Approaching a Mortuary Monument Landscape using GIS- and ALS-Generated 3D Models

Ole Risbøl, Troels Petersen and Gro B. Jerpåsen
Norwegian Institute for Cultural Heritage Research, P.O. Box 736, Sentrum, N-0105 Oslo, Norway

Approaching a Mortuary Monument Landscape using GIS- and ALS-Generated 3D Models

Ole Risbøl, Troels Petersen and Gro B. Jerpåsen

Abstract

In this study we examined how a GIS-based viewshed analysis that integrates movement could be used to provide substantial knowledge about the placement of Bronze Age grave cairns along the coast in a study area in Brunlanes, Larvik in South-East Norway. Additionally we studied the significance of digital elevation model quality for the interpretation of the viewshed analysis and for encluding palaeo-environmental changes (uplifting of land) in the analysis. Two sets of viewshed analyses were carried out from seven potential sailing routes based on a 20-metre and one-metre resolution DEM. The results indicate that the grave cairns were placed on the skyline in order to stand out more clearly to observers approaching from the sea, and that the DEM quality is of importance for the interpretation. Taking palaeo-environmental issues into consideration, we found that the effects of the uplifting of land were proven to affect visibility whereas vegetation was not an obstacle.

Key words: Viewshed, movement, digital elevation models, airborne laser scanning, GIS, burial cairns.

1. Introduction

Geographical information systems (GIS) have been an important part of archaeology since they became available to the community in the 1980s, and landscape archaeology in particular has benefited from the opportunity to conduct digital landscape analysis through the application of visual approaches. The opportunity to generate high-quality digital elevation models (DEMs) has been a precondition for conducting detailed visibility studies based for instance on line-of-sight and viewshed analysis. In that respect new advances made within laser technology and especially the development of airborne laser scanning (ALS) are important. ALS has been well received by the archaeological community and is increasingly implemented in the constant drive to improve archaeological inventories as a way of optimising landscape research as well as cultural resource management [1–3]. So far the use of ALS data for landscape studies has received little attention from archaeologists. One exception is a landscape study which resulted in increased understanding of a monastery complex in an Austrian forest [4]. ALS has made it possible to generate detailed 3D DEMs of hitherto unattainable resolution over large geographical areas and thus has a potential advantage over GIS-based digital landscape analysis. In this paper we study the impact of DEM quality on GIS-based viewshed analysis that also takes movement and palaeo-environmental changes into consideration.

1.1. GIS, visual methods and movement

The introduction of GIS in archaeology in the late 1980s/early 1990s coincided with the emergence of a new theoretical focus within landscape archaeology and led to an upsurge in archaeological landscape studies. The emphasis on subsistence and ecology characterising processual landscape archaeology from the 1960s onwards was followed by a post-processual understanding of landscape studies attaching more importance to the cognitive aspects of human relations with the landscape from the early 1990s [5]. Vision and thereby visibility came into focus and analysis involving line-of-sight and viewshed became increasingly important in archaeological landscape studies. The watershed publication *Interpreting Space* by Allen and colleagues in 1990 [6] indicates the incipient utilisation of GIS in archaeological landscape analyses. The initial application of GIS in archaeology was rather simplistic and aimed mainly at inventorying - but also prediction modelling gained quite a lot of interest [7]. Almost contemporaneously more advanced GIS applications were taken into use with the aim of deducing the cultural-historic meaning of spatial structures using approaches like cost surface and viewshed analysis [8].

Thus the paradigm shift in theoretical landscape archaeology coincided with the emergence of GIS and its potential for approaching landscape studies in a way that was not possible previously. Still, it has been claimed that many archaeologists have either a theoretical or a methodological approach to landscape studies and tend to stick to either the one or the other and thereby fail to integrate formal methods in theoretical landscape studies and vice versa [9]. Archaeological landscape analyses which are either exclusively theoretical or practical can be criticised for being less trustworthy than those that try to unite the two approaches. Post-processual theoretical landscape analyses emphasising cognitive aspects 'are incorporated within a narrative and lack any form of validation or means by which they can be faithfully explored', as Llobera puts it [10]. Correspondingly it can be noted that uncritical use of GIS applications is in danger of being simplistic or technology-deterministic. Hence it is important to try to bridge the gap between theory and practice. The use of computers and GIS is by no means an unbiased practice but is firmly integrated in the hermeneutic circle, as noted by Lock [11], and does not produce objective truth about how people related to landscapes in the past but must be understood as probability studies [12] which can contribute to hypotheses about humans' interaction with their physical surroundings.

GIS-based visibility studies have been dominated by viewshed analysis since the first successful use of this application in 1991 [13] and have impacted heavily on how archaeological landscape studies have been conducted [14]. Starting with simple binary analysis where intervisibility between two points is represented digitally, the implementation of viewshed applications has become increasingly more complicated with the introduction of variable approaches such as cumulative, multiple, fuzzy and Higuchi viewsheds. These are refinements of the conventional viewshed application and appeared in response to the criticism of the initial use of viewsheds as too simple and far removed from the reality of the past [15]. Further criticism has identified the serious challenges connected with palaeo-environmental issues – how to reconstruct the vegetation situation as it was in the period studied and how to deal with the topographical changes that occurred over a long time [15–17]. A central criticism which has gained a lot of attention lately is connected with the absence of mobility in viewshed analysis. The static method of analysing visibility from certain defined stands has been pointed out as being in contrast to how people normally experience their surroundings, which is while they are on the move. To integrate movement in visibility analyses is an obvious consequence of post-processual landscape studies with their emphasis on cognitive and embodied experiences [14]. The challenges of integrating movement in visual landscape studies have been met by the implementation of multiple viewsheds or the creation of analysis from several points along potential paths of movement [18]. Llobera has approached movement from a theoretical stance, emphasising cultural and social aspects in his studies [10] as opposed to the topographic deterministic cost-surface and least-coast techniques used in others [19–22]. Finally, a criticism or rather a challenge connected with viewshed analysis is the quality and accuracy of the DEMs used to conduct these. The resolution of digital models used in visual studies is of vital importance to the outcome [23] but it should be noted that the relation between the accuracy of a DEM and the resulting interpretations concerning visibility is not straightforward because distance to the observed landscape as well as variable landscape types strongly affects visibility [14].

Visual archaeological analyses are based on phenomenological theory and are one way to come closer to human perception and intention. Phenomenology is concerned with humans, places and landscape and humans' actual use and shaping of their environments. It is based on the assumption that people actively shape their rooms into lived and meaningful places. Visual studies try to reveal the intention behind the placement of archaeological sites and objects. Our interpretation of prehistoric landscape perception is an allegory that represents today's understanding. Yet we can place ourselves in the same physical environments that were essential in the past – formulated as inhabiting the past in the present [24], [25]. Phenomenological studies have been criticised for being too subjective, and lack of methodology is one of the reasons for this. Another reason is that the relationships claimed are not always supported adequately by other kinds of data and methods [26], [27], [28]. Manual visual analyses can be difficult to carry out because of landscape changes such as change of vegetation and changes of sea level [29], [30]. Movement is also hard to map manually and GIS methods are useful for reconstructing prehistoric landscapes and mapping possible routes for movement.

In this study we examined how GIS-based viewshed analysis that integrates movement can be used to provide knowledge about how people related to their surroundings in the past. We concentrated on the meaning behind the placement of Bronze Age grave cairns along the coast in a study area in South-East Norway (Figure 1). The localisation of these grave cairns has been the subject of much debate amongst archaeologists. Their proximity to the sea has been

Figure 1. A Bronze Age grave cairn in its surroundings. A second cairn is observable in the middle of the photo (marked by a red arrow). Photo: NIKU.

emphasised by all but the reasons cited vary considerably (see overview in [31]). Some authors emphasise the view from the cairns over the sea, others accentuate the significance of transport by sea routes and thereby communication and trade, and some suggest that the cairns belonged to a group of fishers and sea hunters separated from the predominant farming population. Additionally we studied the significance of DEM quality for the interpretation of viewshed analysis using the mortuary monuments and their geographical relation to landscape and human perception as an example. The study is summarised by these two questions:

- How can viewshed analysis contribute to an improved understanding of the meaning behind the topographical localisation of Bronze Age burial cairns?
- In terms of interpreting viewsheds, what are the effects of (1) improved DEM quality and (2) palaeo-environmental changes (uplifting of land)?

2. Methods

2.1. Study area

The geographical area used in this study is situated within a region called Brunlanes in Larvik municipality in South-Eastern Norway (58° 58'N, 9° 53'E) (Figure 2). Brunlanes is a coastbound district dominated by rather small-scale agriculture. The landscape is quite flat but undulating and in many places split by crags and hills usually not exceeding 100 metres above sea level. The shore line is irregular and characterised by a great many tongues of land, inlets, skerries and islets.

Besides a large number of Stone Age sites, archaeology in this area is dominated by the presence of many mortuary monuments. These monuments can be divided into two distinct categories: (1) grave mounds built of soil and/or turf and (2) grave cairns built of stone.

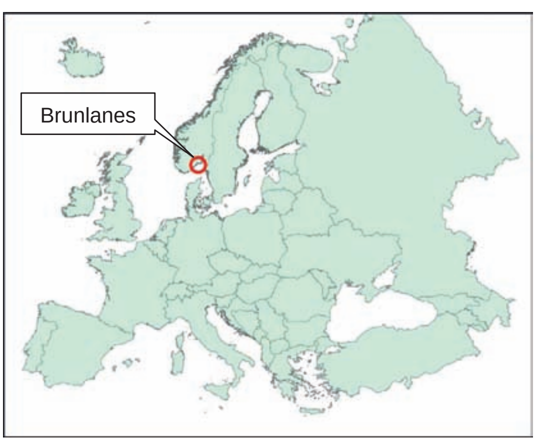
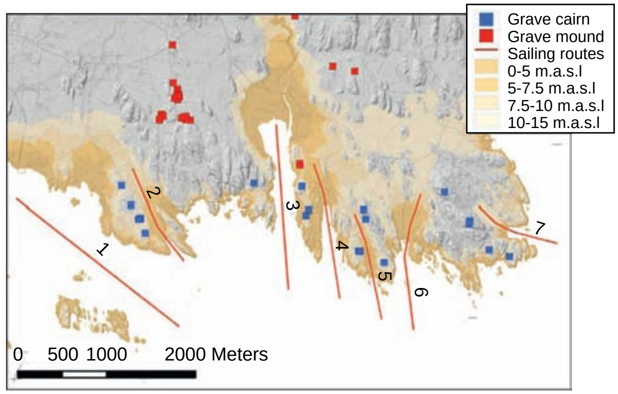


Figure 2. The geographical location of the study area.

Figure 3. The study area showing the distribution of mortuary monuments and potential sailing routes. (Copyright: Norwegian Mapping Authority).



Within the study area 26 grave mounds and 23 grave cairns are known (Figure 3). Generally the grave mounds can be dated to the Iron Age (500 B.C. to A.D. 1050) and the grave cairns to the Bronze Age (1800 B.C. to 500 B.C.) and even though deviations occur, as noted by Sollund [31], these dating frames are essentially correct.

2.2. Viewshed and movement

In order to approach the cultural meaning of the location of grave cairns in the landscape, a series of binary viewshed calculations were conducted in ArcGIS Spatial Analyst. These included viewsheds from grave mounds to grave cairns and vice versa, from roads to grave mounds and from sailing routes to grave cairns, etc. Since the study was carried out in a coastal environment, it was an obvious move to study relationships between sea routes and monuments. The viewsheds from the sailing routes gave the most interesting result, indicating a repetitive pattern: i.e. that the grave cairns were placed more or less in the transition zone between visible and non-visible areas. In order to determine the potential sea routes used in the study, historical maps in combination with consideration of the topography in relation to natural ports of call were studied. Quite detailed maps from the early nineteenth century are available for the study area; based on the premise of long continuity in infrastructure the most likely movement lines towards the coast were established and integrated in GIS. Thus the problem of taking movement into consideration in the attempt to understand how humans related to landscape in the past was solved by creating digital lines indicating potential sea routes along which people might have moved and experienced the surrounding landscape. An important factor which had to be taken into account was the uplift of land during the Holocene. In the Brunlanes region, this has had a substantial impact on the landscape, in particular altering the coastline's appearance throughout the post-glacial period (Figure 4).

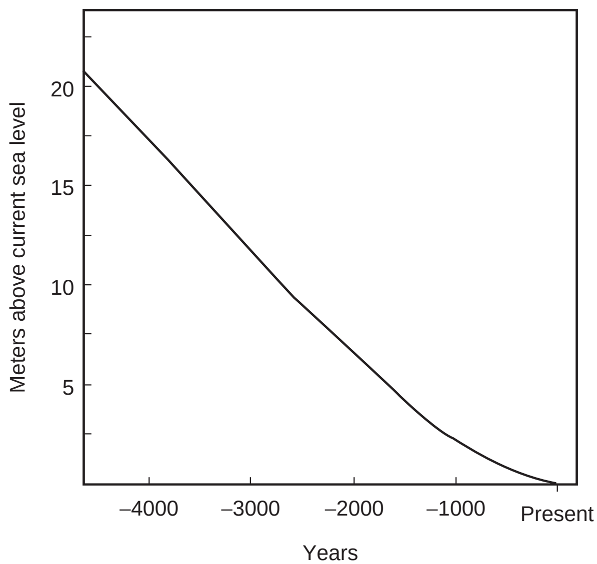


Figure 4. A graph showing how the sea level has changed since prehistory (based on [32]).

Hence a range of different viewshed analyses were defined and assessed with a view to their statement value. After the testing of different approaches the final viewsheds were carried out from seven potential sailing routes (see Figure 3).

Two sets of viewshed analyses were carried out from each of these movement lines in order to evaluate the DEM quality: one set using conventional contours integrated in standard GIS programs and one set with high resolution 3D models based on ALS data. Thus, the study included a 20-metre and a one-metre resolution DEM, hereinafter respectively referred to as DEM 20 and DEM 1. DEM 20 was obtained from the Norwegian mapping authority and relies on contour interpolation (vertical Std 4–6 m). DEM 1 is based on ALS data collected with an average sample density of 22 points/m^2 in June 2010 (vertical Std 0.02 m). The ALS data were automatically classified with Blom software and exported to LAS format. The software Quick Terrain Modeller (QTM) version 7.1.1 (appliedimagery.com) allowed us to interpolate the LAS ground points into a 1-m tiff image, constituting DEM 1.

Further, the significance of the uplift of land was assessed. Prior to the viewshed calculations, the present sea level (zero metres) captured by DEM 20 and DEM 1 was increased in order to simulate an early Iron Age (+ 7.5 m.a.s.l.) and an early Bronze Age situation (+ 15 m.a.s.l.), resulting in three DEM pairs of corresponding sea levels. Further, observation points with a vertical offset of 1.67 m along the proposed 1.6 km sea routes were defined for every 200 m. The binary viewsheds were calculated with the observation points and the six DEMs as input, leading to 48 viewsheds in total (three sea levels x 2 DEM resolutions x 8 observation points). The burial cairn localities, which are represented as polygons in the national cultural heritage database, range in size from 86 to 503 m^2. Furthermore, the viewsheds derived from DTM 20 were resampled from 20 m to 1m resolution by applying the nearest neighbour option. For each viewshed, the raster cells indicating visibility inside each of the polygons were then summed with the Zonal Statistics tool in ArcGIS.

3. Results

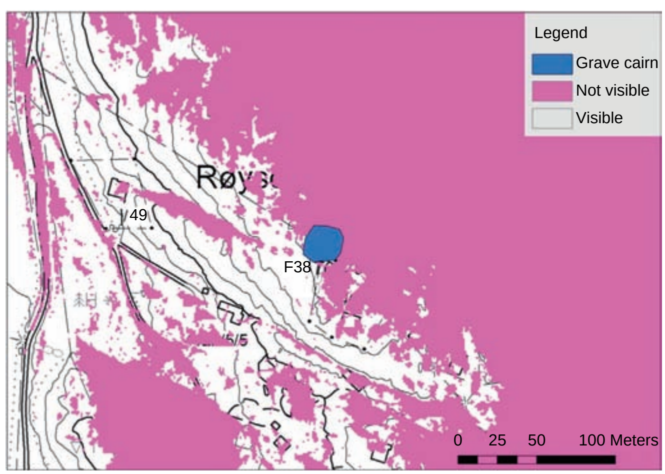
3.1. Landscape, viewshed and movement

The study of the Brunlanes landscape was conducted in a GIS holding standard map information. In addition we added DEMs, information about the spatial distribution of archaeological monuments and sites, information about the old road system as it appears on historical maps as well as information about how the land has uplifted since the early Bronze Age. The grave cairns seemed to form a linearity in the landscape along what might be potential sailing routes towards suitable places of call defined by the local topography.

Viewsheds conducted from the seven sailing routes showed that the grave cairns are situated in the transition zone between visible and non-visible areas as exemplified by grave cairn number 12 (Figure 5). The analysis of the other six sailing routes showed a similar picture. This indicates that the grave cairns are situated at or near crests and thus might have been observable from the sea in silhouette against the skyline, as exemplified in Figure 6.

The quality of the viewshed analysis was studied for 1-m and 20-m resolutions respectively (Figure 7a and 7b). The two sets of viewsheds show a clear difference in terms of visuality. This is further underlined by the statistical analysis that was carried out for four of the 23 cairn

Figure 5. Viewshed analysis (DTM-1) from sailing route 6 showing grave cairn 12. The shortest distance between the sailing route and the cairn is 285 metres. (Copyright: Norwegian Mapping Authority, Geovekst).



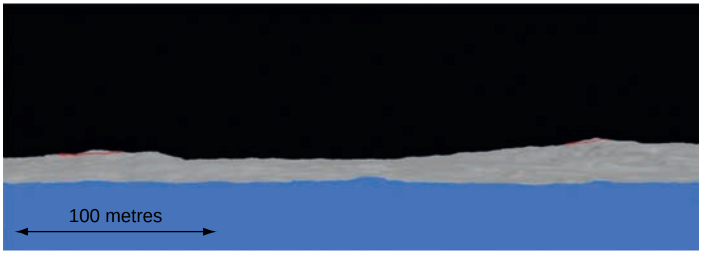


Figure 6. A horizontal image of the coastline as it would appear from the sea (from sailing route 2 and towards the west) and showing grave cairns 8 and 18 (marked with a red line) in profile. The image is a DTM generated from ALS with QTM and with the grave cairn contours as overlay texture. The distance between the observation point and the grave cairns is app. 200 metres.

localities (Figure 8). The figures showed significant differences between the two resolutions in terms of visibility. For the 1-m resolution the visible area covering the grave cairns varied from 9 % to 48 % and for the 20-m resolution it was between 8 % and 100 %. The average variance broken down to the three different sea levels was 21 % to 36 % with regard to the 1-m resolution and 60 % to 76 % with regard to the 20-m resolution. The total average for all visibility calculations was 28 % for

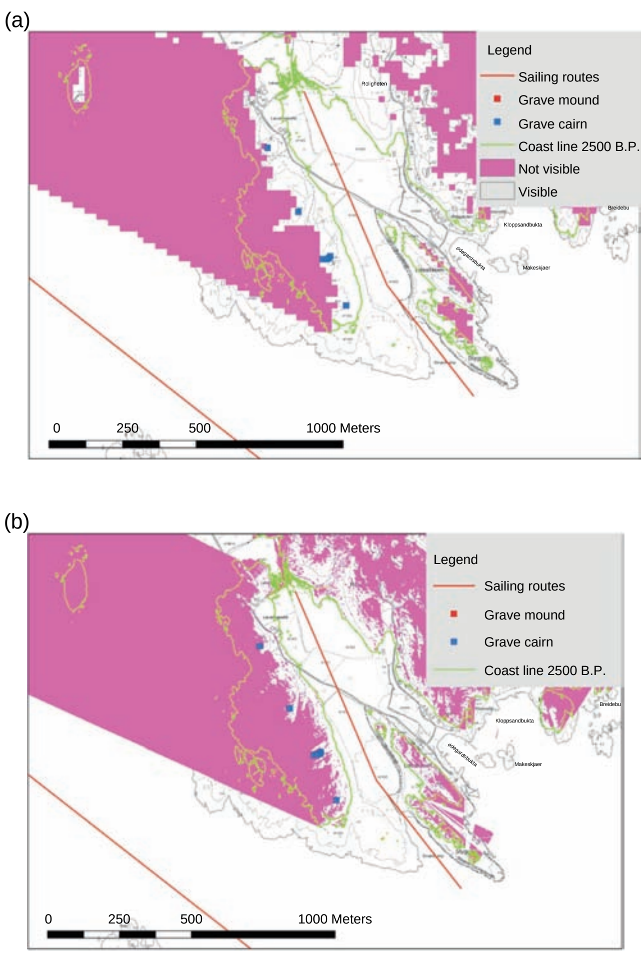


Figure 7a and 7b. Viewsheds showing visibility from sailing route 2 towards grave cairns 1, 8, 18 and 26 lying on the crest to the west. Figure 7a is generated from DEM 20 and 7b from DEM 1. (Copyright: Norwegian Mapping Authority, Geovekst).

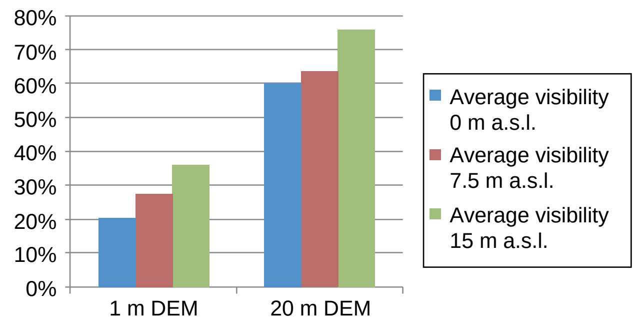


Figure 8. The average visibility rates for two DEM resolutions and three different sea levels.

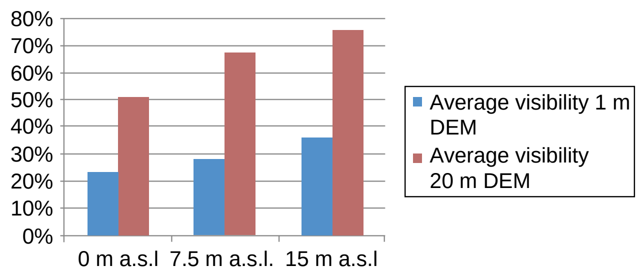


Figure 9. The average visibility rates for three sea levels and two DEM resolutions.

the 1-m resolution and 66 % for the 20-m resolution. This indicates that the coarse resolution (DEM 20) exaggerates visibility whereas DEM 1 gives a more realistic representation.

The visibility calculations performed for the present water level (zero metres), the water level at the transition between the Bronze Age and the Iron Age (7.5 m, 2500 B.P.) and the early Bronze Age (15 m, 3500 B.P.) respectively, were carried out in order to test the effect of the lowering of sea level on visibility studies (Figure 9). The average variance for 0 m was a visibility rate of 24 % to 51 %, 28 % to 67 % for 7.5 m and 36 % to 76 % for 15 m. The total average visibility rate for all calculations was 38, 48 and 56 % for 0, 7.5 and 15 m respectively.

4. Discussion

4.1. Grave cairns and sailing routes

There is a general consensus that the physical location of mortuary monuments in the landscape is intentional and not random [33]. To deduce the meaning behind the staging and how people interacted with landscape is however not straightforward but an extremely complex task that involves space, time and phenomenology.

In the study at hand, we aimed at a better cultural-historic understanding of the location of coastbound Bronze Age cairns in South-East Norway with the use of viewshed analyses. The cairns in the study area are placed at ridges close to the coast and grouped in a number of approximately north-south-oriented lines perpendicular to the predominant coastline direction. These circumstances dictated a focus on the relationship between mobility by sea and the location of the grave cairns. The spatial connection between mortuary monuments and roads is observed in several studies showing that graves were often placed along old roads and transport routes, and graves and roads create a mutual linearity in the landscape [34, 35]. The same situation is observable in the Brunlanes landscape. The request to include movement in visual landscape studies has been met with the development of computation approaches such as cost surface and affordance analyses [19, 36]. These are not applicable at sea, however, and in our study we included a combination of topographical and historical map studies instead in order to determine the sailing routes. Unlike movement by land, movement at sea does not leave physical traces. Hence we transferred the mutual linearity proven on land to the sea as a basis for determining potential sailing routes.

A general weakness with many landscape analyses, including the one at hand, is the lack of precise datings of the monuments. As pointed out by Bourgeois [33], this lack of accurate datings prevents us from studying landscape temporality thoroughly but leaves us with coarse-meshed dating frames for our analyses. Therefore we do not know in which sequence the monuments were built or how many of them existed at the same time.

4.2. Viewshed analyses and visibility

The viewshed analyses were conducted as binary analyses from movement lines. The viewsheds from the sailing routes indicated a repetitive pattern: the grave cairns were placed more or less in the transition zone between visible and non-visible areas. This shows that the grave cairns are situated at or near crests and thus might have been placed there so that they could be seen in silhouette against the background. The importance of the skyline effect on the visibility of monuments is reported in other viewshed-based landscape studies and the effect is described as a way to make the monuments stand out more clearly [21, 33]. We also know of examples where monuments' visibility was accentuated by the use of erected wooden posts or certain types of stones of a different colour from the surrounding environment that made the cairns stand out more clearly [33, 37]. Even though only a few of the grave cairns at Brunlanes have been excavated there are more indications of the presence of what might have been reinforcing visual elements such as erected posts in the centre of the cairns [31]. Together with the fact that the grave cairns have been subjected to decay because of the ravages of time, this indicates that their initial visibility was more evident. Consequently, the present visibility studies under- rather than overestimate the monuments' visibility.

The obscuring effect of vegetation on visibility is perhaps the most frequently mentioned criticism of visibility studies [17]. The change of vegetation conditions from the past to the present will in most cases bias the viewshed interpretations and it is an extremely demanding task – bordering on impossible – to recreate the past vegetative situation. In our study, vegetation is not considered to be a relevant obstacle of any particular significance, since the grave cairns are situated in outfield areas with poor soil conditions preventing good fertile growing conditions for plants. The majority of the cairns lie in open terrain. Even in those cases where the present vegetation is a hindrance to visual studies, this was most certainly not the case a couple of millennia ago when the thin layer of turf needed for bushes and trees to grow had not yet been established. We therefore consider the present vegetation to be more or less representative of the situation in prehistory: the vegetation in any case was not more widespread in the past than in the present.

4.3. DEM quality

The quality of the DEMs is of importance in terms of accuracy because improved resolution offers better opportunities for interpreting the results from the visual analysis in more detail. The quality of the DEMs used in viewshed analysis affects the analysis because of the effect of different resolutions [12, 38]. The results from our study showed that the DEM with 1-m resolution gave a more nuanced picture than the DEM with 20-m resolution. Even if the visibility rate is poorer for the former, we believe it gives a more correct result. The fact that only parts of the area around the cairns were visible strengthens the theory that they stand out on the skyline when seen from the sailing routes. According to the 20-m DEM analyses, more of the areas around the cairns are visible, which actually makes them less visible from the sailing routes, since they become absorbed by their surroundings and do not appear as prominently against the skyline.

4.4. Palaeo-environmental changes – uplifting of land

The most pronounced change in the landscape is the one connected with the uplifting of land. When the Nordic ice cover disappeared the land was released from pressure, resulting in a continuous elevation – hence a change in the shore line followed. This is vital for the process of conducting viewshed analysis and has a serious impact on the interpretation of the analysis. The effect of the uplifting of land was quantified in our study, showing that the areas covering grave cairns has been subjected to reduced visibility from the Bronze Age to the present time. Today most of them are located rather high up, distant and invisible from the shore. When we take the elevation of land into account the connection with the sea becomes more evident and elucidate context and placement of the grave cairns in the Bronze Age. Visual studies that take uplifting of land into account are not possible in the real landscape but must be conducted digitally.

5. Conclusions

Viewshed analyses combined with the assertion ability of topographical circumstances indicate that sailing routes towards land and potential ports of call might have been a decisive factor in the spatial distribution of grave cairns in the Brunlanes area in the Bronze Age. The connection between mortuary monuments and transport routes is proven in visual based landscape studies located to land and our study show that the same relation can be applied to movement by sea. The viewshed analyses indicate that coastbound grave cairns might have been placed at the skyline in order to stand out more clearly to observers approaching from the sea. One weakness of this theory is that the sailing routes and ports of call are hypothetical and their actual existence is founded on other sources than archaeological ones.

The study also shows that the DEM quality is of importance in terms of interpretation abilities, because improved resolution offers improved possibilities for interpreting and understanding the visual analysis in more detail. The coarser resolution tends to exaggerate visibility compared with the finer resolution which probably gives a more realistic picture of the landscape. Reconstruction of past landscapes also implies consideration of palaeo-environmental issues. In this case the effects of the uplifting of land were proven to affect visibility whereas vegetation was deemed not to constitute an obstacle. A critical point is the fact that the absence of a detailed chronology in terms of datings of the grave cairns prevents detailed study of the mutual dynamics of landscape changes and the construction of the monuments.

Viewshed analyses are a valuable approach to landscape studies which, applied with a critical eye, enabling us to put forward hypotheses concerning prehistoric landscape use. In this study they represent a method suitable for analysing the meanings behind the placement of burial cairns in a Bronze Age landscape. In many cases such analyses are only possible by means of a digital approach.

Finally, it is important to observe that visual studies, such as the ones presented here, rather than providing indisputable answers should be understood as probability studies which offer a number of explanations for conditions in past societies.

6. Acknowledgement

The study presented in this paper is part of a research project at the Norwegian Institute for Cultural Heritage Research (NIKU) funded by the Research Council of Norway.

7. References

1. Doneus, M. and C. Briese, Airborne laser scanning in forested areas - potential and limitations of an archaeological prospection technique, in *Remote sensing for archaeological heritage management*, D.C. Cowley, Editor Europae Archaeologia Consilium (EAC), Brussels, 2011, p. 59–76.
2. Risbøl, O., Cultivating the "wilderness" - how lidar can improve archaeological landscape understanding, in *Interpreting archaeological topography. 3D data, visualisation and observation*, R.S. Opitz and D.C. Cowley, Editors, Oxbow Books, Oxford, 2013, p. 51–62.
3. Campana, S., et al., 3D Recording and Total Archaeology: From Landscapes to Historical Buildings, *International Journal of Heritage in the Digital Era*, 1, 3, 2012, p. 443–460.
4. Doneus, M. and T. Küchteiber, Airborne laser scanning and archaeological interpretations - bringing back to people, in *Interpreting archaeological topography: airborne laser scanning, 3D data and ground observation*, R.S. Opitz and D.C. Cowley, Editors, Oxbow Books, Oxford, 2013, p. 32–50.
5. David, B. and J. Thomas, Landscape archaeology: Introduction, in *Handbook of landscape archaeology*, B. David and J. Thomas, Editors, Left Coast Press, Walnut Creek, 2010, p. 27–43.
6. Allen, K.M.S., et al., *Interpreting space: GIS and archaeology*, Taylor & Francis, London, 1990, 1–398.
7. Kvamme, K.L., The fundamental principles and practice of predictive modeling, in *Mathematics and information science in archaeology: A flexible framework*, A. Voorrips, Editor Holos–Verlag, Bonn, 1990, p. 257–295.
8. Harris, T.M. and G. Lock, Toward an evaluation of GIS in European archaeology: the past, present and future of theory and applications, in *Archaeology and Geographical Information Systems: A European Perspective*, G. Lock and Z. Stančič, Editors, Taylor & Francis, London, 1995, p. 349–365.
9. Wheatley, D., Going over old ground: GIS, archaeological theory and the act of perception, in *Computing the past: computer applications and quantitative methods in archaeology. CAA92*, J. Andressen, T. Madsen, and I. Scollar, Editors, Aarhus University Press, Aarhus, 1993, p. 133–138.
10. Llobera, M., Understanding movement: A pilot model towards the sociology of movement, in *Beyond the Map: Archaeology and Spatial Technologies*, G. Lock, Editor, IOS Press, Amsterdam, 2000, p. 65–84.
11. Lock, G.R., *Using computers in archaeology: towards virtual pasts* London, Routledge, 2003, XV, 300 s.
12. Wheatley, D. and M. Gillings, *Spatial technology and archaeology: the archaeological applications of GIS*, Taylor & Francis, London, 2002, XIII, 269 s.
13. Gaffney, V. and Z. Stančič, *GIS approaches to regional analysis: a case study of the island of Hvar* Ljubljana, Znanstveni institut Filozofske fakultete, 1991, 1–100.
14. Wheatley, D. and M. Gillings, Vision, perception and GIS: developing enriched approaches to the study of archaeological visibility, in *Beyond*

the map: archaeology and spatial technologies, G. Lock, Editor, IOS Press, Amsterdam, 2000, p. 1–27.

15. Tschan, A.P., W. Rącheckczkowski, and M. Latałowa, Perception and viewsheds: are they mutually inclusive?, in *Beyond the map: archaeology and spatial technologies*, G. Lock, Editor, IOS Press, Amsterdam, 2000, p. 28–48.
16. Gearey, B.R. and H.P. Chapman, "Digital gardening" An approach to simulating elements of palaeovegetation and some implications for the interpretation of prehistoric sites and landscapes, in *Digital archaeology. Bridging method and theory*, T.L. Evans and P. Daly, Editors, Routledge, Taylor & Francis Group, London and New York, 2006, p. 171–190.
17. Gillings, M. and D. Wheatley, Seeing is not believing: unresolved issues in archaeological visibility analysis, in *On the good use of GIS*, B. Slapsack, Editor, Brussels, 2001.
18. Davis, S., et al., Lidar survey in the Brú na Bóinne World Heritage Site, in *Interpreting archaeological topography. 3D data, visualisation and observation*, R.S. Opitz and D.C. Cowley, Editors, Oxbow Books, Oxford, 2013, p. 223–237.
19. Bell, T. and G. Lock, Topographic and cultural influences on walking the Ridgeway in later prehistoric times, in *Beyond the Map: Archaeology and Spatial Technologies*, G. Lock, Editor, IOS Press, Amsterdam, 2000, p. 85–100.
20. Harris, T., Moving GIS: exploring movement within prehistoric cultural landscapes using GIS, in *Beyond the Map: Archaeology and Spatial Technologies*, G. Lock, Editor, IOS Press, Amsterdam, 2000, p. 116–123.
21. Conolly, J. and M. Lake, *Geographical information systems in archaeology*, Cambridge University Press, Cambridge, 2006, XX, 338 s.
22. van Leusen, P.M., *Pattern to process. Methodological investigations into the formation and interpretation of spatial patterns in the archaeological landscape*, Groningen, 2002, 1–348.
23. Fisher, P.F., Extending the Applicability of Viewsheds in Landscape Planning, *Photogrammetric Engineering & Remote Sensing*, 62, 11, 1996, p. 1297–1302.
24. Thomas, J., Archaeologies of place and landscape, in *Archaeological theory today*, I. Hodder, Editor, Polity Press, Cambridge, 2012 [2001], p. 167–187.
25. Fraser, S.M., The public forum and the space between: the materiality of social strategy in the Irish Neolithic, in *Proceedings of the Prehistoric Society*, 1998, Prehistoric Society.
26. Hamilton, S., et al., Phenomenology in practice: Towards a methodology for a "subjective" approach, *European Journal of Archaeology*, 9, 2006, p. 31–71.
27. Brück, J., Experiencing the past? The development of a phenomenological archaeology in British prehistory, *Archaeological Dialogues*, 12, 1, 2005, p. 45–72.
28. Fleming, A., Post-processual landscape archaeology: a critique, *Cambridge Archaeological Journal*, 16, 3, 2006, p. 267.
29. Jerpåsen, G.B., Application of Visual Archaeological Landscape Analysis: Some Results, *Norwegian Archaeological Review*, 42, 2, 2009, p. 123–145.
30. Solli, B., Comments on Gro B. Jerpåsen: "Application of Visual Archaeological Analysis: Some Results" (Norwegian Archaeological

Review 42 (1) 2009), *Norwegian Archaeological Review*, 43, 1, 2010, p. 63–76.

31. Sollund, M.-L.B., *Åsrøyser – gravminner fra bronsealderen. En analyse av åsrøysene fra Vestfold*. Varia. Vol. 34, Oslo, Universitetets Oldsaksamling, 1996, 1–116.
32. Henningsmoen, K., En karbon-datert strandforskyvningskurve fra søndre Vestfold, in *Fortiden i søkelyset. ^{14}C datering gjennom 25 år*Laboratoriet for Radiologisk Datering, Trondheim, 1979, p. 239–247.
33. Bourgeois, Q., *Monuments of the horizon. The formation of the barrow landscape throughout the 3rd and 2nd millennium BC* Sidestone Press, Leiden, 2013.
34. Løvschal, M., Ways of wandering. In the late Bronze Age barrow landscape of the Himmerland-area, Denmark, in *Beyond Barrows. Current research on the structuration and perception of the prehistoric landscape through monuments*, D. Fontijn, et al., Editors, Sidestone Press, Leiden, 2013, p. 225–250.
35. Rudebeck, E., Vägar, vägkorsningar och vadställen – liminala platser och arkeologi, in *Kommunikation i tid och rom*, L. Larsson, Editor University of Lund, Lund, 2001.
36. Llobera, M., P. Fábrega-Álvarez, and C. Parcero-Oubina, Order in movement: a GIS approach to accessibility, *Journal of Archaeological Science*, 38, 2011, p. 843–851.
37. Tuovinen, T., *The burial cairns and the landscape in the archipelago of Åboland, SW Finland, in the Bronze Age and the Iron Age*, in *Faculty of* Humanities, University of Oulu, Oulu, 2002.
38. Hageman, J.B. and D.A. Bennett, Construction of Digital Elevation Models for archaeological applications, in *Practical applications of GIS for archaeologists. A predictive modeling kit*, K.L. Westcott and R.J. Brandon, Editors, Taylor & Francis, London, 2000, p. 121 – 136.