this approach is less appropriate however we would certainly apply it at other sites.

A further strength of this approach which is more difficult to quantify, is the telepresence offered by the landscape reconstruction. Engaging with the data in 3D provides a much clearer presentation which aids comprehension and opportunity for interpretation. This also offers new methods of dissemination that 2D drawings and maps alone cannot offer. In this way, the application of 3D landscape analysis techniques begins to bridge the gap identified by phenomenologists and other archaeologists, who call for a more experiential engagement with the past before drawing conclusions (Barrett and Ko, 2009; Forbes, 2007; Hamilton and Whitehouse, 2006; Tilley, 1994). Clearly this 3D model of Mount Dutton Bay does not yet completely replicate the experience of living in the shearers' cottage. However, the ability to address important questions about the social implications of space and building constructions through visibility analysis provide a sense of the past which is richer and closer to a human perspective than is available through plans, maps or photographs. As further developments in technology facilitate even more realistic reconstructions, this avenue of archaeological research can be expected to continue to develop.

One final strength of this approach relates to the preservation of data. The structures and site have been recorded in their current conditions in a high amount of detail. These data are thus preserved and can be viewed (either digitally or reproduced via a 3D printer), even when the conditions of the site change. This is critical from a cultural heritage management perspective as well as for any future research, as it facilitates asking questions about the site which may no longer be possible in the future due to changes in preservation or access. These data offer the opportunity of interaction via a digital platform accessible from anywhere in the world and experienced in a detail that 2D data does not offer.

Conclusions

This study demonstrates the potential of 3D landscape analysis to address the dichotomy that exists between theoretical approaches based on empirical spatial information and nuanced comprehensions of past human attitudes and relationships towards space. Representing data from Mount Dutton Bay in a 3D, scene integrated way, revealed the complexities of maritime culture and the diverse nature of this coastal site.

Figure 10. The difference in height above ground level visibility from true window height of 2.3m and hypothetical height of 1.4m from the shearers' cottage.

The approach to this spatial analysis enabled the cognition of various data from several existing and previous sources. This highlighted the relationships between natural site features and built material culture, which when organised in this way can be used to test and form hypotheses.

The research also demonstrated the fit of 3D landscape analysis within traditional archaeological landscape analysis methods, determining its ability to capture, unify, test, and add to a broad range of landscape and theoretical perspectives. The application of experiential methodologies via the extension of visualisation principles into 3D data, showed the ways that colonial people at Mount Dutton Bay engaged with coastal space by considering the environmental range of vision in relation to local topography.

The engagement of these data in a holistic and visually detailed way, has produced a number of interpretations of the attitudes towards the coastal space which support the views within the literature of a unique coastal landscape occurring at the transition between terrestrial and marine spaces. These data provided both a description of site activities that unify and validate the historical records, as well as providing insights into the attitudes and complex relationship between land and sea within the mind of those colonists who created this site.

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