Recording Archaeological Excavation Using Terrestrial Laser Scanning and Low-Cost Balloon-Based Photogrammetry

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Abstract

The Discovery Programme has successfully implemented terrestrial laser scanning for the recording of archaeological excavations. However, a number of weaknesses in the process were identified, particularly the poor quality of the derived orthoimages, the basic visual record of the excavation. Searching for a solution lead us to consider the potential of using a low-cost PC based photogrammetric system. In these systems images are taken using inexpensive non-metric cameras and processed in the software to generate DEM's and orthoimages. A helium kite/balloon was implemented as a low level aerial platform from which to capture our images. This paper describes the practicalities encountered in operating such a system using comparative data from our excavation. Our research ultimately addresses the question as to how these technologies relate to each other. Are they competing or complementary approaches to the recording process?

Keywords

Laser scanning, digital photogrammetry, helium balloon, kite, excavation

1. Recording archaeological excavations

On an archaeological excavation new technologies, for example total stations and survey grade GPS, are commonly used for tasks such as positioning finds or recording surface levels. However for the creation of plans and sections it is still the case that traditional hand drawn techniques will normally be used.

They make use of drawing aids such as plane tables or planning frames to improve the positional accuracy. The planning frame, used extensively by the Discovery Programme, is positioned over the desired position within the trench by measuring tape and offsets from a base line. The recorder observes the surface, selects the features which are considered necessary to depict, and then graphically represents them using a pencil, drawing directly onto paper or drawing film at the chosen scale. It is, in effect, a controlled sketch of each 20cm division of the surface. Each metre square is drawn in turn building up a complete plan of the excavation. With practice, experience and careful attention to detail the end result can be a satisfactory plan, accurate within the tolerences of the method and precise to the limitations of scale. The third dimension of the excavation is captured by creating measured drawings of the section faces of the trench, level lines are careful set up and offsets measured.

There are some serious concerns about the use of such graphical approaches, particularly given the aspiration to have GIS compatible data to further the analysis in the post-excavation phase:

Inconsistency – The representation on the plan will vary depending on the experience and ability of the recorder. It is a highly subjective process yet the result will become the basis for subsequent analysis.

Inaccuracy – The potential for error is high, with little in the way of independent checking in the system. Accuracy to within 5cm would be a good result – yet subsequent analysis may well require plans of the same trench to be compared and features matched as the excavation proceeds.

Time-consuming – To create a high quality, accurate representation of the excavation surface takes considerable time. In our experience a medium sized trench (20m x 6m) would take up to 2 days to adequately record. During this time excavation of the area being recorded has to be suspended, with the consequent need to re-deploy the digging team.

Results in 2D only – Perhaps the most significant issue with the graphical approach is the fact that the plan contains only limited detail of the third dimension (from levels and section drawing). Post-excavation analysis is increasingly examining 3D relationships, something which will only increase in importance with developments in full 3D GIS.

2. Terrestrial laser scanning

Time-of–flight terrestrial laser scanners were developed primarily for engineering applications, such as undertaking 'as-built' surveys of industrial plants. It soon became obvious that such instruments could have significant applications in heritage and archaeology, where surveys aim to detect the irregularities and complexities which is the strength of laser scanning.

A terrestrial laser scanner uses a laser to emit a pulse of light and the time delay before the sensor detects the reflected light is timed. From basic physics, *distance = speed of light x time,* knowing the speed of light and precisely measuring the time we can calculate the distance of the round trip, twice the distance from scanner to the object. The direction of the laser is rapidly and precisely moved by a combination of rotating the instrument around its horizontal axis using a motor mechanism, and by a rotating mirror around the vertical axis. *Fig. 1* shows the scanner used by the Discovery Programme (Trimble GS101). The instrument gathers huge volumes of highly precise and accurate 3D points, commonly known as *point cloud* data. A significant difference with this survey technique is that the points gathered are no longer subjectively chosen by the surveyor but are gathered in a largely objective way.

2.1. The potential of laser scanning for excavation recording

Laser scanning, with its rapid gathering of essentially objective data appeared to offer a substantially better way of recording archaeological surfaces. The graphical method tends to blur the important distinction between creating a record of the excavation process with the equally valid need to present the interpretation. With laser scanning these tasks can be separated out into a distinct survey activity – the measurement and position of features using the scanner, and an archaeological task, the interpretation, to be done in the field using the results from the scanner as a precise and accurate framework.

Approaching the recording in this way would result in a highly accurate, largely objective 3D data set which, in a GIS environment would allow for a more complex, analytical approach to post-excavation research, and would lead to considerable time savings.

The Discovery Programme took the decision to implement TLS on excavations in Co. Roscommon, Ireland, as part of its Medieval Rural Settlement Project. The archaeological team initially planned to continue with conventional recording but quickly the scan results proved their value, and drawing was abandoned.

2.2. Field procedure

Before scanning commences a control framework of targets is established around the trench area. These spherical targets serve two functions; they provide the framework to reference scans together and provide geo-referencing to the project – Irish National grid coordinates. Once established these spheres will provide consistent control throughout the duration of the excavation. When a surface is ready for scanning an assessment is made to find the optimum positions to set up the scanner to ensure the best coverage of the surface which will minimize the effects of 'laser shadow'. Laser shadow is the result of the laser not reaching parts of the surface obscured by other features, such as large stones, or the edges of deep pits. Normally four set-ups at approximately 90° to each other will solve this problem, or at least minimize its impact as it will always exist to some extent. From each set up a minimum of three targets (four gives redundancy) are scanned at a high resolution (3mm) and the scanning software indicates successful target recognition. Target scanning is a fast process; each target is completed in

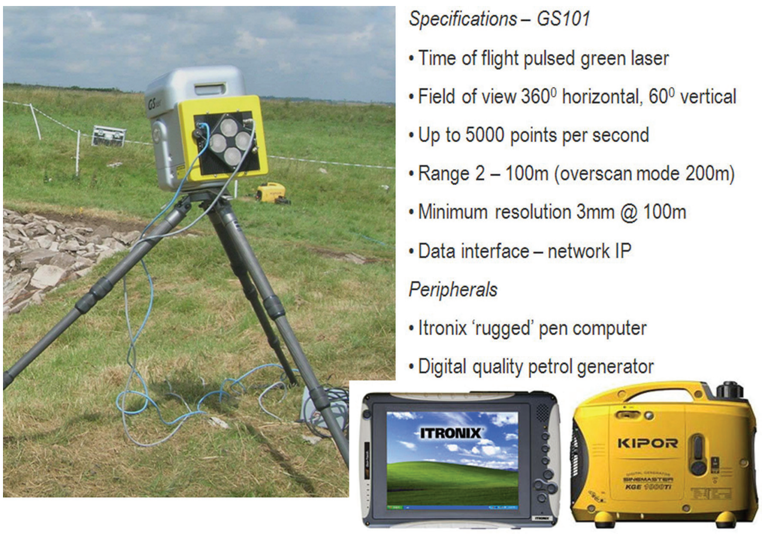

Fig. 1. The Trimble GS101 scanner used by the Discovery Programme.

around one minute. The object (excavation surface) is then defined by the video framing tool, a resolution of 5mm set, and the scan executed. The length of time for each object scan will depend on the size of the surface, normally ranging from 20–40 minutes. The field scanning time to complete a surface is normally around two hours, which compares favourably with the 'days' needed to complete the hand drawn plans. However this is just the data gathering phase, our objective is to output plots which can be verified and where necessary completed in the field.

2.3. Processing laser-scan data

Data is processed in Realworks 5.1 software. The project is downloaded from the field computer and imported into a Realworks project. The following is the sequence of processing stages:

1. Register the scans from the independent stations using the target based registration function. The software indicates the quality of this registration through a list of residual values – 3mm would be an average value. Rarely are excessive values encountered, and in such cases the redundant targets, or cloud based registration can be used to resolve the problem.
2. The Irish Grid coordinates are input to the georeferencing function and the data is transformed into the Irish Grid system.
3. The data is then segmented, that is the data beyond the trench edges is segregated out; leaving a registered 3D point cloud of our excavation trench (*Fig. 2*).
4. Using the Orthoprojection function we are able to extract a true plan view of the point cloud, as required for the verification and completion phase.
5. This is exported as a high resolution geo-referenced tiff image which we then enhance in Photoshop, adjusting the levels to improve the image quality.
6. The final processing stage is to place the geo-tiff in ArcGIS to add a site grid before printing out a plot at a specified scale. This is laminated and taken out for field completion.

These are quick and easy processing stages and the plot will usually be produced less than an hour after leaving the field.

2.4. Field verification and resultant issues

Our archaeologists take the plots back into the field and use the grid lines to measure on features which are missing or poorly defined (*Fig. 3*). It was at this stage we became aware of some of the serious limitations in the laser scanning process. While features with well defined edges, such as stone walls and cobbled surfaces were well represented in the scan data, important features were often missing. In particular the scan data failed to reflect any subtle changes in texture or colour, a major issue given the importance of these in defining and recording context.

An interim solution was to use geometrically controlled site photography. A total station was used to survey the frame corners and these coordinates used in ArcGIS to rectify the image. As shown in

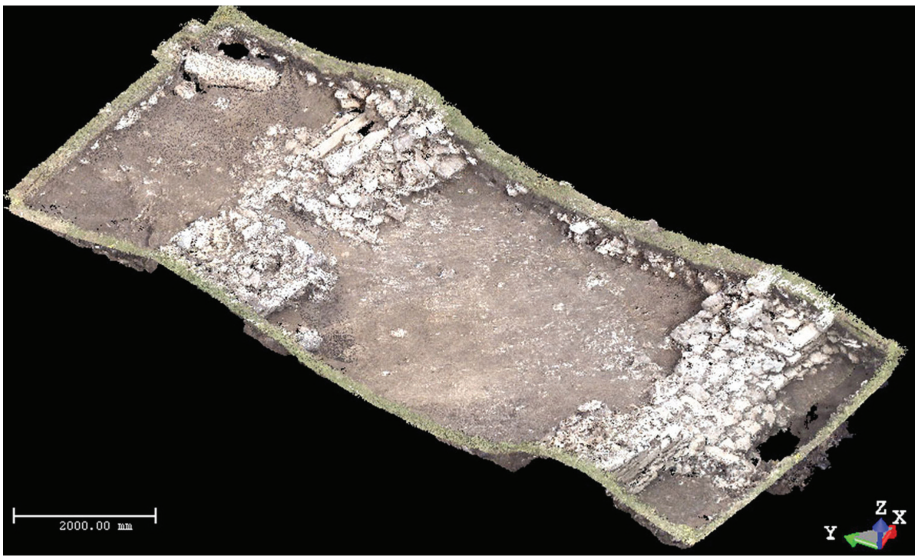

Fig. 2. A 3D view of the point cloud data from excavation surface scan.

Fig. 4 this partially solved the problem but it wasn't a satisfactory solution. It could only be done for small areas, and was not a geometrically accurate approach.

It did, however, lead us to believe the solution lay in the use of photography. What we wanted to find was a way of using photography across the whole trench and to an appropriate geometric accuracy.

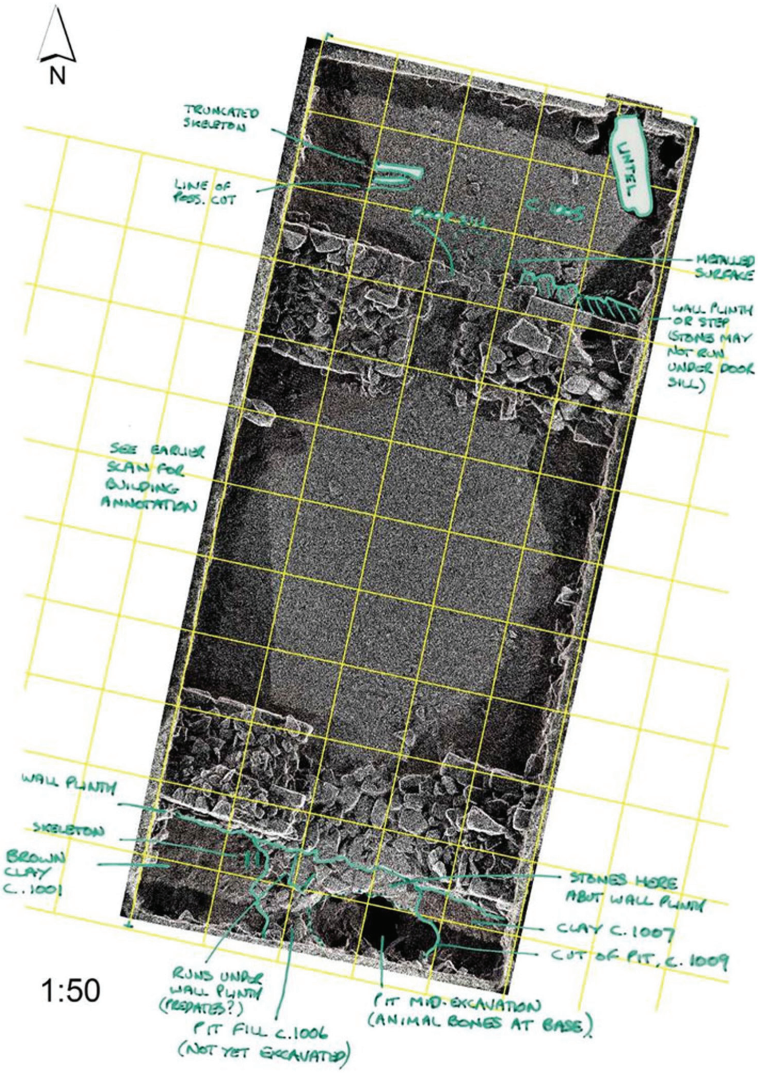

Fig. 3. Orthometric plot showing archaeologists interpretation and ammendments.

3. Kite/balloon-based low-cost photogrammetry

To attempt to photograph the whole of a trench some form of elevated platform was essential. Mobile elevated platforms (cherry pickers) are the ideal solution and have been used extensively for site photography in archaeology. However they are not always available, nor is it always practical to get them to remote sites, as was the case with our excavation.

Helium balloons offered a realistic alternative and a relatively low-cost platform (Ahmet 2004). The design of such balloons has developed recently to incorporate a kite tail which adds stability in windy conditions, ideal for use in Ireland.

3.1. Low-cost photogrammetry

With a kite/balloon sourced to provide the platform for the camera our research turned to finding an appropriate system to process the images. After some research we came across a potential solution in the form of TOPCON PI3000 image surveying station software. This software applies less rigorous processing

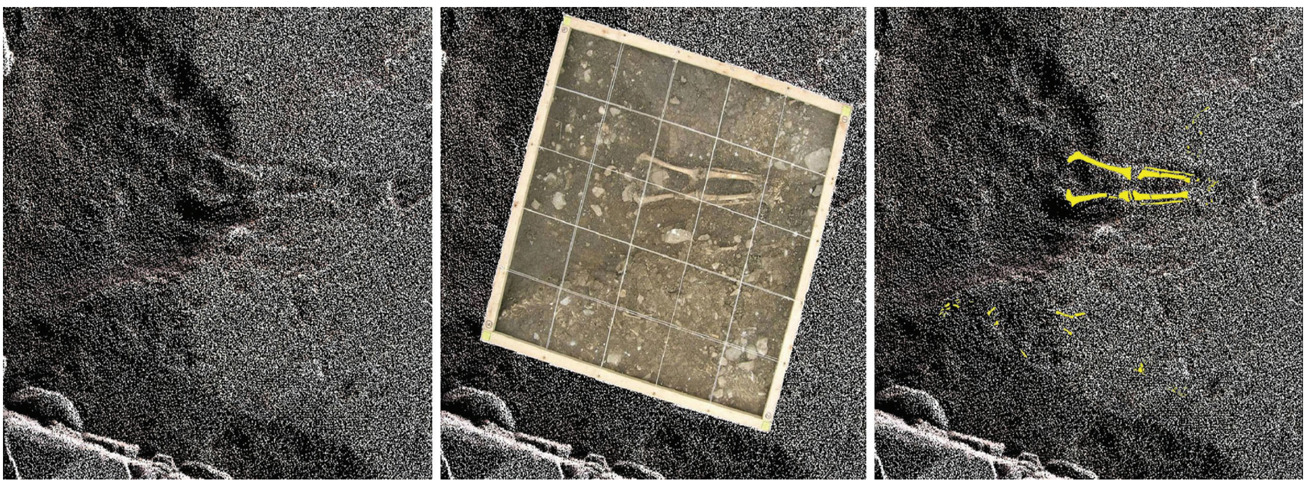

Fig. 4. This image shows how the detail missing from the original scan can be added using rectified site photography.

algorithms than high end photogrammetry and as a consequence it allows the use of images from non-metric cameras taken with less than perfect geometry. A standard GR Ricoh camera was used, calibrated using the Topcon software. *Plate 1* shows the components and system in operation.

3.2. Field procedure

The camera is attached to the balloon rig, the focus set to infinity and the camera timer set to take an image every 10 seconds. The balloon is tethered out to 10-15m and guided across the trench by two people, working as a team. One pilots the balloon, the other acts as a guide instructing the pilot how the position should be adjusted to obtain the images needed. The result of the flight is a sequence of images taken from launch to landing amongst which the aim is to identify a stereo pair with the correct overlap ratio, trench coverage and sharp imagery. For large trenches it is possible to use multiple stereo-pairs, but this does require tighter geometry, hence a more stable and carefully piloted balloon.

Plate 1. The kite/balloon in operation. Insets show the compact camera and balloon rig.

Fig. 5. The plot output from the low-cost photgrammetric system.

3.3. Photogrammetric processing

Topcon PI 3000 software is relatively easy to use, with the operator following through a sequence of operations.

1. The images which make up the stereo-pair are imported into the software
2. Survey control points are identified on the two images, and the coordinates, previously surveyed in the field are imported into the project. The software then performs a bundle adjustment which resolves the geometric relationships at exposure – the positions, rotations and attitude for both images.
3. This generates an epipolar pair on which the operator defines the model area. At this stage the operator can define breaklines to improve the definition of sharp features. The software then uses the inputs to create a TIN model through a process of pixel matching.
4. The TIN model is then used to generate an orthoimage of the site using the original imagery.
5. The final processing stage is to export an orthometric view to create the plan output needed by the archaeologists. The plot is compiled, as with the laser scans, in ArcGIS (*Fig. 5*). This is a high quality texture representation containing far more detail of the surface textures than we achieved with the point cloud.

4. Comparison of the two techniques

We are now in a position to compare the results from the two techniques, and assess what this means in terms of our field practice. *Fig. 6* shows an isometric view of the trench as recorded using laser scanning and low-cost photogrammetry. In this case the laser surface is clearly inferior, failing to make a record of the subtle soil colours and textures which the photogrammetric plot displays so well. However this masks some important considerations. The photogrammetric orthoimage is created from the TIN model, which, developed from pixel matching has some inherent limitations. They are generally coarse models (10cm spacing) , which affects the positional quality of the orthoimage, and the 3D representation of subtle features. In the example shown the stone features towards the top of the trench are 'flattened' into the general shape of the trench surface.

On the other hand the laser scan derived surface is a high resolution representation of the 3D surface with a reliable, quantifiable accuracy. As such we can compare scans of the same site over time as the excavation progresses and develop relationships between features or even compute volumetric analysis. The obvious drawback with laser scanning is the exceptionally limited textural detail which is discernable. *Table 1* summarizes the issues with each approach, including some important practical issues such as cost, expertise required and field time. The significant elements of the table are, however, the quality indicators (xyz accuracy and 3D resolution). The poor image quality from the laser scanning forces the use of the photogrammetry to enable the full record of the surface to be made. But photogrammetry alone is not a sufficiently accurate or high resolution solution to be a stand alone solution.

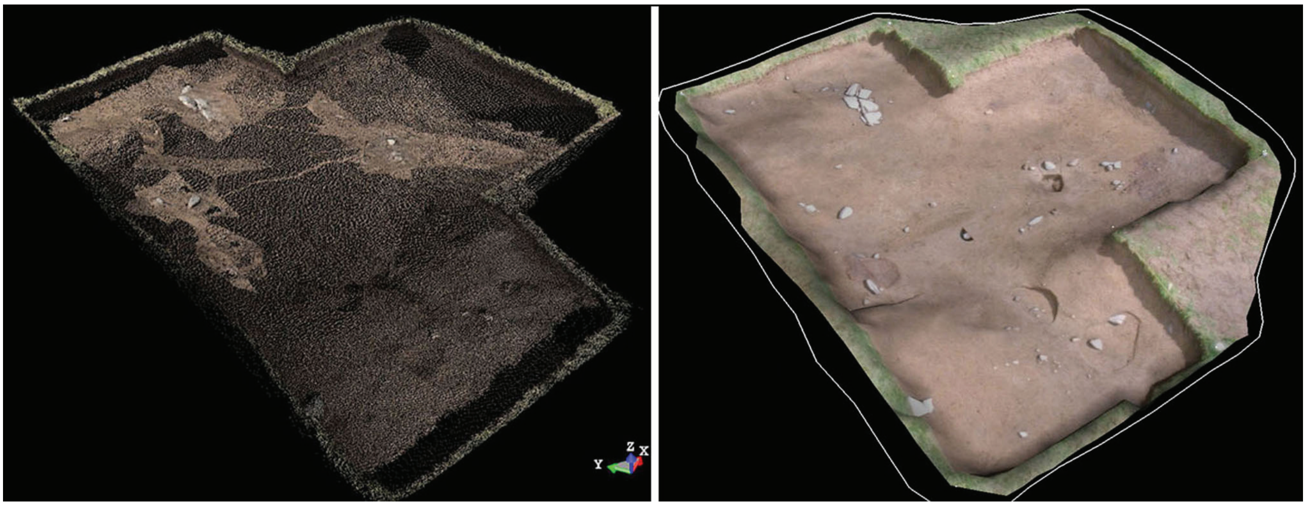

Fig. 6. Left shows the 3D point cloud surface from laser scanning; right, the photogrammetric orthoimage draped over the TIN surface.

	Scanner (Mensi GS 101)	Photogrammetry (Topcon PI3000)
Cost	€100,000	€10,000
Expertise	High	Low
Field time	2 hours	20 min
Processing	1 hour	40 min
XYZ Accuracy	High	Poor
3D Resolution	High	Moderate - poor
Imagery	Poor	Good (balloon) – very good (terrestrial)

Table 1. Summary of the issues relating to scanning and photogrammetry

4.1. Complimentary techniques

The comparison has proved that these technologies, given the current state of technological development, are complementary rather than competing techniques. Our research then examined whether it would be possible to integrate the two approaches, utilising the strengths of each to improve our overall result. We examined the processing stages and looked at the potential to use the 3D surface model from the scanner, the high resolution and reliably accurate data to enhance the quality of our photogrammetric orthoimagery. *Fig. 7* outlines the data flow envisaged. The result of this was a dramatic improvement in the positional accuracy and surface definition for the photogrammetrically generated orthoimages, a significant improvement over the quality achieved through the pixel matching process.

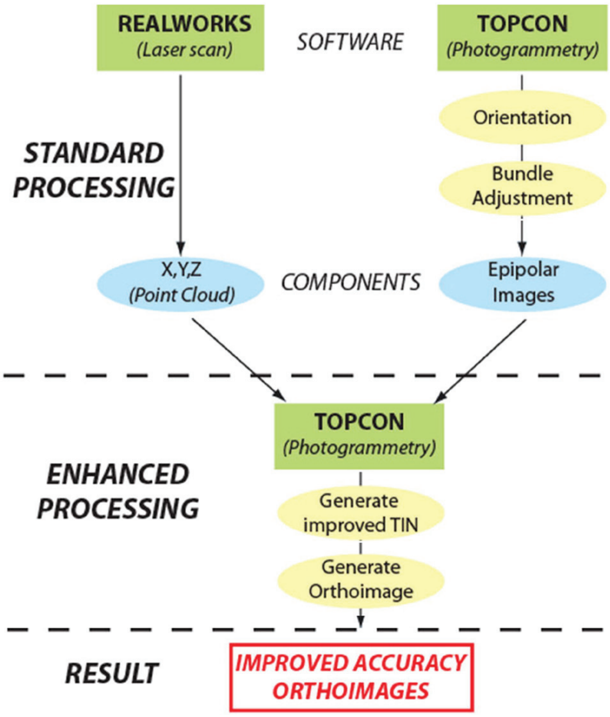

Fig. 7. The work flow proposed to intregrate the two methods.

5. Conclusions

Answering our initial research question, these are two complementary rather than competing technologies. The 3D strength of laser scanning is complimented by the image quality from low-cost balloon-based photogrammetry. However, this is based on the current equipment available to us at the Discovery Programme, a 5-year-old Trimble GS101 laser scanner. Current developments in laser scanner design, both the instruments and the processing software are moving towards high resolution image capture and integration. This should address the limitations that we first encountered when applying laser scanning to excavation recording without the need to resort to applying two separate approaches in the field.

It reinforces our observation that 3D point clouds alone are not the solution to recording problem, and require the addition of high resolution imagery to complete the process.

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