ARCHAEOLOGICAL VISIBILITY ANALYSIS WITH GIS

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ABSTRACT:

Spatial information is of great importance to archaeologists. Many archaeologists have adopted Geographical Information Systems (GIS) in their studies because GISs can make managing, interpreting and visualising geographical information easier. Visibility issues are of great importance to archaeologists, especially in landscape studies. A GIS can be used to analyse visibility, but the available tools have been criticised by archaeologists and GIS researchers. The standard analysis that can be conducted using GIS does not always represent reality well enough and does not take all factors into account that could have an impact on visibility. In this study the factors influencing visibility have been researched. Vegetation is one of the factors mentioned in literature that can influence visibility significantly. Several approaches have been proposed in literature, ranging from very simple methods to methods taking the possibility of seeing through vegetation into account. Uncertainty is also an issue in visibility analysis. The output of the visibility analysis is often seen as the truth whereas in reality the analysis is the result of modelling and is therefore one of the possible outcomes. Several approaches are named in literature. This study focusses on archaeological visibility studies in general, but a study area in Scotland has been used as a study case. The best approaches for the study area have been chosen to incorporate vegetation and uncertainty by developing tools that can be used in a GIS. The resulting tools have been used to analyse the visibility with the incorporation of factors influencing visibility. The analyses have been useful for the archaeologists to assess the visibility of and/or from points of interest but also to see the influence of factors on visibility. The tools give a better insight in the factors influencing visibility and invite archaeologists to think through their questions about the significance and meaning of particular sites.

1. INTRODUCTION

The popularity of the usage of Geographical Information Systems (GIS) to analyse and explore past landscapes has grown rapidly over the last few decades. The purpose of visibility analysis in landscape archaeology is to explore the visual organisation of features across a landscape (Kay and Sly, 2001). Visibility is of major importance to how humans relate to and interpret the landscape. People often describe a place based on the visibility (Wheatley and Gillings, 2001). Visibility analysis is therefore an important element in the interpretation of the landscape for understanding past societies. Visibility analyses can help analyse the spatial distribution of features in the landscape or help answer the question why a particular site was in a particular place (Wheatley and Gillings, 2001).

2. THEORETICAL BACKGROUND

2.1 Visibility analysis

Different GIS packages contain different visibility analysis tools. This research focusses on ArcGIS version 9.3 (with Spatial Analyst and 3D Analyst extensions) which is used at the Department of Archaeology at the moment. Focus will be on the 'Viewshed Tool' which generates an overview of the visibility of the area from one or more viewpoints.

The most common viewshed analysis is the binary viewshed analysis. The output is a raster that shows the cells that are visible and cells that are not visible from one or more viewpoints. The raster is created by producing a line-of-sight analysis from the viewpoint to each cell in the height input model; a Digital Elevation Model (DEM). Cells that are not blocked by elevation heights of other cells are classified as visible and are assigned the value '1'. All other cells are invisible and are assigned the value '0'. Each raster contains cells with either the value 1 or 0 and is therefore called binary. Variations to the binary viewsheds exist, such as cumulative viewsheds where viewsheds from different viewpoints are added.

2.2 Limitations

Visibility analysis is complex. Wheatley and Gillings (2000) classify the issues relating to visibility analysis into three categories:

- Pragmatic - pragmatic issues are those which apply to both GIS and non-GIS based visibility studies
  e.g. vegetation, human perception and temporal changes

- Procedural – procedural issues refer to concerns that arise as a product of using GIS for visibility analysis
  e.g. DEM accuracy and the undifferentiated nature of the viewshed (binary output)

- Theoretical – theoretical issues are those which arise from debates in the humanities (e.g. geography)

The list of issues relating to visibility analysis is long. Several methods, algorithms and tools have been proposed by several authors to overcome these limitations and to enrich existing methods. Focus of this research will be on exploring the possibilities of incorporating vegetation and visualising uncertainty of the viewshed outcome caused by DEM uncertainty and human perception for a study area in Scotland.

2.3 Research question

This research focusses on addressing and evaluating the limitations of not incorporating vegetation and the inability to model uncertainty caused by human perception and error in the DEM. It also focusses on applying enriched forms of viewshed analysis mentioned in literature to overcome these limitations.

The main research question is:
'Can the incorporation of vegetation and visualisation of uncertainty lead to better visibility analysis for landscape archaeology and for the SERF project in particular?'

3. STUDY AREA

The SERF project serves as a study area for this research. SERF stands for Strathearn Environs & Royal Forteviot. Strathearn is a district in Scotland (part of the council area Perth and Kinross). Forteviot is a village in Strathearn. Archaeological research has been conducted in Strathearn and in and around Forteviot in particular. Archaeologists from the University of Glasgow are involved in this long-term project that has been running since 2006. A 10m DEM, which represents the bare terrain, is available for the study area. The DTM has been created by Ordnance Survey based on their contour data. Two study periods where visibility is of importance have been used as study cases; the Neolithic period, researching the visibility from Neolithic ceremonial structures and the Iron Age, researching the visibility from hill forts.

Figure 1. Location of the SERF project (source map: ArcGIS Explorer topography basemap)

Neolithic
Cropmarks have revealed enclosures and ceremonial structures near the village Forteviot in Scotland. It is likely that the surrounding area of Forteviot was largely wooded in the Neolithic. Questions raised relating to visibility are: were the two Neolithic complexes intervisible? What was the visibility from a Neolithic complex?

Iron Age
The Iron Age in Scotland began around 700 BC and ended around 500 AC. Forts were built on hills and would have been built predominantly as centres of power in the Iron Age. Most of these forts stand on the northern slopes of the Ochils, with views across Strathearn. Questions raised relating to visibility are: what was the visibility from a fort? Which other hill forts were visible from a particular hill fort?

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4. CONDITIONS FOR THE TOOLS

Most archaeologists use GISs for basic analysis of gathered data. More sophisticated analysis tools, such as visibility tools, are being used in archaeology but nothing has been done on viewshed analysis for the SERF project. For most archaeologists, a GIS is one of the tools to explore past landscapes and study past human societies. Not all archaeologists use a GIS every day. A few conditions have been formulated in order to develop tools that are useful to archaeologists.
The main conditions are that the tools need to be user friendly and relatively easy to understand. Therefore straightforward tools with a tutorial need to be provided. Another condition is that the tools need to be integrated with ArcGIS 9.3 because this is used at the department.

5. METHODOLOGY: improving the DEM input

The DEM available only represents the terrain. Man-made structures and vegetation also have an influence on visibility however. The study area was not urban and only a few prominent man-made structures were present that will serve as viewpoints in the viewshed analysis. Man-made structures are therefore not considered to be incorporated. Vegetation, however, was present and archaeologists are interested in exploring the effects vegetation could have had on visibility.
The inability of incorporating vegetation in visibility analysis has been a limitation to model visibility accurately. In flat areas the correct modelling of vegetation is of high importance when modelling an area for visibility purposes, especially in wooded areas. In steeper areas both vegetation and topography are important (Ashton, 2010). Including vegetation in the DEM would contribute to obtain a visibility analysis as close as possible to reality. Vegetation can be considered as an accident of the terrain model. A vegetation elevation model can be created that can be added to the DEM. This method is mentioned in ArcGIS 9.3 Desktop Help and it is the easiest approach to incorporate vegetation. It basically means rasterising vegetation height information in case it is in vector format and correcting the raster DEM with vegetation heights by adding vegetation height values. This approach does not take the nature of the vegetation, its spatial distribution or density into account. It is a relative easy to use approach and this method has been used in several studies including Domingo-Santos et al. (2011)'s. The relative simple approach to incorporate vegetation has been applied to the SERF study area.

A few assumptions need to be taken into account when adding a vegetation elevation model to the DEM as mentioned by Domingo-Santos et al. (2011) and Hernández (2003). The main assumption is that vegetation must be dense enough to be impenetrable to sight because the possibility of seeing through vegetation is not taken into account.

The vegetation maps for the Iron Age were based on a generalised theory that many areas were deforested by this time period, or at least the woodlands were heavily managed. Therefore it is assumed that much of the improved land that can be seen now would not have large-scale forestry.

Only woodland has been modelled. Woodland would have had consisted of mixed species, such as oak, birch, alder, hazel and pine. Heights of these trees vary from 12 to 30 meters. Woodland would have been partly managed in the Iron Age and are therefore unlikely to have grown to the maximum height. An average height of 15 meters has been set.

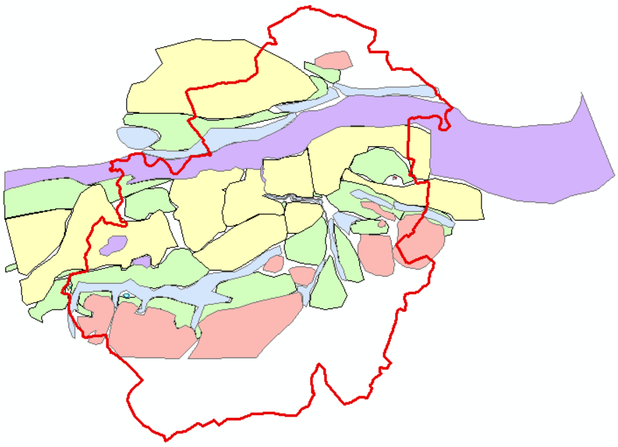

Figure 2. Iron Age vegetation layer. Yellow represents Scrubs & Grassland, green represents Open Woodland, blue represents Dense Woodland, rose represents Heather & Moor and purple represents Wetland & Bog.

A similar vegetation cover has been drawn for the Neolithic. The modelling of vegetation was rather difficult according to the archaeologists. There is little evidence of tree cover in certain areas. This is not only true for the SERF area but it is common in archaeology that the patterns of vegetation can never be reconstructed with any degree of precision, especially for prehistoric times (Llobera, 2007).

The developed tool converts the polygon vegetation cover into a raster, adds the height values of the raster

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to the DEM raster values and creates a DEM with vegetation incorporated. The corrected DEM can be used as input for visibility analysis.

6. METHODOLOGY: adjusting the viewshed output

The main criticism on visibility analysis with GIS has been with the binary output that does not reflect the complexities of reality (Chapman, 2006). Fisher (1992) tested a visibility tool in different GISs and came to the conclusion that the results differ. Visibility analysis is not precise, due to the sources of error listed before. The Boolean representation (binary output) is therefore not acceptable (Fisher, 1992). Alternative methods have been proposed including generating fuzzy viewsheds, where the degree of visibility is being calculated (Fisher, 1992; Fisher 1993) and probable viewsheds, where DEM uncertainty is taken into account (Llobera, 2007; Fisher, 1992, 1993, 1994, 1998).

6.1 Incorporating human constraints

Visibility is constrained by different factors such as optical physics, atmospheric effects and psychological and cultural factors (Ervin and Steinitz, 2003). Some of these effects are integrated in the tools in GIS software nowadays, such as atmospheric refraction (e.g. ArcGIS 9.3 has the option to check a box to use a 'refractivity coefficient' in some visibility tools). Distance is also a factor constraining visibility. Work has been done on so called fuzzy viewsheds by (among others) Fisher (1995) and Ogburn (2006). These fuzzy viewsheds take the effect of distance on visibility into account. The underlying theory behind these fuzzy viewsheds is that visibility decreases with distance from the viewpoint. The resulting viewshed gives an indication of the degree of visibility based on distance from the viewpoint(s) with a lower degree of visibility with a lower 'fuzzy membership'. Fisher's basic steps involved, that have been adopted for this research, are summed up below:

1. Creating a binary viewshed
2. Creating a distance buffer around the viewpoint(s)
3. Creating a distance decay buffer around the viewpoint(s) by applying a distance decay function (see figure 3) to the distance buffer
4. Combining the distance decay buffer with the binary viewshed

$$\mu\left(x_{ij}\right) = \frac{1}{1+\left(\frac{d-b1}{b2}\right)^2} \quad for\ d_{vp\rightarrow ij} \geq b1$$

$$\mu\left(x_{ij}\right) = 1\ for\ \ d_{vp\rightarrow ij} < b1$$

Figure 3. Fisher's distance decay function, where: μ = fuzzy membership, b1 = distance from viewpoint with good visibility (foreground), b2 = distance from viewpoint at which the visibility is 50%, $d_{vp\rightarrow ij}$ = distance from the viewpoint to column 1 and row j

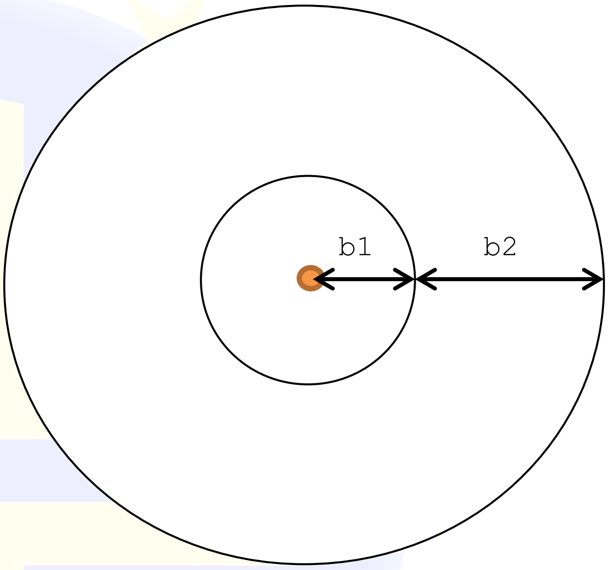

Figure 4. Distances b1 and b2. The outer circle represents the cross-over point where visibility is assumed to be 50% (source: Beaulieu (2007), figure 3)

6.2 Incorporating DEM uncertainty

Darnell at al. (2000) states that even a small amount of elevation can greatly affect derivative products. When using an ordinary viewshed tool, the accuracy of the DEM will not be taken into account. Incorporating DEM error will give a better representation of reality to the end-user. The uncertainty of DEMs have been discussed by multiple authors (among others Carlisle, 2002; Fisher, 1990, Darnell et al, 2007). Fisher (1992, 1993, 1994, 1995, 2006) discusses the importance of incorporating the uncertainty of DEMs for visibility analyses.

The accuracy of the DEM is normally described with the standard deviation or RMSE. The accuracy of the DEM can be incorporated in viewshed analysis by using a Monte Carlo approach where DEM values are randomly changed based on their error. The Monte Carlo simulation is based on the principle that the DEM is one of an infinite number of possible representations of reality (Carlisle, 2002). A number of realisations has to be chosen and for each of these realisations a binary viewshed will be calculated. A

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probable viewshed will be the result with values between 0 and the number of realisations. Values close to the value of the number of realisations will have a high probability of being visible. The basics steps involved are summed up below.

1. Determine the required number of realisations
2. Create random values for each cell in the DEM with a normal distribution with a mean of 0 and a standard deviation
3. Repeat creating random values for the DEM for the number of realisations
4. Perform viewshed analysis for each of the realisations
5. Generate a probable viewshed by summing the realisations

7. RESULTS AND DISCUSSION

Four enriched ArcGIS tools were created with the ArcGIS ModelBuilder; 'Incorporate Vegetation', 'Fuzzy Viewshed', 'Probable Viewshed' and 'Combine Fuzzy and Probable Viewsheds'. These tools have been used to analyse (inter)visibility of the ceremonial complexes in the Neolithic and the forts in the Iron Age.

7.1 Improving the DEM input

The main purpose of developing this tool was creating a possibility to explore the effects of vegetation on visibility. The approach used to accomplish this is a relative simple approach but it does allow the user to draw a vegetation model in the GIS and use this model as an input vegetation layer to add to the DEM. The number of visible cells from different features from the Iron Age and Neolithic has been analysed.

Fort viewpoint (offset 2m)	Number of visible cells: without vegetation	Number of visible cells: with vegetation	Number of visible cells: difference	Change of number of visible cells
Castle Law	792328	722403	69925	-9%
Dunknock	100466	81277	19189	-19%
Jackschairs Wood	384647	322696	61951	-16%
Law of Dumbuils	369421	280746	88675	-24%
Ben Effrey	278522	260064	18458	-7%
Rossie Law	1019303	963498	55805	-6%

Table 1. Effect of incorporating vegetation on the number of visible cell calculated by using the ArcGIS 9.3 Spatial Analyst 'Viewshed' tool (single viewpoint). Iron Age forts are the viewpoints.

Viewshed analyses with and without vegetation result in a different number of visible cells (see table 1). The number of visible cells is higher when viewshed analysis is done without vegetation incorporated than when viewshed analysis is done with vegetation incorporated. This result is not surprising because adding a vegetation layer increases the elevation height of the cells with the height of the vegetation cover (excluding the cells very near to the viewpoints, which are assumed to be cleared from vegetation). This will cause less cells to be visible. From the data shown in table 1, the incorporation of vegetation seems to have the biggest impact on the viewshed from the fort Law of Dumbuils, with 24% less cells visible. The fort Law of Dumbuils is surrounded by open woodland with a given screening height of 7.5m in the vegetation model. This vegetation, relatively close to the fort, blocks part of the view. Vegetation seems to have a lesser impact on the viewsheds from the forts Ben Effrey and Rossie Law. Ben Effrey and Rossie Law are also surrounded by woodland but these forts are situated on high hills with a steeper slope. Vegetation does not have a big influence on visibility here.

Similar analysis has been done for the Neolithic. The discussed results are the outcomes of viewshed analyses based on vegetation models. Other vegetation models might be more accurate and/or appropriate.

As can be concluded from the above, vegetation does have an influence on visibility. Archaeologists think that this tool, despite being based on a simple approach, is useful for exploring the effects that vegetation can have on visibility. Improvements are possible but it is a good starting point for the incorporation of vegetation.

7.2 Adjusting the viewshed output

Fuzzy viewsheds - *Incorporating human constraints*

Fuzzy viewsheds incorporate a human perception factor, human eyesight, that is causing uncertainty in viewshed analysis. Making this uncertainty factor visible to the user of viewshed analysis, gives an insight to the uncertainty caused by this factor.
The visibility of cultural objects, however, not only depends on the distance from the viewpoint and the size of the object but also on the colour of the background, the colour of the object and many other factors. These factors are also applicable to the cultural objects in the SERF area. For example, forts may have been made more or less visible by using distinctive colours or colours that camouflage the fort.

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Archaeologists think, speaking from experience, that the formula and values used to calculate visibility might be underestimating the limits of visibility for some situations. It still gives an indication of the degree of visibility depending on the distance from the viewpoint and it makes archaeologists aware that there is a limitation to human eyesight and that cells further away are less likely to be seen by a human viewer.

Probable viewsheds - *Incorporating DEM uncertainty*

Probable viewsheds incorporate the uncertainty of the DEM into viewshed analysis. Visualising the effect of the uncertainty of the DEM on visibility makes the user aware of this effect. GIS users are often not aware of or ignore the fact that a DEM has a certain degree of uncertainty and that this uncertainty can have a significant influence on their analyses.
Archaeologists find this tool useful because it makes them think about DEM uncertainty and it gives them an indication of where cells were highly likely to be visible and where cells were less likely to be visible, depending on the DEM error.
The standard deviation value used is an estimate of the real standard deviation because the real standard deviation is not reported by Ordnance Survey. The used standard deviation value to generate a probable viewshed will most likely be a good approximation of the actual standard deviation because the standard deviation of an area relatively close and comparable to the SERF area has been used. Therefore the resulting probable viewsheds will give a good insight in the probability of cells being visible depending on DEM uncertainty.

8. CONCLUSION AND FUTURE WORK

Viewsheds are the result of modelling. A model will always be a representation of reality, rather than reality itself. But therein also lies the strength of a model. It is possible to generate possible outcomes rather than realities. This is especially useful for historical modelling because one does not exactly know what the situation was like in the past.

"Consideration of the theoretical issues associated with GIS is a necessary precursor to wise use of the technology in archaeological analysis." – Wheatley and Gillings (2000).

The incorporation of vegetation and the visualisation of uncertainty does lead to better visibility analysis for landscape archaeology and the SERF project. The tools give a better insight in the factors influencing visibility and invite archaeologists to think through their questions about the significance and meaning of particular sites. The improved visibility tools could be used at various stages of archaeological research; it would not only be useful at the analysis stage but it could also be very useful in the planning stage to develop and refine research questions and to identify areas that might have been of great importance.
The relative simple approaches used for this research give a good indication of the influence of the named factors (vegetation, the distance between the observer and the target and the DEM error) and the usage results in a more critical approach to visibility analysis. More research on factors influencing visibility and how to integrate these in GIS could lead to an improvement of the existing tools. More evidence about past vegetation would help to refine the vegetation model. Field observations could help assess and improve the formula and values used to calculate the distance that can be seen by an observer. The determination of the exact DEM error would improve the probable viewsheds. For the SERF project it is recommended to carry out visibility analysis with accustomed tools because they help to evaluate the influence of factors on visibility which is not possible with ordinary visibility analyses provided by GISs.

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