The application of traditional traverse control using a Terrestrial LASER scanner, a case study of the Gold Hill Scheduled Monument, Shaftesbury, Dorset UK

Derek SPALTON, Giacomo Mauro ANDERSON and James STATHAM, United Kingdom

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SUMMARY

Dorset Council (DC) must maintain accurate records of the Buttress wall retaining the grounds of Shaftesbury Abbey, which was built in the 14th century. Working with DC, the University of Derby has generated several models of the structure over a period of one and a half years. The problem with the data generated is that cross matching the models and control profiles used by multiple parties can generate working tolerances of over +/- 20mm. This tolerance was not accurate enough to allow adequate monitoring of the structures, this would include the Gold Hill Scheduled Monument. The objective was to provide data which can be cross referenced to the past work undertaken by the study utilising existing stations and generating new reference points. The functionality of the LASER scanner provides the option to perform a control survey using "traditional traverse" measurement methods akin to those on a total station. To further enhance the process and add to the existing control, a series of resumption points were installed on ancillary features, these were then picked up by both parties to aid in cross-referencing the data.

The results the team generated led to models which had much tighter control and reduced the working tolerance to +/- 3mm, this aligned well to the working limitation of the Scanner of 3.1mm centres at 10m, and the Robotic Total Station working to 3 seconds of arc. The work led to a series of unexpected operational benefits, the data collection of the scanner required less tie points to be used, thus saving time, manual handling and reducing the risk to the public and having less visual impact on the tourist site compared to other current target-based scan registration methods. The post processing was simplified, and significant time savings were found.

Many of the features of traditional Topographical surveying can be completed using scanners with accuracy and working benefits, if providers had sufficient geospatial experience and suitable equipment. The work has embraced development from existing research by the team, utilising resumption points which improve the existing local control network on-site. Further development will be targeted towards generating GNSS fixed data allowing for improved data sharing while also converting the existing local control network into a geotagged one.

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1. INTRODUCTION

Providing students with real life projects whilst studying is a vital part of their transition to future careers and understanding how the construction industry functions. The authors have long been advocates of highly practical delivery and embedding key aspects of survey practice into the teaching resources and having progressive development from the concepts of simple linear surveying (chain surveys) up to elements of emerging data collection (UAV and LiDAR surveys). It is therefore vital that as students and junior surveyors develop, they can relate aspects of prior learning to the next phase of study.

The progression would be linking the practical skills adopted in automatic levelling to the use of a theodolite, by reinforcing the practice of setting up an instrument and the use of survey control (Young *et al.* 2012). It is with the focus on these transitional skills that this paper will focus on utilising field practice in the use of Total Station and projecting that practice onto the practical data collection with a terrestrial LiDAR scanner.

The research aims to establish a field procedure to relate interstation control between fixed scanning positions to assist students' development of the practice whilst being familiar with former skills and processes which they have been exposed to in earlier studies.

Within the research the authors have revisited a past project that has historical value which being relatively confined in its area and complexity. The site in question is the Gold Hill Scheduled Monument (figure 1) in Shaftesbury, Dorset (Historic England, 2024) and the data gathered is further being used as part of ongoing monitoring of the 800-year-old retaining structure. Access to the site is via the steep cobbled carriage at the northern end of Gold Hill and is a public highway, therefore road space approvals were obtained from the Highway Authority and the works complied with Chapter 8 of the Traffic Signs Manual.

Figures 1 & 2. A section of the scheduled monument and a view of the site at Gold Hill, Shaftesbury. (Author's Image, 2023)

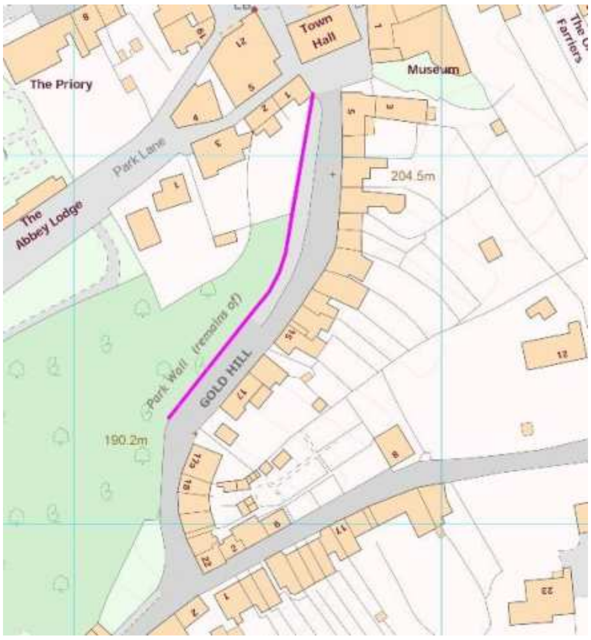


Figure 3. Topographical map of Gold Hill with the retaining wall highlighted in purple. (Ordnance Survey, 2024)

2. PAST STUDY

Over the last 6 years the authors have been involved in enhancing educational field practice to extend the skills of both Undergraduate and Postgraduate Students. This work has been around coastal monitoring and the monitoring of accessible structure which a predominately historic in nature, such as the tunnels and viaduct on the Monsal Trail, Derbyshire, windmills and windpumps in Norfolk, the Falkirk Wheel, Falkirk Scotland and Gold Hill Scheduled monument in Dorset.

The focus of the research has been in the main to introduce control and look to maximise field time and reduce post data correction work. The work manifested itself into two distinct areas of application:

1. Field operation of the instrumentation
2. Survey control utilising a variety of control targets systems (see Figures 4 & 5)


Figures 4 & 5. Typical scanning targets used for survey control. (Author's Image, 2022)

The studies undertaken by the team focussed on the skill base of the students and applied theoretical aspects of data gathering to real life examples. In the main the students undertaking the work had suitable prior experience in the use of Total Stations and traverse control.

The study was mainly driven by issues related to ensure that students could maintain control and tie scans together using fixed and mobile control points. The work looked at the application of prisms with fixed resumption points or flat disc targets. These resolved issues around surveying in tunnels and where the sighting distances were below 5m or over 150m and were lighting conditions were below 30 lux (Thorn Lighting, 2024).

3. DATA COLLECTION

The data was collected on 3 separate visits to the site, in each visit a further aspect was explored to advance the student learning experience. The site visits took place on:
- 4th May 2022
- 26th January 2023
- 10th September 2023

The visits have been arranged to undertake assessment during different seasons and weather conditions, noting that the scanner is not used below freezing or in periods of heavy precipitation.

3.1 Equipment

The LiDAR scanner used in this set of scans was a Topcon GLS2000 (see figure 5) which can operate at up to 135,000 points a second with a working range of up to 350m using a pulse class 3R LASER (Topcon, 2014). To enable great stability in use and noting the steep site the scanners were set on to heavy duty wooden tripod legs.

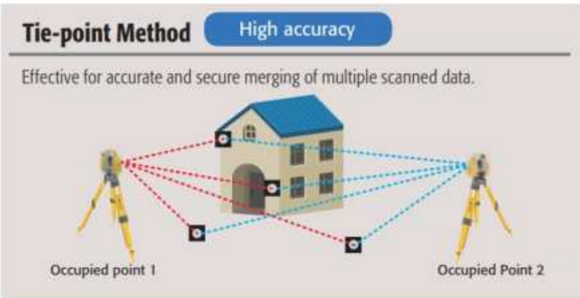
Tie points were established using elevating tripods with circular flat reflective target faces while the traverse measurements were taken with a circular retro-reflective prism. (Fan, L. *et al.* 2015)

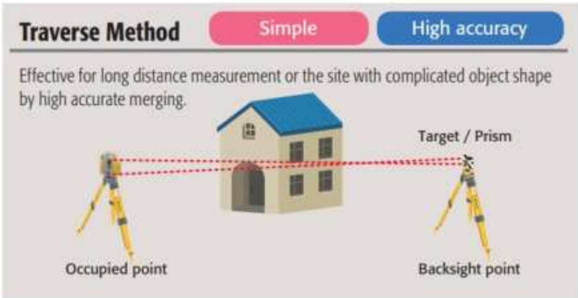
Figure 5 & 6. The GLS-2000 scanner and the station setups on site – the retaining wall can be seen to the right. (Author's Image, 2023)

3.2 On-site Work

The on-site data collection process for each survey started with a walk-around of the site to determine an appropriate plan for the work to be carried out. As part of this step, the scanning locations and positioning of the targets were also determined. Safety signage and other relevant control measures were then placed along the site prior to any equipment being set up. After this, the aluminium target tripods and the wooden instrument tripods were installed at the pre-determined locations across the site according to the scan layout which was established during the initial site inspection. Particular care had to be taken when installing all tripods and equipment to ensure that the setups were as stable as possible, minimising the risk of any unwanted movement during the survey.

Having installed and levelled all the equipment, the scanner setups were traversed with a total station to obtain the station coordinates for each station, which could then be used as a reference when traversing with the LASER scanner. After this, the scanner was installed and the data collection process started by performing a half-hemisphere scan to collect point cloud data for the surrounding area. After this, the target measurements were recorded using the scanner, ensuring that a minimum of three common targets were maintained between adjoining scanning locations. When all the target data had been acquired, the backsight measurement to the prism was performed by using the appropriate function on the instrument. The station coordinates provided by the total station were used as a benchmark for the LASER scanner measurements, with the instrument then providing a raw error measurement and verification on-site. When the work from the initial setup had been terminated, the scanner and prism were then swapped while keeping the tripod and tribrach setups in place, and the targets were re-oriented and repositioned where necessary in order for the work to progress to the following scanning setup. From here, an initial backsight measurement was taken with the instrument in order to orient the work before the steps carried out for the first scanning location were repeated. The scanning and traversing process was then continued until all the required point cloud data had been collected.





Figures 7 & 8. The two registration methods used as part of the data collection (Topcon, 2015)

3.3 Further Processes and Considerations

Previous research such as the one conducted by Becerik-Gerber et al. (2011) has found that the positioning and layout of the scan targets can have a major impact on the overall accuracy of the registration process. As a result, the survey team carrying out the on-site portion of the work had to take particular care to choose an optimal layout for the targets across the survey area. This was done with the main aim of reducing any errors due to poor horizontal and vertical separation of the targets, which in turn could create an excessive amount of rotational freedom of the data which could be a source of error. This is of particular note given the relatively linear nature of the site in question, which limits the degree of horizontal displacement of the targets across the site (Dong, Z. *et al*. 2020).

It was also noted that the target-based method was a lot more time consuming than the traverse approach, owing to the amount of time that it takes to set up and manage a number of target setups across the site. Taking measurements of the targets with the instrument was also time-consuming as multiple targets had to be scanned from various scan locations in order for the tie point data to be usable. In comparison, the prism-based method was a lot quicker, as only two measurements had to be taken with the scanner using the reference coordinates provided by the total station. It should be noted with these findings that given the relatively small nature of the survey area, the time-savings involved in using the traverse-based approach would be even more noticeable given a larger or more complex site.

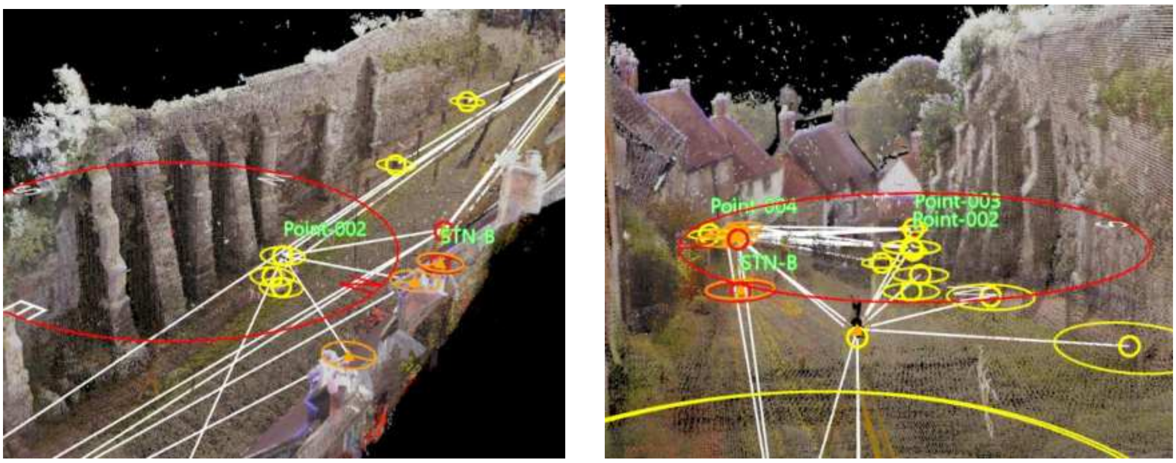
3.4 Editing the Data

The raw data produced by the on-site survey work was extracted from the instruments and imported into a specialist software for editing. The software that was used is called Magnet Collage and is a licensed product provided by the manufacturer of the LASER scanners for use with their instruments. In the software, the raw scan data was edited and registered to form a complete model of the site at Gold Hill. The registration process varied depending on whether the data was connected using targets or the prism-based method. For the surveys which made use of target scans, the software was used to label the individual targets and convert them into tie points which could then be used as constraints to connect the scans together. As part of the process, the software also generated a report detailing the registration errors for each target and scan position.

The registration process for the survey which used the prism-based approach was more straightforward, as there was less data to process and the bulk of the work had already been done on-site. The registration consisted in linking the raw backsight and foresight measurements taken on-site to their respective scan positions and prism setups. Again, the software produced an error report for the registration process. The results of the data collection were obtained from the error reports generated in tabular format by the software as part of the registration process for the scans. The raw data was then imported into graphs to provide a better visual representation of trends and to ease the analysis process. The data was initially exported in sub-millimetre values, and these were then adjusted to the nearest millimetre in order to ease the analysis process. An example of the raw data for one of the surveys is shown below (this includes mean and maximum values).

Point Name	Residual X [m]	Residual Y [m]	Residual Z [m]	Horizontal Residual [m]	Vertical Residual [m]
TR001A	0.0006	-0.0020	0.0005	0.0021	0.0005
TR002A	0.0012	0.0020	-0.0002	0.0023	-0.0002
TR003A	-0.0019	0.0000	-0.0003	0.0019	-0.0003
Statistics	**X [m]**	**Y [m]**	**Z [m]**	**Horizontal [m]**	**Vertical [m]**
RMS	0.0013	0.0016	0.0003	0.0021	0.0003
MAX	-0.0019	-0.0020	0.0005	0.0027	0.0005

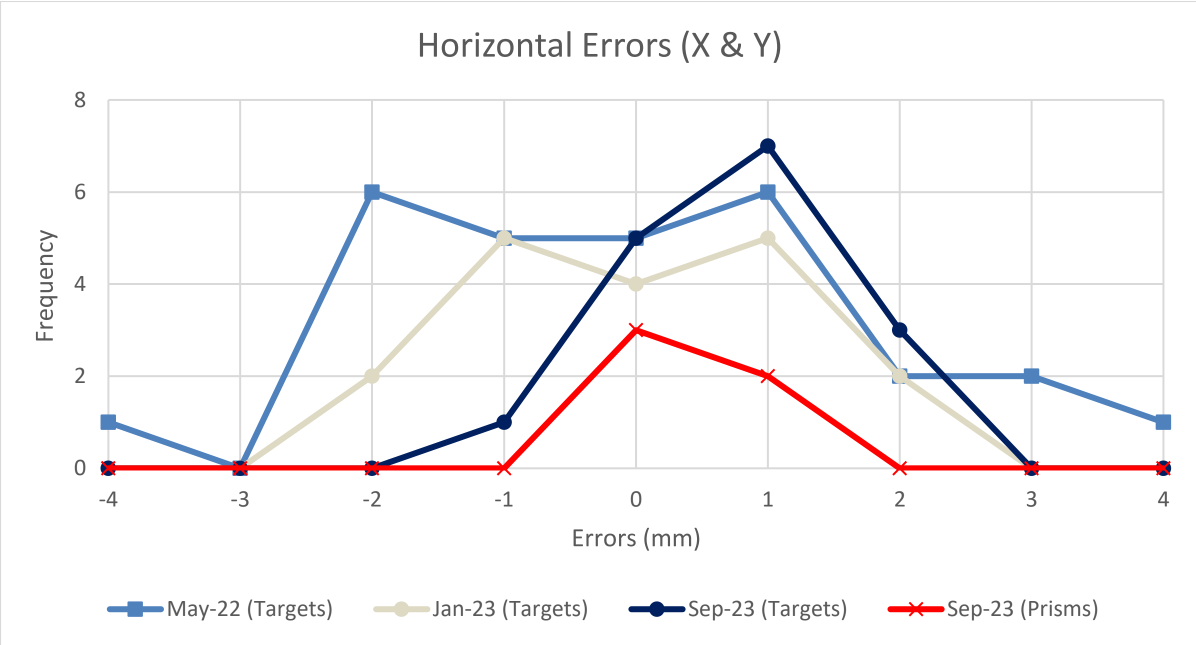
Table 1. Raw data example for STN-A from the January 2023 dataset.



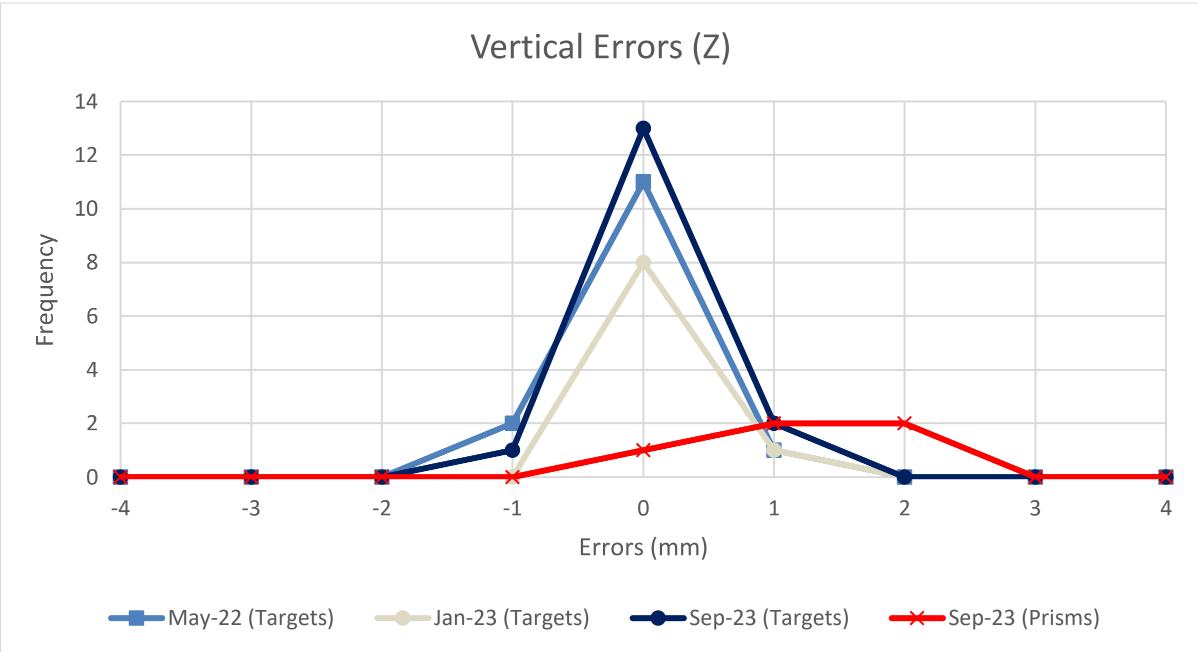
Figures 9 & 10. Data processing in Magnet Collage, showing the tie points created as part of the registration process.

4. RESULTS AND ANALYSIS OF THE DATA

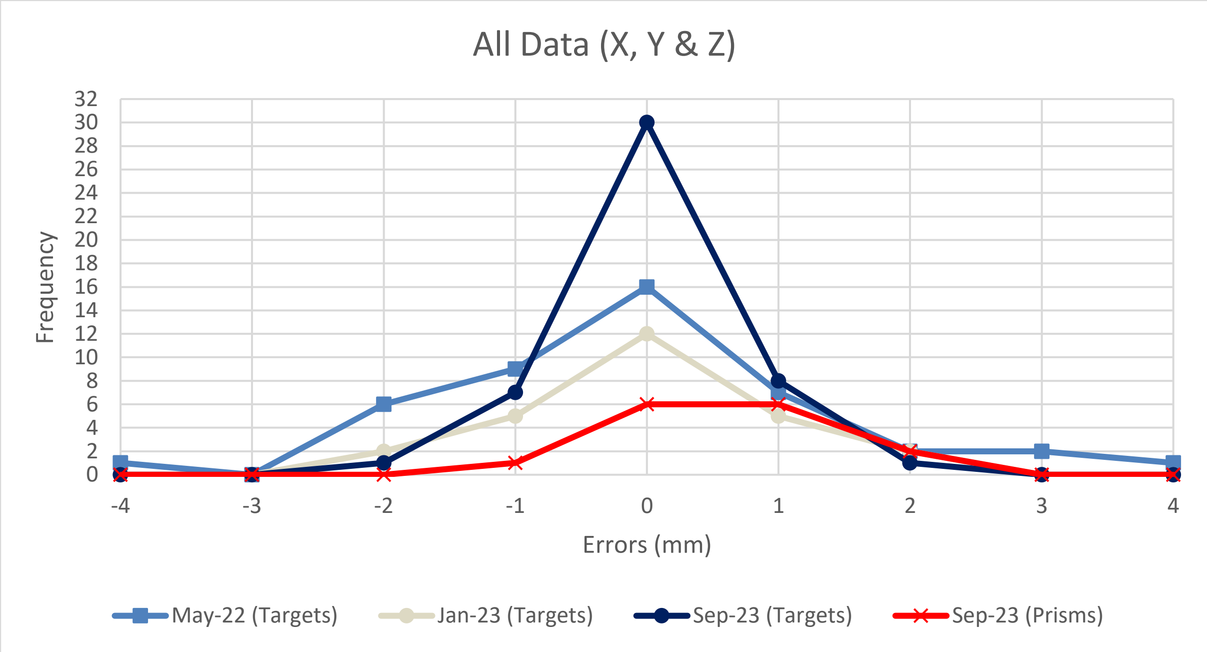
The graphs below provide a representation of the frequency with which errors appeared in the surveys, broken down into horizontal (x and y), vertical (z) and all data (x, y and x).



Graph 1. Horizontal Error Graph.



Graph 2. Vertical Error Graph.



Graph 3. All Data Graph.

The data collated in the graphs gives a good visual representation of the distribution of errors, allowing us to draw comparisons between the different datasets (visualised in the graphs with the data lines).

When comparing the overall results, a couple of key observations were made with regards to the frequency and value of errors in the horizontal and vertical planes. Firstly, it can be noted that in general, the majority of errors for the target-based registration were recorded in the x and y directions (with errors of up to +/- 4mm being measured), as evidenced by the spread of errors in each survey. On the other hand, the prism-based method was significantly more accurate in the horizontal plane, with the data being more robust and accurate than that provided by the target-based approach.

The opposite situation can be observed with regards to the z-direction, where the majority of data recorded in the target-based method resulted in no registration error and the overall data was very accurate. The vertical data for traverse-based approach was relatively less accurate in the z-plane and errors of up to 2mm were recorded. In this case, it is theorised that the number of errors in the vertical direction could be due to the reliance on manually measuring and recording the height of each instrument and prism setup, which could introduce human error into the data. An accurate direct measurement is challenging in this case due to the positioning of the instrument which could lead to excessively inclined measurements being recorded. The target-based method does not rely on measuring the height of the targets, so this error is absent in the rest of the data.

Given the fact that the target-based data presented errors in the horizontal plane but not in the vertical, it can be theorised that these errors did note arise from an excessive movement of the targets during the on-site portion of the work. This high degree of horizontal inaccuracy in the target-based data could in fact be due to the limited horizontal displacement of the targets on-site as a direct result of the linear nature of the area which was surveyed as part of this research. Despite the best efforts of the on-site team with regards to target placement and layout of the scan, the errors in the survey work demonstrate that there was a certain degree of rotational freedom of the data which was highlighted by the registration process. On the other hand, the high level of vertical information given the sloped nature of the site may have improved the accuracy with regards to the z-plane, explaining why the data in this direction is more precise.

As far as the target-based method is concerned, it can be observed that a lot more measurements had to be collected across the site in order to complete the registration process. As previously mentioned, the minimum number of common targets needed to connect two adjoining scans is 3, increasing the amount of measurements taken and as a result the amount of time needed to carry out the work. The prism-based approach was quicker and produced less raw data, as a single foresight and backsight measurement was required between each adjoining station setup in order to complete the traverse. This also significantly simplified the workflow in the software, reducing the amount of time needed for data editing. On top of this, the measurements for the traverse approach could be checked against the coordinates provided by the total station, allowing for on-site verification as the work is being carried out. On the other hand, due to the nature of the measurements collected, the prism-based method suffers from an inherent lack of redundancy when compared to the target-based approach.

Figures 11 & 12. Final 3-dimensional model of the retaining wall at Gold Hill viewed in Autodesk ReCAP

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

There are some well-defined outcomes from this research and some areas that emerge beyond the current scope. It was found that the study had ample data to draw conclusions and establish trends with the different approaches to controlling the point cloud formation.

All the process undertaken produced some error in practice, one key observation noted by the authors was around redundancy. It was found that using the target reference points although generating working errors (+/- 3mm) without excessive post editing, did created adequate redundancy to further reduce the error within the case study.

There was a lack of redundancy for traverse-based approaches, mainly attributed to the instrumentation achieving a tighter lock on the centre of the prism and the scanner is not being able to do face-left and face-right measurements due to its design. This did not impact on the working accuracy of the field data with a working tolerance of +/- 1mm with no post correction, but this cannot be easily verified due to no field redundancy in this study.

One notable deviation between the sample groups was the vertical error. The vertical error and the range for the traverse approach is generated by the fact that in the field the heights of the working axis of the scanners and prisms are being measured with a steel tape and a direct measurement, when the instrumentation is in place, is restricted, potentially leading to inclined measurements being recorded.

5.1 Recommendations

- It would be advantageous to have a couple of targets to back up the data and generate a small level of redundancy to assess for any significant variations.
- As an alternative to this, the surveyors could make use of robust geo-located control on-site in order to improve the accuracy of the data collected.
- On-site processes need to consider minimising the amount of equipment that needs to be set up on site, reducing obstructions and manual handling

5.2 Future Development

Future development for the research would include the integration of Geotagging of the stations used, thus allowing the 3D models generated to be geolocated. Using this geotagged control network would aid in the repeatability of the work as well as the overall accuracy of the geospatial checks being carried out by adding a further element of control.

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CONTACTS

Mr Derek Spalton
University of Derby
Markeaton Street
Derby
DE22 3AW
United Kingdom
Tel. +44 1332 593185
Email: d.spalton@derby.ac.uk
Web site: derby.ac.uk

Mr Giacomo Anderson
University of Derby
Markeaton Street
Derby
DE22 3AW
United Kingdom
Tel. +44 1332 594104
Email: g.anderson3@derby.ac.uk
Web site: derby.ac.uk

Mr James Statham
Dorset Council
County Hall
Colliton Park
Dorchester
Dorset
DT1 1XJ
United Kingdom
Tel. +44 1305 225609
Email: james.statham@dorsetcouncil.gov.uk
Web site: dorsetcouncil.gov.uk