An investigation of the potential of Structure from Motion photogrammetry for recording and analysing archaeological sites in County Roscommon

Project Report

for Roscommon Heritage Bursary

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Brian Shanahan, Hardiman Scholar, NUI Galway

Summary

This report is being submitted to the Heritage Office, towards the partial fulfilment of the conditions of my grant of a County Roscommon Heritage Research Bursary. The report contains a brief overview of the research which was supported by the bursary and issues arising from that research.

This research is part of my PhD research, which is being carried out in NUI Galway, is based on an investigation of landscape archaeology of historic settlement and community in County Roscommon. During the course of my research I have utilised a range of satellite and remote sensing data and historical information to investigate landscape change. I have augmented this data with additional fieldwork. One area of particular potential, which I have highlighted in my work, it the role of Structure from Motion Photogrammetry (SfM), which can be used to generate high resolution three dimensional records of buildings, structures and earthworks of archaeological interest.

I was particularly interested in investigating applicability of SfM techniques for documenting the many very well-preserved and highly important archaeological earthworks that are a characteristic component of the heritage of the predominantly pastoral County of Roscommon.

The full value of this bursary was used to purchase specialist aerial photographic digital imagery of archaeological sites in county Roscommon. I used these photographs to generate high-resolution 3D models of the earthworks. The datasets have allowed me to test and investigate the potential of the software and to refine methodologies for project design, image capture and pointcloud output.

My research has confirmed that Structure from Motion photogrammetry is a cost-effective and a suitable system for high resolution recording of a range of heritage site types in county Roscommon and that it works well in grassland environments, where potential lack of textural detail could have caused problems.

Aims of module

Capturing sites and landscapes

Basic information about target landscapes can be derived from a range of sources starting with existing archives and ordnance survey GIS map layers. In many instances a higher level of detail will be necessary. This requires additional survey. Traditionally, topographic surveys have been undertaken using theodolites, total stations, and more recently using differential GPS systems. They are all expensive to implement because they require investment in equipment and in fieldwork time.

Photogrammetry, which is a sensor based approach, was traditionally used in combination with aerial photography for both large scale topographic mapping and with terrestrial photography for recording complex building structures. Once again, it required expensive specialist equipment. While, results could be impressive they were predicated on using a tight network of control points and specially calibrated equipment.

Over the last decade laser scanners have been employed to undertake high resolution surveys of heritage buildings and archaeological sites. This technology has been used at a number of heritage sites in County Roscommon, such as the Cistercian abbey, Boyle, the Dominican Priory at Tulsk and series of sites and excavations carried out by the Discovery Programme at Tulsk and Carns between 2006 and 2011. Laser instruments have also been mounted on light aircraft and used to capture high resolution records of the topography of large areas of landscape. Such Lidar data is a highly effective resource for modelling archaeological sites in their landscape context. However, the major focus of these surveys is large-scale topography. Consequently, while the resolution of such surveys is generally suitable for archaeological prospection and the identification of new sites, it is not always suitable for high-resolution topographical modelling and intensive analysis of individual sites. Although some high-resolution Lidar datasets exist (such as the Ordnance Survey pilot survey of the Rathcroghan complex) they are still relatively rare. That said, the flymap system, where the instruments are mounted on a helicopter, has been used to great effect in recording the archaeological sites of Tara and Newtown Jerpoint at sub-metre resolution.

However, these systems are incredibly costly to commission and they remain beyond the budget of most researchers and local heritage interest groups. Luckily, recent advances in fabrication of Unmanned Aerial Vehicles (UAVs) and developments in computer vision based photogrammetry hold out another option for surveying discrete archaeological sites and their environs. The methodology that I outline below is based on both elements and it may prove to be a more affordable way to carry out cost-effective high-resolution surveys of archaeological sites.

The report is based on investigations that I carried out at two sites: the holy well at Oran and the ritual enclosure at Rathra, near Castlerea.

Basic concepts

Photogrammetry

Photogrammetry is an old method, which has been given a new lease of life due to advances in computer vision software. Detailed pointclouds of buildings and earthworks can be generated using photogrammetry. The development of Structure from Motion (SFM) techniques allied with advances in computer processing and visualisation hardware means that it is possible to generate detailed topographic models of buildings and archaeological earthwork sites. This report aims to review cost-effective software which may be used to record archaeological sites, to edit the resulting survey data and to present it in a variety of formats for analysis, illustration and general dissemination to the public. I will provide a brief overview of a suggested workflow and suggest future outcomes and applications for this approach.

Photogrammetry and Structure from Motion

Photogrammetry is the "art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena".[1] Traditional methods are based on the use of stereo imagery. Stereo vision uses parallax between two images to create 3D models.[2] By contrast Structure from Motion (SfM) uses a single moving camera where the movement between sequential images creates enough parallax to infer 3D data.[3] Traditional methods were costly because they required specially calibrated stereo cameras and expensive photogrammetry suites. More recently the Structure from Motion (SfM) technique has been successfully applied to the survey of buildings and structures and for generating accurate aerial surveys and Digital Surface Models (DSMs). The advantage of this method is that it is cost effective, it does not require specialist optical equipment and there is a wide range of commercial and freely available software to process the images.

Structure from Motion: an affordable solution for recording buildings and landscapes?

One notable advance in recent years is the development of software which can generate pointclouds from unstructured photography collections. New algorithms and increased processing power has allowed the use of previously unsuitable images. Computer processors can calculate the position of cameras and other factors based on a comparison of a series of photographs of a particular scene or object. Previously these had to be precisely known factors, which required expensive instrumentation and telemetry. Precise camera calibration is less crucial than in the past and much of this information can be estimated/calculated through a comparison of a sequence of pairs of images.

The major breakthrough was encapsulated by the Photo Tourism Project which sought to use unstructured photo collections gathered from the internet to reconstruct monuments and tourist sites.[4] That research was adopted by Microsoft's Photosynth.[5] It is an online system that stitches together multiple photographs of a site to create a three dimensional virtual tour.

These concepts were then utilised in Bundler which is a command line system that uses the concept of Structure from Motion. Bundler uses a set of images and produces a 3D reconstruction of the camera locations and the basic scene geometry in the form of point cloud data. This output, particularly the solved camera locations, can form the basis for dense point cloud computation using further specialist algorithms such as CMVS or PMVS2.

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[1] 'What Photogrammetric Engineering and Remote Sensing is', in *Journal of Photogrammetric Engineering and Remote Sensing,* **XLVI:10** p.1249 (American Society of Photogrammetry Hanover, Pa., 1980)

[2] Koenderink, J. and Van Doorn, A., 1991. Affine Structure from Motion. Journal of the Optical Society of America A 8(2), pp. 377–385.

[3] Brance P. Hudzietz and Srikanth Saripalli 'An experimental evaluation of 3D terrain mapping with an autonomous helicopter' in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVIII-1/C22 UAV-g 2011, Conference on Unmanned Aerial Vehicle in Geomatics, Zurich, Switzerland pp 1-6 .p. 1

[4] Noah Snavely, Steven M. Seitz, Richard Szeliski 'Modeling the World from Internet Photo Collections' in *International Journal of Computer Vision*, vol. 80, No. 2, (2008) pp 189-210

[5] http://photosynth.net/

Clustering Views for Multi-View Stereo (CMVS).

'CMVS takes the output of structure-from-motion (SfM) software as input, then decomposes the input images into a set of image clusters of manageable size. An MVS software can be used to process each cluster independently and in parallel, where the union of reconstructions from all the clusters should not miss any details that can be otherwise obtained from the whole image set'.

'MULTI-view stereo (MVS) matching and reconstruction is a key ingredient in the automated acquisition of geometric object and scene models from multiple photographs or video clips, a process known as image-based modeling or 3D photography'[6].

Patch-based Multi-view Stereo Software (PMVS)

'PMVS is a multi-view stereo software that takes a set of images and camera parameters, then reconstructs 3D structure of an object or a scene visible in the images. Only rigid structure is reconstructed, in other words, the software automatically ignores non-rigid objects such as pedestrians in front of a building. The software outputs a set of oriented points instead of a polygonal (or a mesh) model, where both the 3D coordinate and the surface normal are estimated at each oriented point'.

An alternative pipeline would be to use cloud-based software such as Autodesk 123D Catch or Microsoft Photosynth (which was developed from bundler) instead of bundler (which appears to have problems running on a 64bit system). These packages will calculate the basic camera and object geometry which can then be used as the basis for a CMVS or PMVS analysis to create a dense point cloud.

I chose the Visual SfM software. It was developed by Changchang Wu.[7] It is free for personal, non-profit, or academic use.[8] It has a graphic user interface (GUI) and command line options, which can be more suitable for large-scale batch processing of imagery. It is effectively an alternative to Bundler, while it allows for dense point cloud computation because the CMVS and PMVS algorithms can be inserted into the GUI.

Control

Traditionally, a network of control points, observed using a theodolite, total station or a differential GPS unit forms the basis of any survey. A typical control network, suitable for photogrammetry would consist of high-visibility targets that will be clearly visible in the photographs and which are laid out prior to image capture. Traditional photogrammetry utilises control points within the transformation. However, VisualSfM does not use control points during the solving exercise, although they can be used to undertake a basic georeferencing transformation after the model has

[6] Yasutaka Furukawa and Jean Ponce, 'Accurate, Dense and Robust Multi-View Stereopsis', in *IEEE Transactions on Pattern Analysis and Machine Intelligence* Vol. 32, No. 8, August 2010 pp 1-14
[7] Changchang Wu, "Towards Linear-time Incremental Structure From Motion", 3DV 2013; Changchang Wu, "VisualSFM: A Visual Structure from Motion System" http://ccwu.me/vsfm/
[8] http://ccwu.me/vsfm/README

been generated. I used a series of targets of known size in order to rescale the models, although their locations were not logged so the resulting models are not georeferenced. It should be possible to provide some level of georeferencing by extracting coordinates from existing maps. The pointcloud is also detailed enough to identify distinctive features that can be identified in the field and logged in the future using a differential GPS and so allow for a retrospective georeferencing.

Camera Calibration

The camera lenses were not calibrated. Visual SfM calculates the focal length of the images using the EXIF data appended to each digital photograph. Visual Sfm then performs a basic radial undistort function on the input imagery.

Image capture

Photographs are taken using a camera set to a fixed focal length. Unlike in traditional photogrammetry, the camera's position is unknown at this stage (ie. it is not tied to a particular baseline or coordinate system). A network of overlapping photographs is taken of the surface to be modelled. Every part of that surface must feature in at least three of the photographs and preferably more. It makes sense to plan for redundancy (take too many photographs and from additional positions). It is best to avoid taking photographs where the subject is viewed in very tight or oblique angles because they will magnify the effect of lense distortion.

Camera mounting systems

This report is based on an investigation of two archaeological sites. The holy well at Oran was documented using a camera mounted on a pole. The ritual enclosure at Rathra was documented using a camera mounted on an unmanned aerial drone.

Pole-mounted camera

The camera was mounted on a telescopic pole which allowed for oblique and near vertical image capture from a height of between three and five metres. The shutter was triggered remotely after the camera was placed in position.

Aerial drone

The Irish Aviation Authority has stringent conditions governing the flying of UAVs within Irish airspace. It requires public liability insurance and specialist aerial work permits. Consequently, I commissioned Airview Ltd. to undertake specialist aerial photography that I required for my research. AirView operate under the SkyTec UAS Ireland Aerial Work Permit (AWP). Airview is also based in county Roscommon and is supported by the Roscommon Leader Partnership. The aerial platform employed was a *DJI S800 HYBRID Unmanned Aerial Vehicle (AUV).* This is a high-end aerial photography drone, which can employ Global Positioning System (GPS) hold. It has a Zenmuse gimbal (to hold the camera steady) which provides a stable and vibration free platform for high-end aerial photography. The aerial photographs were captured using a Sony Nex-7 camera. A fixed focal length (16mm) was selected for all photography. The drone can maintain an altitude of up to 120m. The image capture at Rathra was done at 90m and 75m altitudes.

Data processing

Hardware

I used a Lenovo ideapad, with an Intel Core i3, 8mb RAM and an Nvidia Geforce with CUDA graphics card GeForce GT 520M. I used a windows 7 64 bit operating system.

Generation of 3D pointcloud and resulting models

1. Acquisition of photographs of site or object

2. Production of a sparse point cloud, calculation and reconstruction of camera locations using Visual SfM.

3. Production of a dense point cloud based on previously calculated camera locations using Yasutaka Furukawa's CMVS/PMVS, within Visual SfM GUI.

4. Generation of dense pointcloud output

4. Export of camera and pointcloud data in PLY file formats for post-processing of pointcloud in specialist software (Meshlab)

5. Export to GIS or to 3D modelling software for presentation and analysis

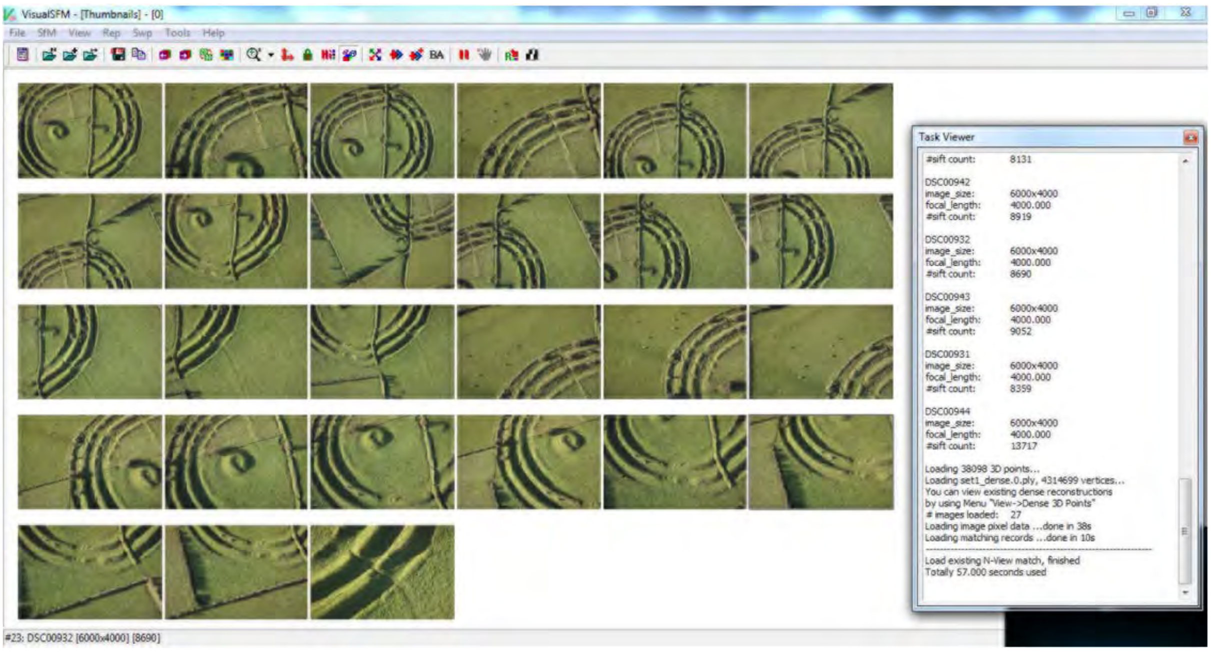

Fig. 1 Sequence of aerial photographs input to VisualSfM

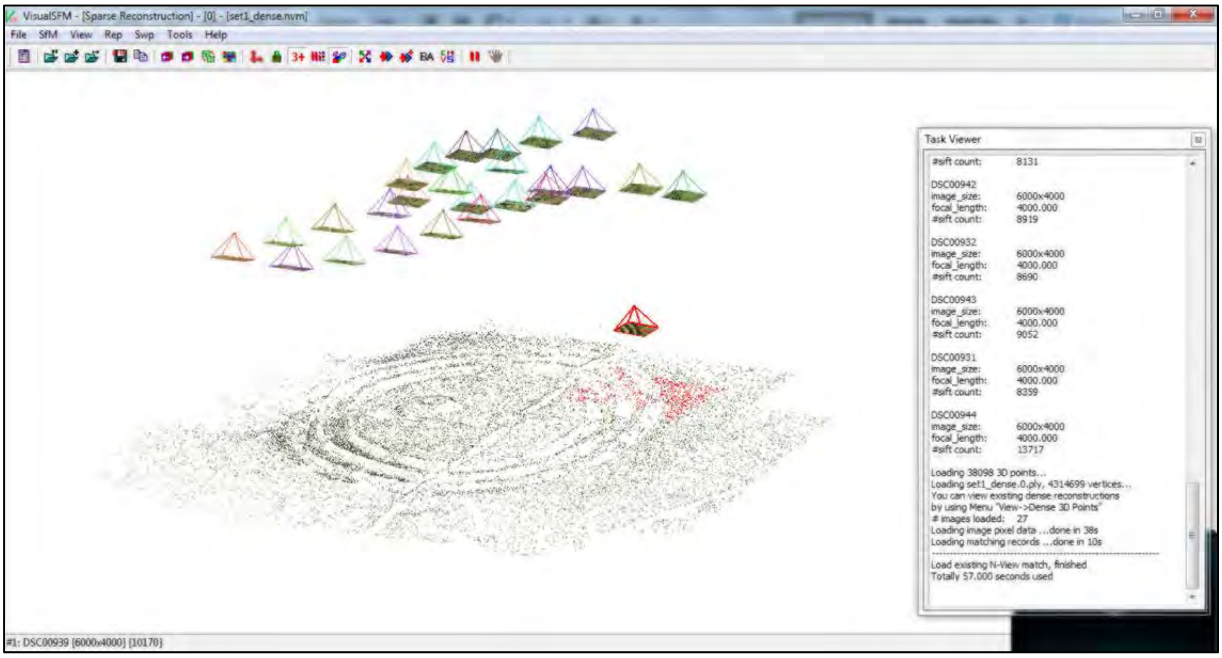

Fig. 2 View of sparse poincloud output with the solved camera positions

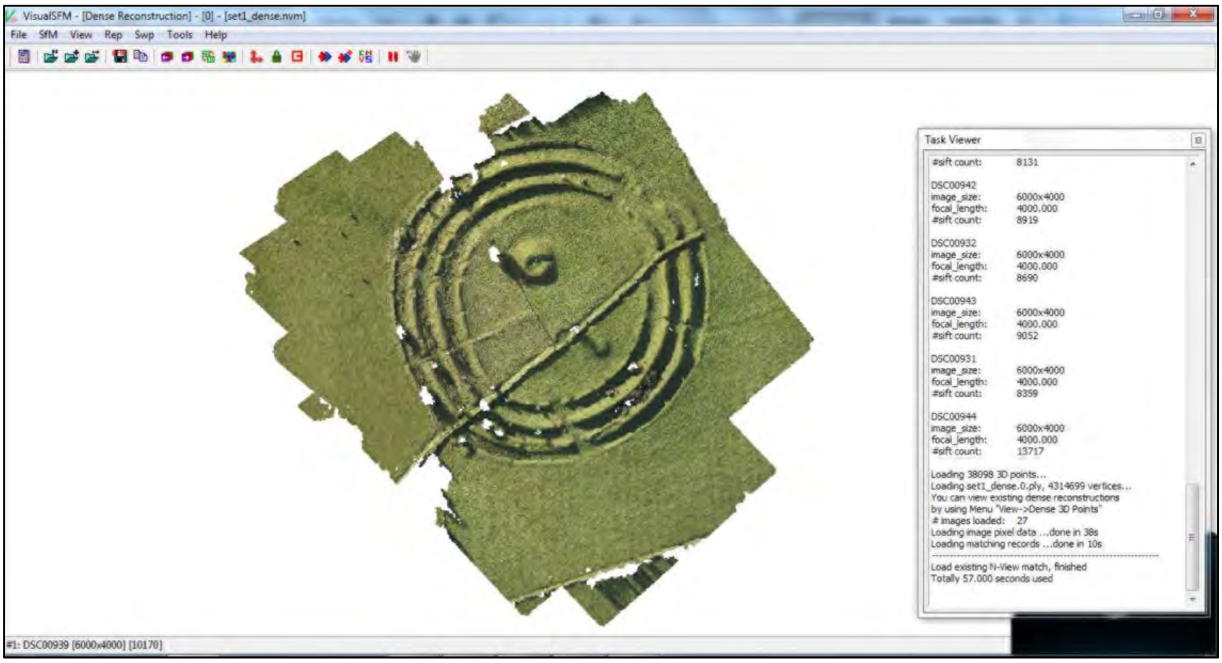

Fig. 3 View of dense pointcloud output. There are 4.3 million individual points in this model (note that each single point has a RGB value). This is **not** a photograph

Editing and manipulating pointcloud data

The resulting point cloud data can then be previewed and edited in specialist software. I chose to use *Meshlab*, which is a very functional and powerful free-to-use option.[9] It is for processing and editing of unstructured 3D triangular meshes and it was developed by the Computer Science Department in the University of Pisa. Point data can be edited and there are many options for

[9] http://meshlab.sourceforge.net/

generating mesh surfaces. The basic geometry of a terrain model or of a building can then be exported in a variety of formats. Basic functions which may be performed include scaling and georeferencing so that the data situated in real world coordinates and comparisons can be made with other surveys. Unstructured pointclouds may be edited to remove stray, random or duplicate points.

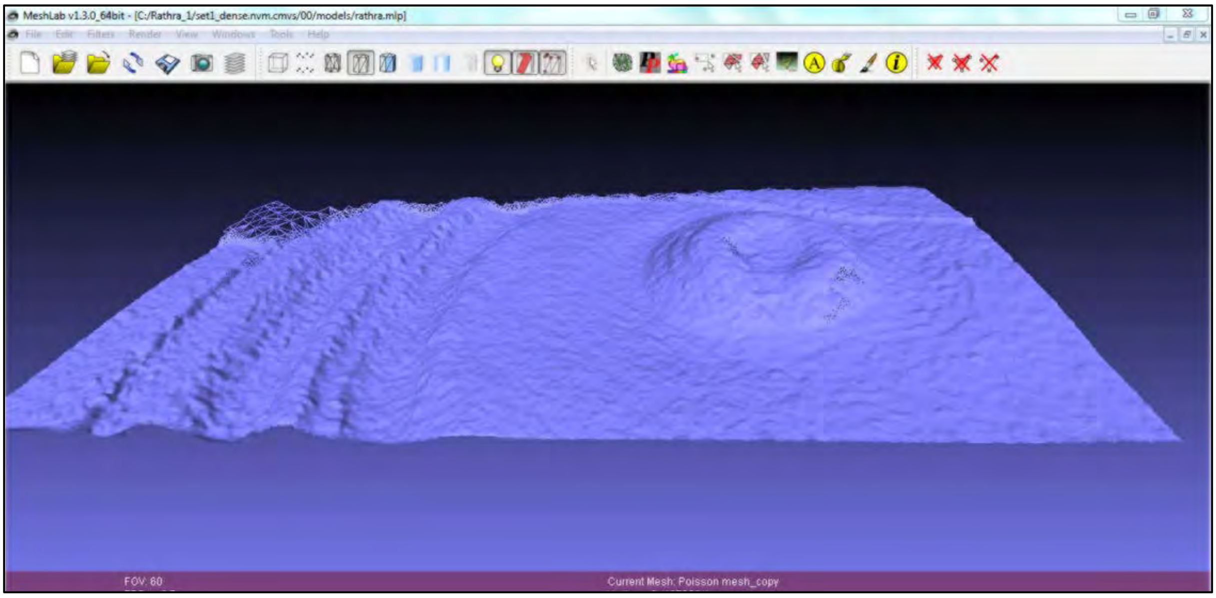

Fig. 4 View of mesh surface modelled from pointcloud data

Case studies

I have provided a brief overview of two case studies that I have used to investigate the potential of SfM photogrammetry and the mesh editing capabilities of meshlab.

Oran holy well

The well (RO0340010) of Uaran Garad was famed as far back as the 7th century AD. It is part of a much bigger religious complex.[10] The modern graveyard (RO0034-002), on the other side of the road contains the remains of post medieval vaults, a late medieval church (RO0034-001) and a round tower (RO0034-003), which is probably of eleventh or twelfth century date. The fields surrounding the graveyard contain the remains of earthworks indicating that the church site was once very extensive and substantial place. The well site could be expected to reflect traces at least one and a half millennia or more of communal devotional and ritual activity.

The well is defined by a masonry wall. It exits into a narrow channel which has been defined by stones and there are steps on either side which lead down to the water. The water gathers in a smaller rectangular pool before draining-off into a hollow. There are traces of wall footings that mark the curtilage of a small enclosure that at some stage defined the immediate precinct of the well.

[10] (Archaeological Survey of Ireland Record Details) All entries by Michael Moore uploaded 24th August 2010 on www.archeology.ie

The holy well was the focus of later activity too. A memorial stone (RO034-080012) set into the masonry basin at the source of the well commemorates Fr. William Hanley who renovated the well in 1687. It seems likely that the masonry remains around the well substantially reflect this phase of re-edification. The remains of the socket of a finial cross (RO034-0080013) are recorded in the bank along the roadside and another stone cross (RO034-0009) set on a drystone plinth is inscribed with the date 1729. More recent elements include a statue of Saint Patrick and Statue of the Blessed Virgin, which is set on a drystone wall south of the main well.

558 photographs were taken of the holy well and its environs. A sparse pointcloud consisting of 180,000 points was generated after two days processing. My computer was not powerful enough to complete a dense process. The resulting data was model was remarkably good.

One advantage of this method is that it was possible to take a sequence of connecting photographs of the ground surface but also of the stone walls and revetments. This resulted in a relatively comprehensive record of both the topography and of the positive or horizontal features too.

The resulting point clouds have the appearance of the output of a low resolution laser scan, but they differ in a number of ways. When using laser scanning the point cloud output is captured and rendered in real time. By contrast, the point clouds derived through SfM photogrammetry are the result of off-site post-processing. As a result, it is more difficult to be sure that there has been sufficient data capture. Limitations of the survey were due to the relatively low camera elevation (4-5m above ground level). This made it necessary to take a large number of photographs to ensure there was sufficient overlap. The resulting dataset was very large (over 500 images) and this led to an exponential growth in processing time and resources. Managing such large datasets also increases the risk that areas of overlap may be missed because it is difficult to plan such a detailed survey manually and to review the resulting images. The surveyor must await the outcome of the SfM process in order to review the resulting point could so as to be entirely sure that the image capture was successful.

The modelling process also raised a few more issues. Clarity is required as to whether a survey is intended to generate a topographic model or a three dimensional record of all the material remains. Processing strategies can vary. For example, the basic shape of the statue of St. Patrick emerged in the sparse model of the site but a detailed model could only be created using a densely overlapping series of images processed specifically to derive a model of the statue. In such instances it would be more prudent to record and model individual elements separately and to combine them later using networks of control points established using a total station.

One way to streamline the survey of such as site would be to take photographs at a higher elevation. This can be achieved using more complex pole rigs combined with remote viewing and triggering mechanisms or by using an aerial drone. Higher altitude would result in greater coverage per image leading to the need take fewer photographs. Greater distance would also mean that all or most of the scene could be included within the images improving the image matching. This would reduce processing time and it would also reduce the likelihood of error due to a reduction in the number of overlapping images.

Fig. 5   Example of photograph of holy at Oran taken with a camera mounted on a telescopic pole.

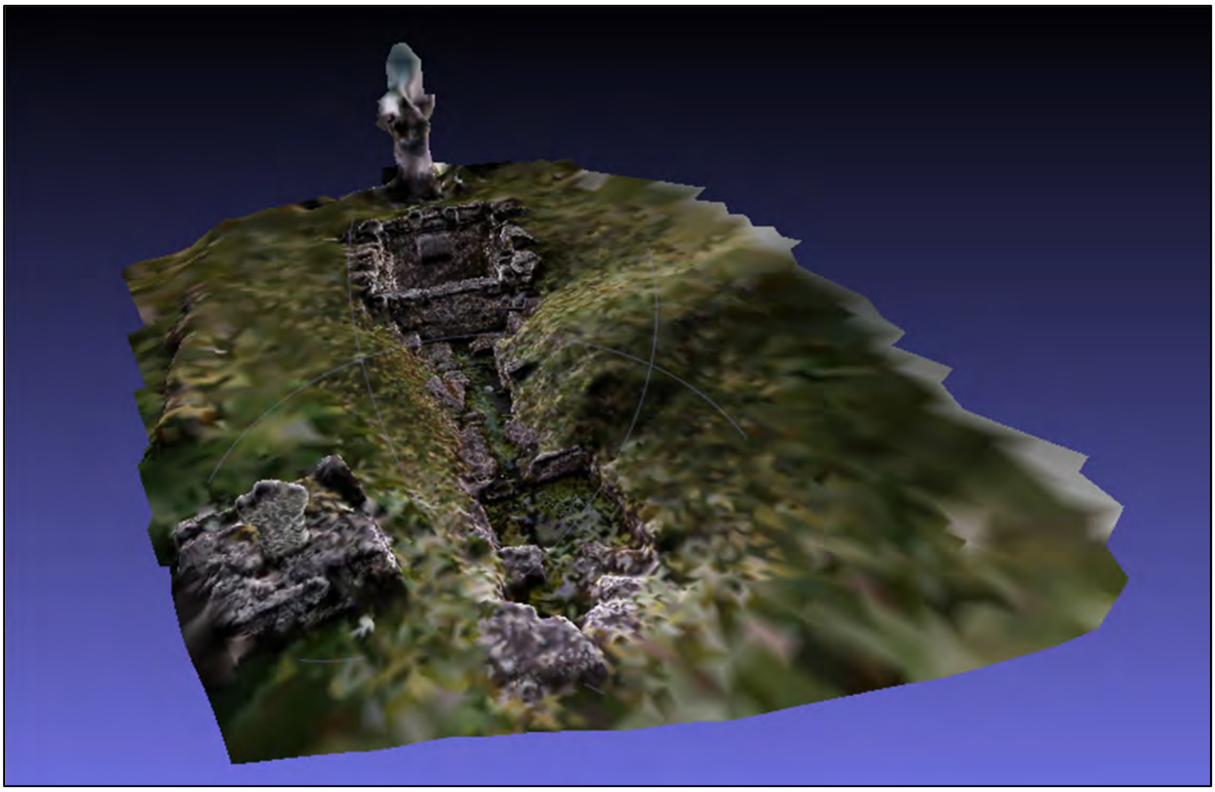

Fig. 6   Mesh surface with RGB values sampled from the original pointcloud

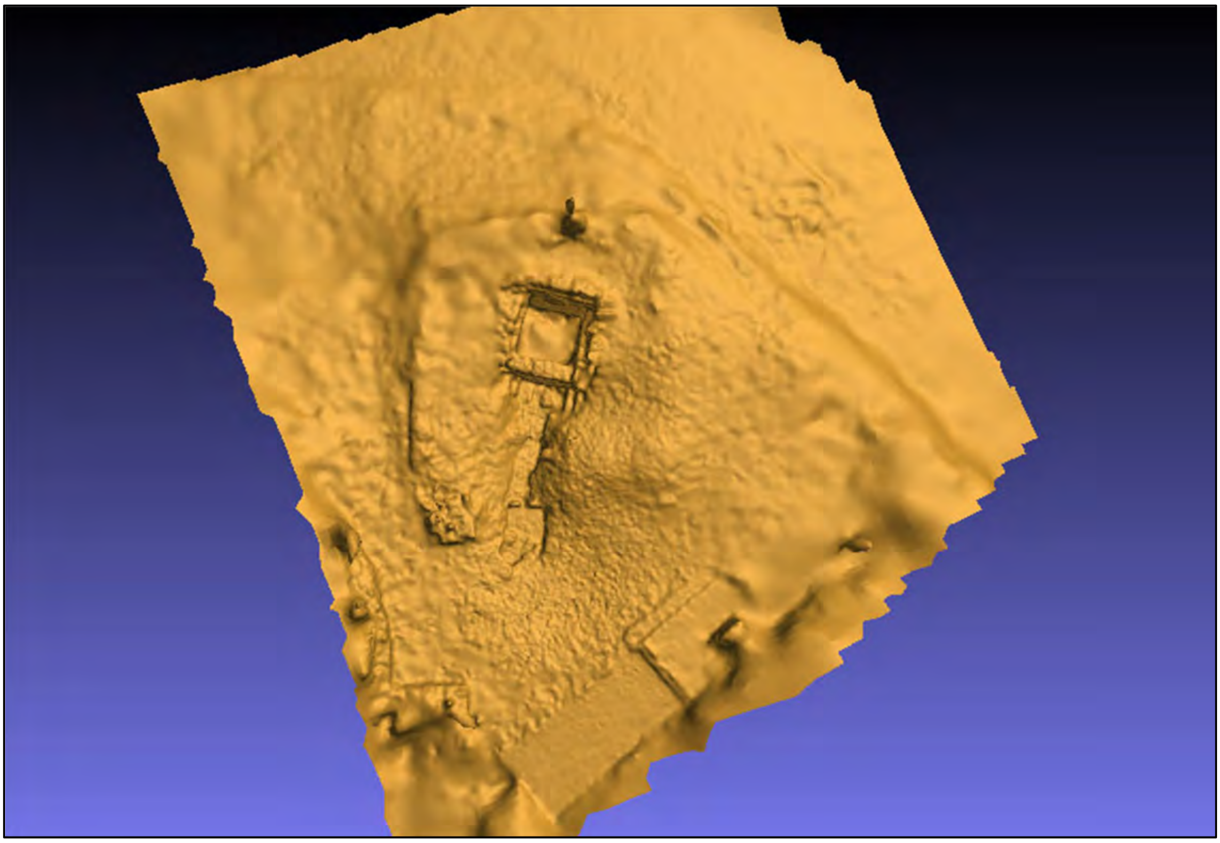

Fig. 7   Aerial view of mesh surface rendered with a 'lattice' shader so that elements of the topography are more clearly visible

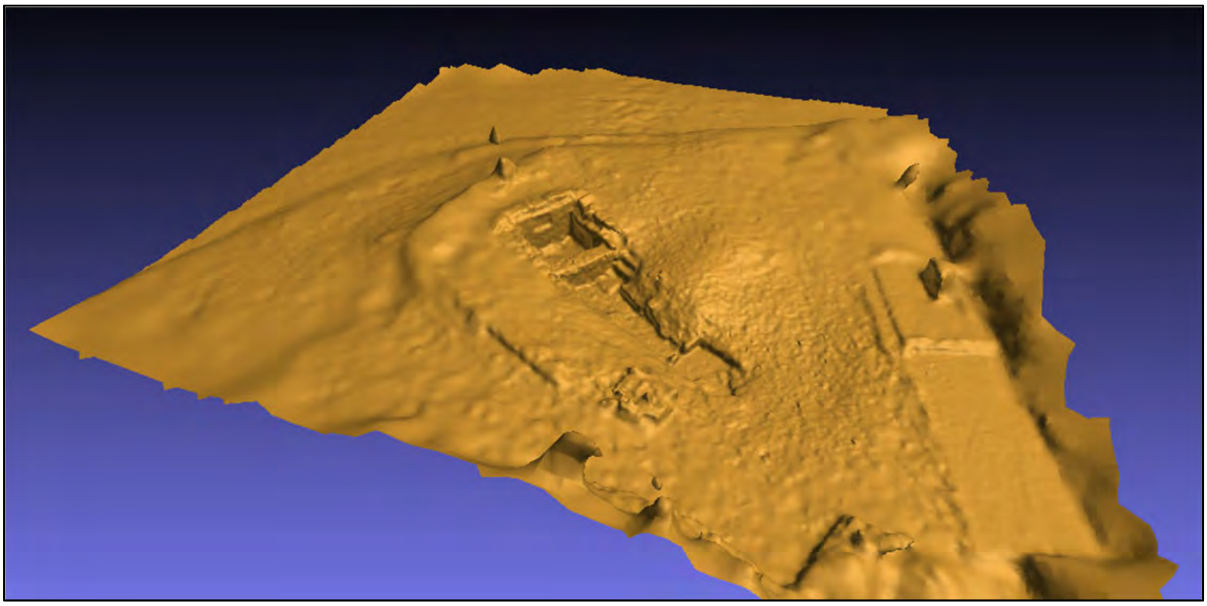

Fig. 8   Oblique view of mesh surface rendered with a 'lattice' shader

The 3D views of the holy well also clearly show that the site is a multi-period structure. Although the well precinct is now basically unenclosed, it was previously defined by a stone wall and an earthen bank at some time in the past.

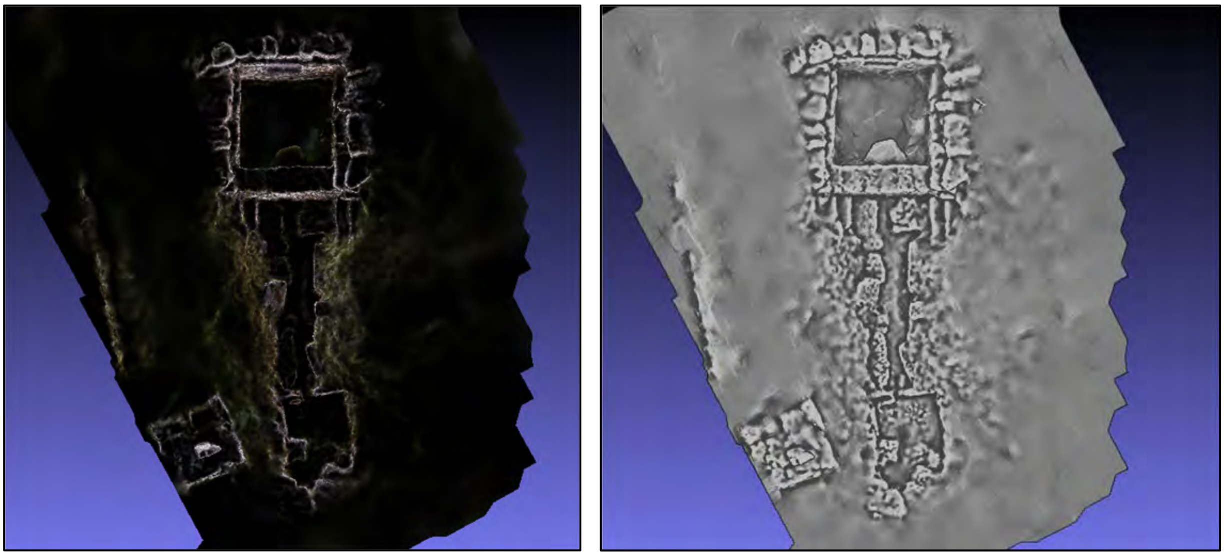

Fig. 9 Contrasting visualisations of the main structural elements at the holy well

Rathra enclosure

The enclosure at Rathra is an excellent example of a rare multi-vallate type. It is significant because it is one of only a few quadrivallate enclosures that are known about on the island. The multi vallate enclosure is part of a more extensive ritual landscape which is focussed on an east west running ridge, located about 5km to the east of Castlerea and roughly 4km to the north of Ballintober. It is marks the margin between the higher land running north and east towards Rathcroghan and the lower lands around the watersheds of the Suck and Termon rivers, to the west and south. The morphology and range of archaeological monuments situated along this stretch of high ground suggest that it was memorialised as a significant burial place since the early Bronze Age and that it was the venue for major assemblies during the Bronze Age and the Iron Age.

The site is defined as a 'Ceremonial enclosure' (RO027-012001). Two barrows are situated within the enclosure. One is a bowl barrow (RO027-012002) and the other is a mound barrow (RO027-012003), which apparently once had the stump of a standing stone (RO027-012004).[11] A pit (c.4m diameter and 1m deep) has a stone exposed at its base and could be the remains of a souterrain (RO027-012005). If so, this suggests that the site was occupied into the early medieval period (*c.*AD450-1100).

A hillfort is located east of the multi-vallate enclosure (RO027-014001). Two ring barrows (RO027-014003 & RO027-14004) are on the line of the perimeter of the hillfort, while a bowl barrow (RO027-014002) is located SW of the centre of the hillfort. The enclosure measures approximately 200m E-W and 150m N-S. It is defined by a very low bank (c.6m wide) and by a low scarp on its eastern side. It has been truncated by the modern road and by later field boundaries.

A ringfort (RO27-011) is located a short distance to the west of the multi-vallate enclosure.

[11] (Archaeological survey of Ireland, Record details) on http://www.archaeology.ie. Compiled by Michael Moore and posted 24th August 2010

Fig. 10 Views of Rathra enclosure taken with aerial drone

I commissioned aerial photography at the site to provide a range of high quality views of the earthwork and to gather a dataset that could be used to experiment with SfM photogrammetry of a complex earthwork. This will allow for additional visualisations of the site as a basis for analysis and to provide a virtual record of the site, which can be accessed by others. They will facilitate a more detailed discussion of the site.

I decided that a high camera platform was necessary to model such a large earthwork site. I had failed in previous attempts to model complex earthworks using cameras mounted from low elevations. It required too many photographs to cover a limited area. The presence of many extraneous features and horizon lines within oblique imagery also distracted from the surface which I wanted to model. From a practical viewpoint and based on my experience of the Oran site, I decided that it made sense to maximise elevation so as to reduce the number of images required for the SfM and dense point cloud processing. This would reduce unnecessary processing time and I could always add additional vertical shots to the process later if I deemed it necessary to generate a more detailed model.

Fig. 11 Screencap of poincloud of Rathra

Output

68 aerial photographs and a selection of oblique contextual photographs were taken using a camera mounted on the UAV. A preliminary model was generated based on a selection of 26 photographs. This took about five to six hours processing time. The resulting pointcloud consisted of 4.3 million individual points. The resolution is relatively even. There are fewer points and a few black spots in shadow areas, where a lack of textural variation prevented feature matching. In general, however, the point cloud resolution represents a sample every couple of centimetres. It should be possible to generate an even more detailed model using the larger dataset and it may also be possible to extract more information from the shadow areas by pre-processing the photographs prior to the SfM phase.

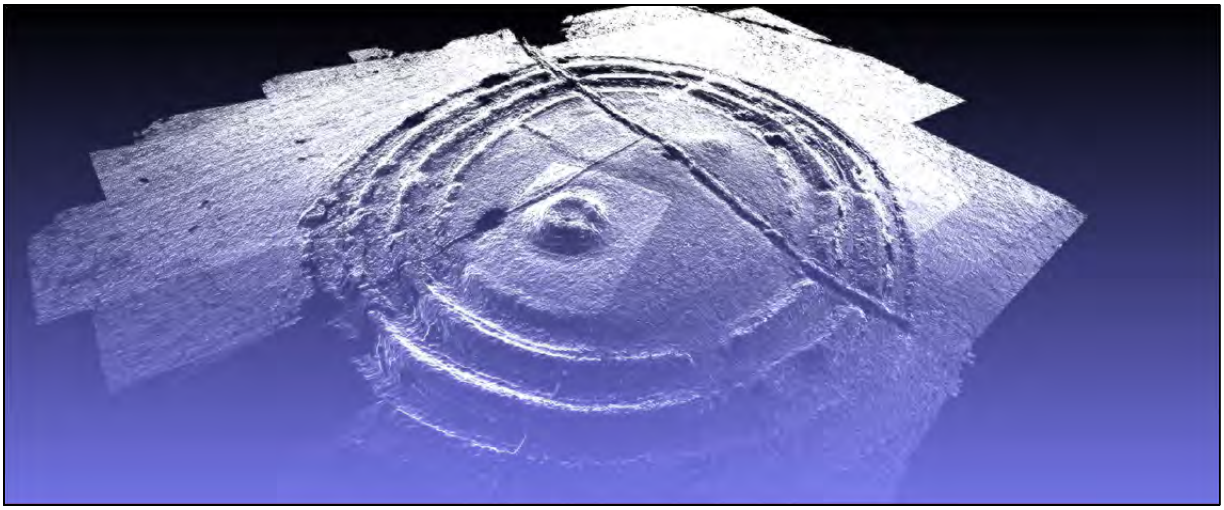

Fig. 12 Alternative visualisation of Rathra earthworks

The output resolution is highly detailed and is ideal for highly localised topographic analysis of the site. The next step will be to decimate the data and process it for export to a Geographical Information Systems GIS package.

Data visualisation

The real advantage of point cloud output is that it is really just the first step. The poincloud may be converted into meshes, which are continuous surfaces. Textures may also be applied. For example colour (RGB) values derived from point clouds or from the original photographs can be used to apply a photorealistic appearance. Other filters can accentual textures and shadows.

Output of the holy well at Oran facilitated a clearer overview of a relatively complex site that is made up of earthwork and masonry components. Already, preliminary visualisation has revealed that the well was once surrounded by a walled precinct. When the point cloud is georeferenced and imported into GIS it will be possibly to generate a topographic map of the site.

The data from the Rathra survey will also form an ideal basis to import into 3D modelling and gaming software in order to investigate the potential of such platforms for creating virtual tours or investigations of heritage earthworks.

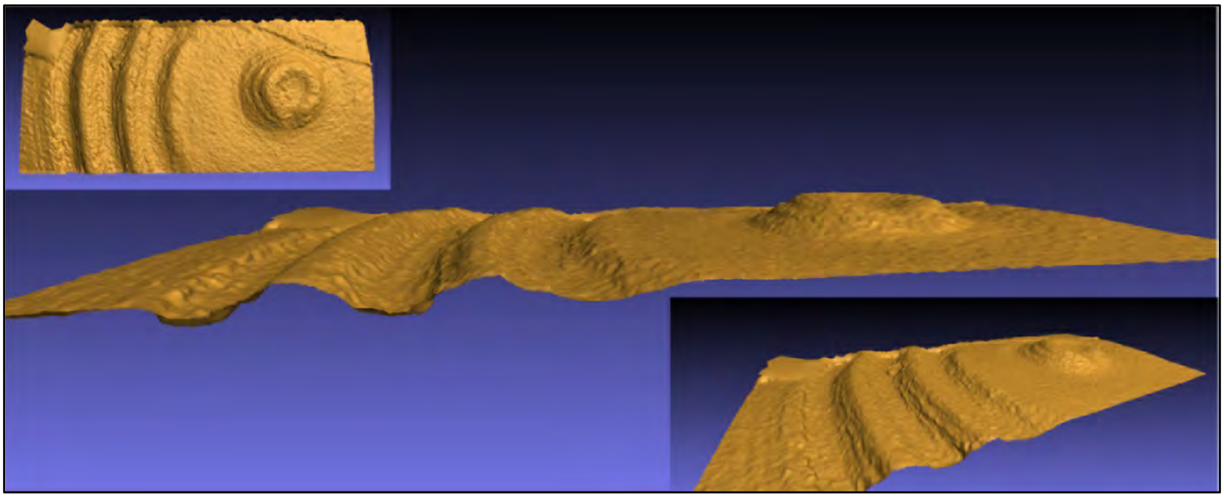

Fig. 13 Sample of the mesh surface derived from pointcloud showing enclosing earthworks and the larger mound barrow at Rathra. This data can also be used to generate profiles through earthworks

Assessment of the methodology

Structure from Motion is cost effective. Basic requirements are a decent consumer grade digital camera and a computer with a good processor and RAM, running a Linux or Windows 7 Operating system. The system is flexible and the basic equipment is highly portable and it can be implemented on a variety of scales. Although ideally a control network of targets should be surveyed using a total station other objects of known scale (such as ranging poles or rulers) do allow for a basic rescaling of the resulting model, along two axes (although not the Z axis).

The resulting output from both Oran and Rathra could not be achievable using more traditional methods. The data is of a higher resolution and it is more versatile. By way of comparison, a topographic survey of Relignaree (a smaller site) took two professional surveyors over a week to accomplish. The resulting data represented a sample interval of between 1-5m, which is considerably less detailed than Rathra. Furthermore, decisions about what to include or not to include leave open the possibility that minor features can be missed entirely. Additional products, lacking in traditional survey methods but available using the SfM approach include orthoimagery.

The method is generally less accurate and less reliable than laser scanning and Lidar. The resulting point clouds tend to be of a lower resolution and they do not have additional information such as reflectance values embedded. Therefore laser scanning, or more tightly controlled photogrammetry, remain the most appropriate options for conservation management. However the prohibitive costs of laser scanners – in terms of capital expenditure and the requirement to use a highly-skilled survey team in the field means that the flexibility offered by SfM photogrammetry could be deemed more appropriate in some other circumstances, such as the roll-out of community archaeology initiatives. Image capture can be undertaken by relatively inexperienced fieldworkers with clear guidance.

Processing could then be undertaken by trained or experienced personnel with access to a suitable workstation.

The software that I have used is licensed for research use rather than for commercial operation. However, there are a number of commercial alternatives available for purchase.

Research outcomes

The bursary facilitated data gathering for my research. The data acquired has allowed me to investigate and to demonstrate the potential of photogrammetric processes for recording a range of heritage sites in county Roscommon.

I have investigated image capture and data processing of a series of site types and under a range of conditions. I will now be able to develop a tighter methodology which can be more effectively implemented when recording heritage sites.

I have demonstrated that this approach is effective when dealing with heritage sites in County Roscommon.

The material will be used to form the basis of one or more articles in suitable publications aimed at local and national audiences. They could include the Journal of the County Roscommon archaeological and historical society but I will also investigate the possibility of national impact, such as through, for example, Archaeology Ireland.

I have generated a series of 3D virtual records of archaeological sites during the course of my research in County Roscommon. One next step will be to investigate ways to make this data available to a wider audience. I will investigate ways to use the data to

1) Publish using select images
2) Publish 3D models online
3) Ultimately make the data available in downloadable format.

Acknowledgements

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