

# Surveying Knowlton Church and Henge using 3D Laser Scanning

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## Abstract

The use of terrestrial 3D laser scanning devices is increasing in all surveying areas including topographic surveys and building recording. However, a dichotomy exists in that the deliverables produced by such “surface-rich” acquisition devices generally tend to be surface-less clouds of points.

This article discusses the use of a Callidus 3D laser scanner on a multi-phase site at Knowlton, Dorset. This site originally featured a Neolithic “henge” earthwork (circular bank and ditch) with two “causeways” crossing the ditch. Later, in mediaeval times, a church was built in the centre of the henge to effectively “Christianise” the pagan monument.

The purpose of the exercise was to acquire not only a complete dataset of the earthwork for topographical analysis, but also a high-resolution scan of the church fabric itself.



*Figure 1: Knowlton Church and Henge. The Callidus 3D laser scanner can be seen to the left edge of the photograph.*

## Historical and Archaeological Background

Knowlton Henge as we know it today is in fact part of a larger group of henges, which date from the Late Neolithic (approx. 3000-2400BCE). The Church Henge, the subject of this study, is the best preserved, with substantial earthworks surviving to this day. It is an oval enclosure, roughly 107m by 98m with a ditch surrounded by a bank. The bank is up to 1.8m high, and the ditch up to 11m wide and up to 1.2m deep in places. The remaining henge monuments have been ploughed out or are no longer directly visible, although their locations are known through aerial photography and excavation.

The Church Henge is particularly interesting, since the remains medieval church stand in the middle. The chancel and nave were constructed in the 12<sup>th</sup> century, with the subsequent addition of the north chapel and tower in the 15<sup>th</sup> century. It is constructed mainly of flint, with ashlar dressings of Greensand and Heathstone. In the 18<sup>th</sup> century the roof collapsed, and the church fell into disuse, leaving us the ruined structure we have today.

Creating an accurate record is essential to enable archaeologists to effectively manage the preservation of such a monument. Surveying the henge monument by laser scanner gives us a great advantage. Even with DGPS systems, the highest practicable resolution obtainable is 0.5m. Whilst this method is useful, it is possible for more ephemeral details to be entirely missed. As shown with Knowlton, laser scanning allows a much greater amount of information to be collected. This may be meshed and used for analyses such as cross sections, contour plots and lighting analyses by archaeologists to gain a greater understanding of the form and function of the monument or object in question.

The structure of Knowlton Church is badly eroded in places, and emergency conservation works have been undertaken from time to time. It is important before any work begins to a historic building such as this, that a survey takes place as a record to allow future researchers to understand what has happened to the building, its state before and after restoration/repair, and to allow a better understanding of the structure.

Over the centuries the lime mortar has eroded, and flints have fallen away, leaving few straight edges for the surveyor. This presents a particular theoretical problem - the surveyor must make a decision as to what to record as an edge on the plan. Where there is no definite edge, an interpretive process begins; an *interpretation* is often recorded where time on-site is limited. This again is where the laser scanner can begin to become essential to archaeologists in the future, enabling an objective record (governed by the accuracy of the equipment) to be captured rapidly in the field.

The henge complex has been the subject of a series of ongoing investigations by Bournemouth University. The most recent survey undertaken being a GPS survey in 1995. This appears to have a resolution of around 1 metre with an unknown vertical accuracy. Additionally, due to the constraints of GPS technology, the church itself was not included in this survey.

### **Scanning Methodology**

The methodology typically used for terrestrial 3D scanning revolves around the time-honoured use of prisms or targets. These are typically surveyed using conventional means, such as a TotalStation, and then scanned with the laser scanner.

This methodology enables the processor of the data to quickly register the separate scans to an existing control network using the known position of the targets within the control and the scanned position of the targets. A transformation to move scans from their local coordinate system to that of the control network is then trivial to generate.

The downside to this approach is that the actual scan data itself is generally ignored in favour of targets. As such, the registration between scans is really only as accurate as the surveying of the targets. Additionally, it requires the positioning of targets around a structure of site that might not be suitable for the use of targets. A scheduled monument, such as Knowlton, is such a case.

As such, we decided on a target-free acquisition of data for the following reasons:

1. The Callidus scanner has a high resolution (or sampling of data) and a good accuracy (+/-8mm), although we did not think the accuracy good enough for high-quality sphere-fitting.
2. The scanner can acquire around 1000 points/second. This would enable us to take multiple 360 degree scans of the church and henge with enough overlap to use an alternative data-driven registration technique.
3. The church and henge are both scheduled monuments. The use of targets when scanning the church may have required targets being applied to the masonry. This may be completely unacceptable for a scheduled monument.

Therefore, our scanning strategy was defined such that we would:

1. Acquire three 360 degree scans from inside the church itself, one per “compartment” of the church
2. Acquire multiple 360 degree scans around the church between the church and earthworks
3. Acquire multiple 360 degree scans from the bottom of the henge ditch
4. Acquire multiple 360 degree scans from the top of the outer henge bank

This strategy would enable us to ensure that we had considerable overlap between scans and acquire data for the entire church and earthwork from multiple viewpoints.

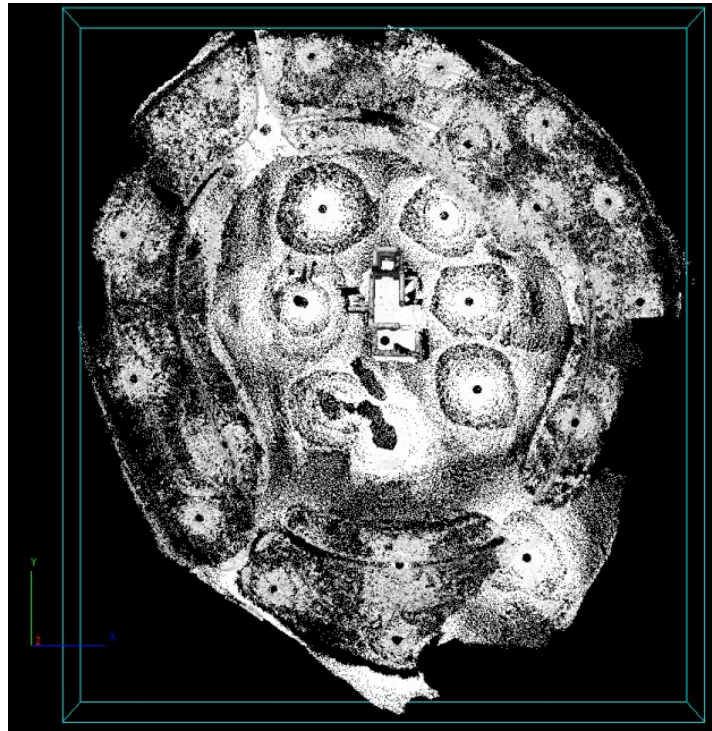


Figure 2: Plan view of the registered point cloud data. The individual station locations can be clearly seen as blank circles

### Acquisition

Once the scanning strategy was decided, the acquisition process is simply a case of moving the scanner to its new position and setting it running. We decided to use a 0.25 degree angular stepover for our scans. This enabled us to acquire a full 360 degree scan in around 15 minutes. We also acquired a few 360 degree scans with a higher horizontal resolution to compare the results.

To support our target-free alignment strategy, we ensured that our scans had around 10-15% overlap between neighbouring scans. This would enable us to use a data-driven registration based on matching points between overlapping scans. This did not considerably add to the acquisition time, in our opinion, and generated a far denser survey than ever before.

In total, we spent around 10 hours on-site, around 8.5 acquiring data and 1.5 for setup and teardown of the equipment and moving the scanner between scan positions. We acquired 32 scans (plus 3 test scans at a higher resolution) containing a total of 17,086,377 points.

### Processing

Once the dataset was acquired, it was necessary that we process the raw Callidus data into a format more useful for metrology and visualisation purposes. Our ultimate goal was not to produce the almost obligatory

point cloud from our dataset, but to generate a fully surfaced mesh. The benefits of this approach include:

1. The finished dataset is visually superior for interpretation and visualisation purposes
2. Metrologically, the topological information present within a meshed dataset is critical for making accurate measurements, especially sectional information
3. Registration inaccuracies are clearly visible as “cracks” or “breaks” in the mesh whereas registration error in point clouds can easily go unnoticed
4. The mesh can be built with only the “best” points acquired with the scanner, as opposed to all points, a good proportion of which will be of “low quality”

Our first stage was to produce accurate registrations between the scans. This was achieved by using a “least-squares fit” algorithm firstly on manually selected matching point pairs on overlapping scans and secondly by running an iterating algorithm which automatically “converges” the overlapping scans. This process, running under our own Demon3D software, took approximately 3 hours to complete and produced registrations of around 4mm RMS deviation.

Once our registrations were as good as we could make them, we meshed the dataset using Demon3D's high-performance 3D fusion routines. This process was done in a piecewise manner enabling us to discard points that we regarded as being “of low confidence”.

#### **An Aside on Quality**

It is assumed that all points measured by a laser scanner are empirically accurate. This is incorrect, especially in the case of time-of-flight terrestrial scanners. The metrics that affect the accuracy of points include the distance of the scanner from the object (for non-collimated beam scanners or scanners within “autofocus” capability); the angle at which the scanner points at the surface; the signal return intensity and the optimal distance at which the scanner works.

For example, a point of “high confidence” (i.e., one which we are fairly certain is accurate) can be classified as one which is around 10 metres from the scanner, is directly facing towards the scanner and is of a non-reflective substrate. This ensures the optimal signal return and minimises the possibility of a “bouncing pulse” in which incorrect range data is generated. A point of “low confidence” could be classified as being at the maximum or minimum range of the scanner and at a glancing angle. Sloping roofs when scanned from the ground are excellent examples of potentially low confidence points.

Additional weighting of a point's confidence can also be introduced by the light conditions at the time of the scan. A scan acquired during the day may be less accurate than a scan acquired during twilight or night time.

All these factors lead to a notional degree of confidence in the accuracy of any given point and this confidence weight should be used during both registration and merging of scans into a complete mesh.

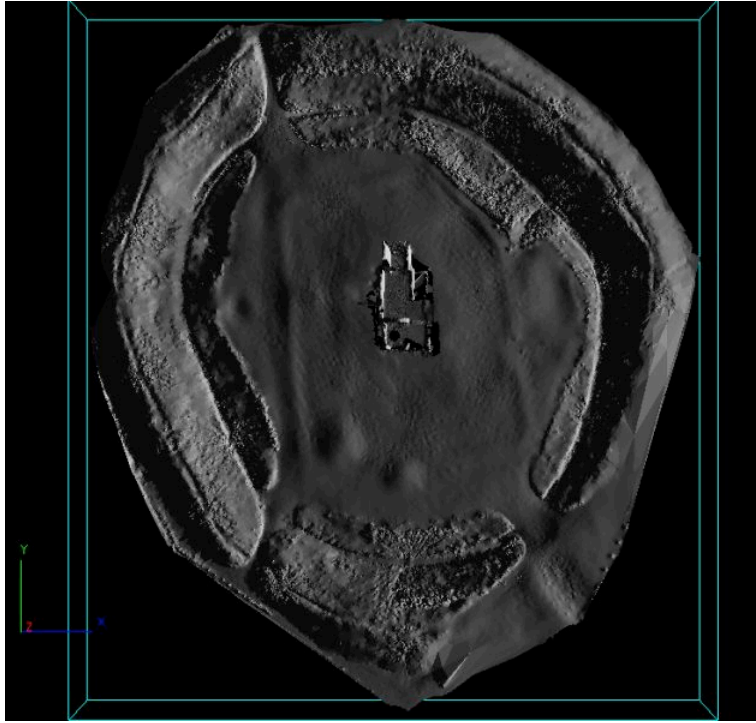
The final stage of processing was simply to clean the mesh by removing redundant triangles, triangles that intersected others, isolated vertices and other topological incongruities. We also filled any small holes present in the mesh. Once the main processing stage was completed, we decimated the dataset down from around 48 million triangles down to just under 4 million. This was done simply to enable the model to be deployed on standard PC hardware.

#### **Final Thoughts**

In summary, the Callidus scanner made it straight-forward to survey the church and henge to a very high resolution and accuracy.

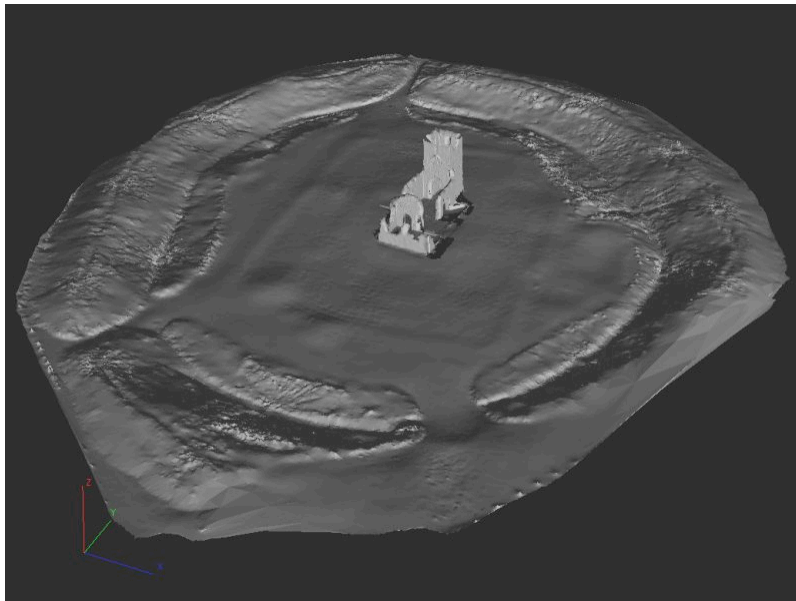
In short, we have demonstrated that 3D laser scanning is a powerful and relatively inexpensive technique for accurately surveying archaeological topographic features, especially extremely subtle earthworks such as the churchyard boundary found at Knowlton Henge. Additionally, scanning provides an excellent snapshot of exactly the condition the site was in during the survey as evinced by the paths worn into places

on the henge bank and the unmown grass in the ditches.



*Figure 3: Plan view of the surfaced and rendered Knowlton Church and Henge. The internal earthworks associated with the church boundary wall are clearly visible as are pathways round the top of the bank and bottom of the ditch.*

This density of data affords the archaeologist huge potential for monitoring deterioration in these fascinating and sometimes threatened landscapes.



*Figure 4: Perspective rendering of the surfaced dataset showing the church fabric*

## **Acknowledgments**

The survey at Knowlton Henge would not have occurred without the assistance of David Hadden of Trimble for loaning Archaeoptics the Callidus scanner used in this survey and Duncan Coe of West Berkshire Council (originally the English Heritage Inspector for Ancient Monuments of Dorset) for granting us permission to undertake the survey.

Knowlton Henge earthworks and church are under the guardianship of English Heritage and are a scheduled ancient monument.

## **Bibliography**

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