Terrestrial laser scanning for applied geoscience studies in the urban environment

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Abstract: This paper will present a series of case study examples of the use of terrestrial laser scanning (LiDAR) techniques for urban landslide detection and delineation. LiDAR is fast becoming an increasingly accessible technology, which has both the portability and accuracy required by the modern day engineering geologist for urban geoscience studies. The level of accuracy in the derived digital terrain models and the ability to overlay digital photography on the DTM enables subtle landslide and slope instability features to be rapidly identified and for subsequent risk management strategies to be implemented.

Various examples will be presented for both rock and engineering soil dominated slopes which have a significant potential impact in the urban environments in which they occur. The paper will detail the terrestrial laser scanning technology and will discuss the use and appropriateness of these techniques.

Résumé: Cet article présentera une série d'exemples d'étude de cas pour de l'utilisation des techniques terrestres de balayage de laser (LiDAR) la détection urbaine d'éboulement et la délinéation. LiDAR est devenir rapide une technologie de plus en plus accessible, qui a la portabilité et exactitude exigée par le géologue moderne de technologie de jour pour des études urbaines de geoscience. Le niveau de l'exactitude dans et les modèles numériques dérivés de terrain la capacité de recouvrir la photographie numérique sur le DTM permet les dispositifs subtiles d'instabilité d'éboulement et de pente à identifier rapidement et pour que les stratégies suivantes de gestion des risques soient mises en application. De divers exemples seront présentés pour la roche et les pentes dominées par sol de technologie qui ont un impact potentiel significatif dans les environnements urbains dans lesquels elles se produisent. Le papier détaillera la technologie terrestre de balayage de laser et discutera l'utilisation et convenance de ces techniques.

Keywords: landslides, remote sensing, discontinuities, rock description, slope stability, terrain analysis.

INTRODUCTION

Recent developments in the use of ground based laser-scanning systems for the study of terrain present landslide researchers with a tool for the rapid acquisition of digital elevation data. Terrestrial laser scanning has been used to study both coastal and inland landslides (Hobbs et al., 2002; Gibson et al., 2003; Rowlands et al., 2003, Rosser et al., 2005) and rock slope stability (Mikos et al., 2005; Ruiz et al., 2004, Kemeny and Donovan, 2005). While other studies have taken advantage of the survey repeatability for change detection and temporal studies of landslide movement (Hsaio et al., 2004).

The laser scanning technology is based on traditional land surveying total stations. However, the laser scanner is an automated system that is able to acquire a dense point cloud of data from surfaces at significant distances from the scanner location. The scanner produces a representation of the world through the collection of x, y, z coordinates of points measured by the laser. The technique is rapid and accurate; current scanners are able to collect up to 12,000 points per second with accuracies of 10mm allowing the terrain to be modelled in extreme detail. Terrestrial laser systems generate terrain data using time-of-flight to determine the distance between the laser and a point on a reflective surface while concurrently recording the relative direction and elevation angle of each measurement. The point cloud data can be analysed using software provided for use with the scanning system. The software typically includes measurement and interrogation tools that can be used to extract accurate quantitative information from the laser scan survey data. The laser scan surveys and software applications provide engineering geologists with desktop tools that allow detailed surface mapping and measurement along with rock mass characterisation.

This paper presents the application of terrestrial laser scanning to landslide mapping in two contrasting sites; firstly, the inland slopes of the Cotswolds escarpment above the village of Broadway, Worcestershire; and secondly; the coastal cliff section near Blackgang on the Isle of Wight, UK.

LASER SCANNING INLAND LANDSLIDE HAZARD MAPPING

The first part of the study focused on the application of laser scanning to the identification and delineation of inland landslides. This study area was situated on the county border between Gloucestershire and Worcestershire in the United Kingdom (Figure 1). The area lies between 80 m and 250m AOD on the west facing scarp slope of the

Cotswold escarpment between the towns of Willersey, Broadway and Snowshill (Grid Reference SP107396 to SP095338). The chosen study area was located in the central valley above the village of Broadway, shown in Figure 1, centred on OS Grid Reference [411000 237500] between the A44 road and Farncombe House. The valley contains a number of landslides on either side of river including shallow and lobate mudslides, rotational landslides and the presence of ridge and furrow cultivation remains which have also been disrupted by landslide activity (Whitworth et al., 2000; 2005).

The study area was imaged during February 2005 using a Reigl LMS-Z420i scanner operated by 3D Laser mapping (3DLM), summarised in Table 1. The scanner is a tripod-mounted system with a range of up to 800 metres and a scan rate of up to 12000 points per second. The scan head is able to rotate in a 360 degrees arc around the scanning location with a rotating mirror, which is able to scan vertically up to an 80 degree angle, 40 degrees above and below the horizontal plane. A connected laptop collects recorded data on range, angles and signal amplitude for each returned laser pulse via a network connection.

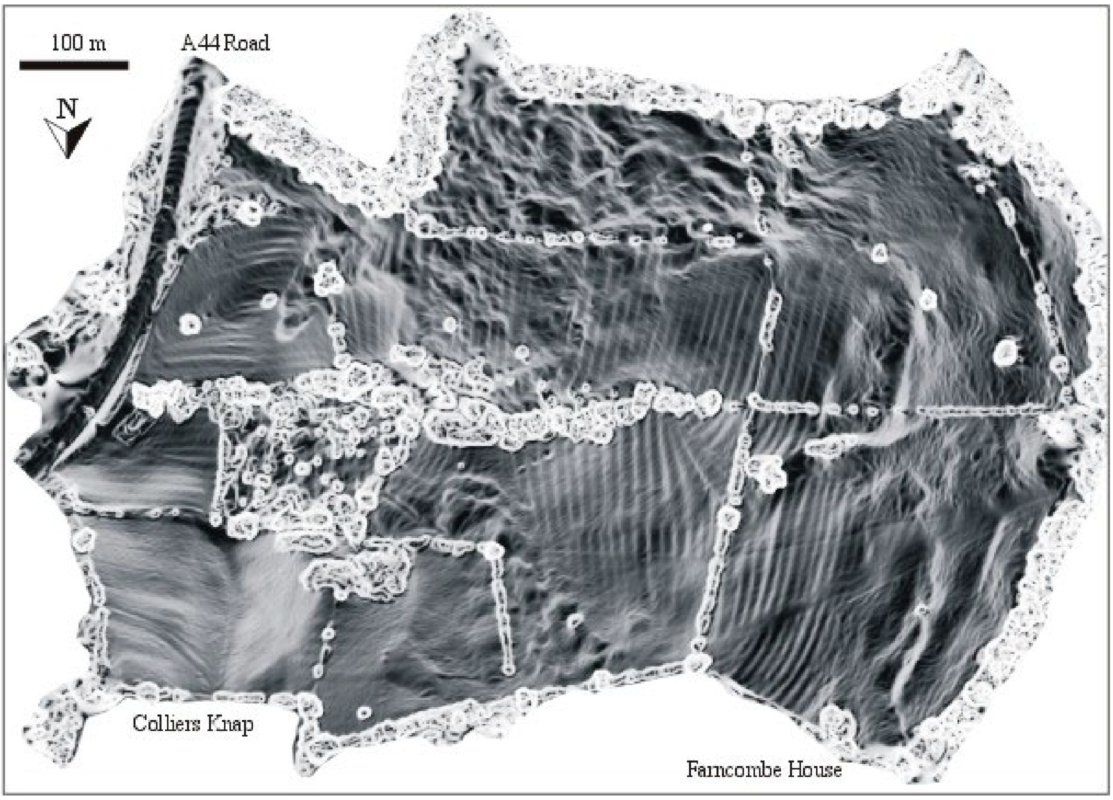
The scanning system also collects simultaneous photography from a digital camera, which is situated on top of the scanner head (Figure 1). These can be used to generate colour ortho-photography when combined with the topographic data during post-processing. The use of terrestrial scanners requires careful planning when dealing with complex terrains. Multiple scans are often required where the extent of the area exceeds the scanner's range or where trees or buildings obstruct the ground surface. The Broadway valley itself is 1000 metres long and 800 metres wide and consisting predominantly of pastureland with isolated pockets of woodland and hedgerows. In order to provide complete coverage, the area was imaged using seven scanning sites located at vantage points along the valley sides (Figure 2).

Table 1. Summary of the properties of the Reigl laser scanner used in this study (Reigl, 2004).

	LMS-Z420i
Vertical scan angle	80°
Horizontal scan angle	360°
Scan range	Up to 800 m
Measurement accuracy	5 mm
Measurement resolution	5 mm
Measurement rate	Up to 12000 pts/sec
Laser wavelength	Near-infrared (0.9 µm)

Figure 1. Reigl LMS-Z420i scanner with top mounted digital camera.

(a)



(b)

Figure 2. (a) Colour aerial photograph of the Broadway valley site indicating the location of each of the laser scan sites and the nature and extent of the slope instability. (b) Slope angle map derived from the digital elevation model of the Broadway valley generated using terrestrial laser scanning (resampled to 1 m grid spacing). In this image the steepest slopes appear white and are associated with landslide scarps and boundaries, frontal lobes and the top of the woodland canopy and hedge boundaries.

LASER SCANNING FOR ROCK SLOPE STABILITY ASSESSMENT

The second part of the project concentrated on an area of instability near Blackgang, on the Isle of Wight. A map showing the location of this area is shown in Figure 3c. An aerial photograph is shown in Figure 3a and the Upper Greensand cliffs are shown in the photography in Figure 3b. Rock falls are one of the main hazards in this area, which pose a risk not only to those using the footpaths, but also may potentially threaten the nearby theme park.

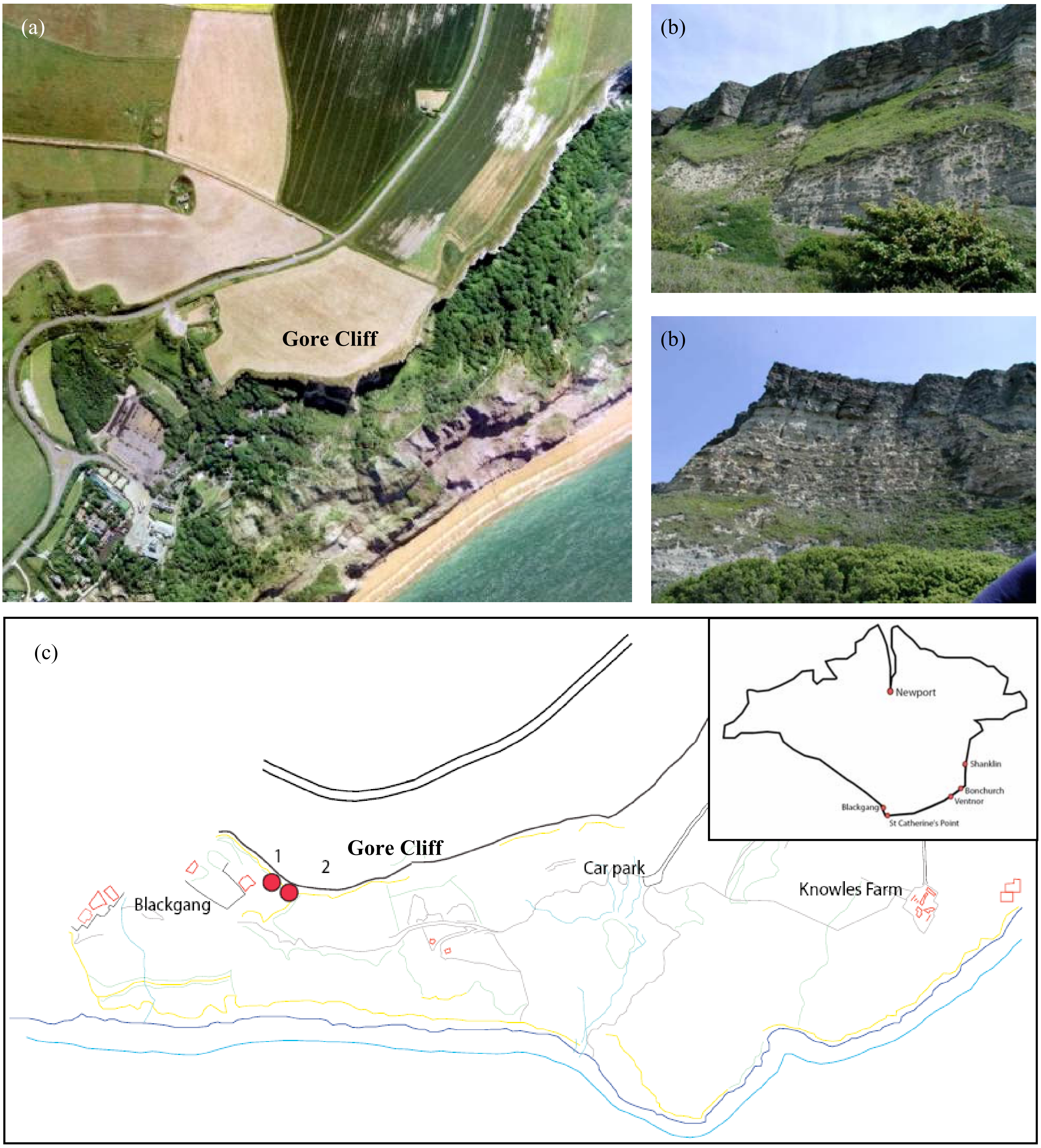


Figure 3. Study area map showing the (a) an aerial photography of the Gore Cliff and Blackgang area (b) Photographs of the Upper Greensand cliffs taken from scan locations 1 and 2 and (c) Map showing the scan locations beneath Gore Cliff. Scans 1 and 2 were taken 20 - 30m from the cliff face. The inset indicated the location of Blackgang on the Isle of Wight, UK.

Laser scan survey at Gore Cliff

A terrestrial laser scanning survey was undertaken around Blackgang during June 2005. A Riegl LMS Z420i was used to scan the cliff faces in the vicinity of Blackgang shown in Figure 3c. Two scan base stations were chosen at Blackgang in order map the Upper Greensand cliffs. The results of the scans of the Blackgang rock faces have been used to construct visualisations of the rock mass within the *RiScan Pro* software that accompanies the scanner hardware to determine block sizes of potential future rock falls, define cliff profiles and map discontinuities within the Upper Greensand.

Block measurement

Interrogation of the laser scanning data allowed source zones for previous rock falls to be identified from the point cloud of the cliff face and the type of failure could then be determined. In this case the predominant failure mechanism was identified as wedge type failures leading to rock fall hazards. Following this, potential falling blocks were located within the scan data through the visual inspection of the point cloud data with a true colour image draped over the top of the surface. Once a block was identified, the volume of the potentially dangerous block was measured in *RiScan Pro* by selecting the block and projecting it onto a series of planes that delineated the intersecting joints onto which the block would fail. These planes were inferred from the orientation of the discontinuities within the cliff face and were used to define the boundary of the block. These boundaries were then used by the software to determine the volume of the block. Each potential rock fall block was visualised separately and can be seen in three dimensions (Figure 4). An initial assessment can also be made from the cliff scan as to how the block may fail, for example if it is more likely to slide from the face (planar or wedge) or topple out. The volumes of the blocks (shown in Figure 4) determined from the laser scanning data are shown in Table 2.

Table 2. Block volume measurements for two potential rocks falls in either side of the Upper Greensand cliff at the Blackgang end of the Gore Cliff.

Identified Block	Calculated Volume
1	2.67 m^3
2	109.68 m^3

Rockfall hazard modelling

The data retrieved from the laser scans of the Upper Greensand have also been used to model another rock fall hazard at Blackgang, from which rock fall hazards could be inferred for the rest of the Gore Cliff section. The Rocscience Inc. *RocFall* software package was then used for this part of the modelling process. To create the Blackgang slope profiles in *RocFall*, a profile of the slope was taken from *RiScan Pro* software and an accurate copy of the slope was defined in *RocFall*. The model required standard values for Coefficient of Restitution for slope material and for block mass properties, which was determined from the volume measurements made within *RiScan Pro* with known rock densities. An example of the output from this rock fall simulation is provide in Figure 5 and provides an indication of the rock fall hazard in the vicinity of the cliff.

Discontinuity assessment

The final stage of the analysis involved the extraction of discontinuity parameters from the laser scan survey data within *RisScan Pro*. Initial analysis of the scan data involved a visual search for discontinuities and the construction of their corresponding planes using *RiScan Pro*. Each plane was constructed using selected areas or lines from exposed discontinuities within the rock mass. The dip and dip directions were recorded from each constructed plane. The dips and dip direction, as measured directly from the 3-D images of the cliff faces, show similar orientations and dips to those measured by Bromhead et al (1991). Figure 6 illustrates this three dimensional visualisation of the rock mass discontinuity pattern.

DISCUSSIONS

The high density of data that can be collected in a comparatively short time, compared to that of more conventional techniques, is one of the most useful aspects of ground based LIDAR scanning for landslides. For example a manual discontinuity survey of a steep cliff may take more than a day, whereas a detailed laser scan of the same area would take no more than two or three hours. Not only does the scan produce detailed three-dimensional digital data, it prevents the need for manual surveys which are often time consuming and often very dangerous, especially on high cliffs. The study by Mikos et al (2005), which involved using a hand-held scanner as an alternative to the bulky LiDAR scanners, would not have had the capability to map the Blackgang cliff face in the same detail as in this study. However the equipment is more difficult to transport and move (often requiring two people or more to carry the laser and supporting ground station), and therein lies the main weakness of the technology. Having said this, it is possible to transport the larger scanners over difficult terrain in land rovers or other all-terrain vehicles such as Quad bikes. Yet another benefit is the variety of uses and analyses that can be performed on 3- D terrain data. As for its use in geology, and in particular for geohazard assessment, laser scanning not only produces a 3-D image of a landscape, it also allows for distance and angle measurements (e.g. dips and dip direction and distances) to be taken directly from the data after processing the information on a computer as has been demonstrated in this study.

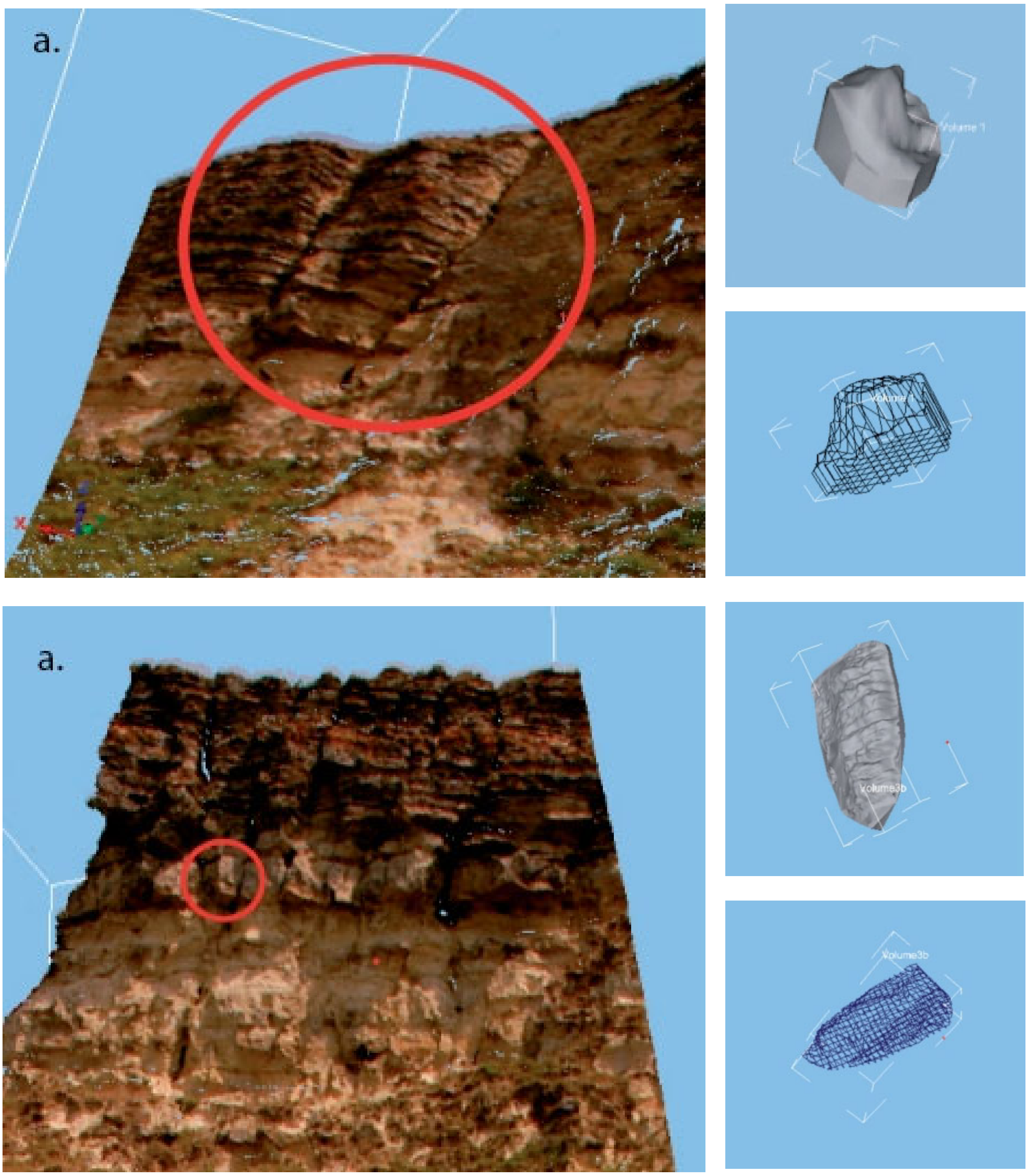


Figure 4. Block measurements of potential rock falls from the Upper Greensand cliffs of the Gore cliff area near Blackgang on the Isle of Wight, UK.

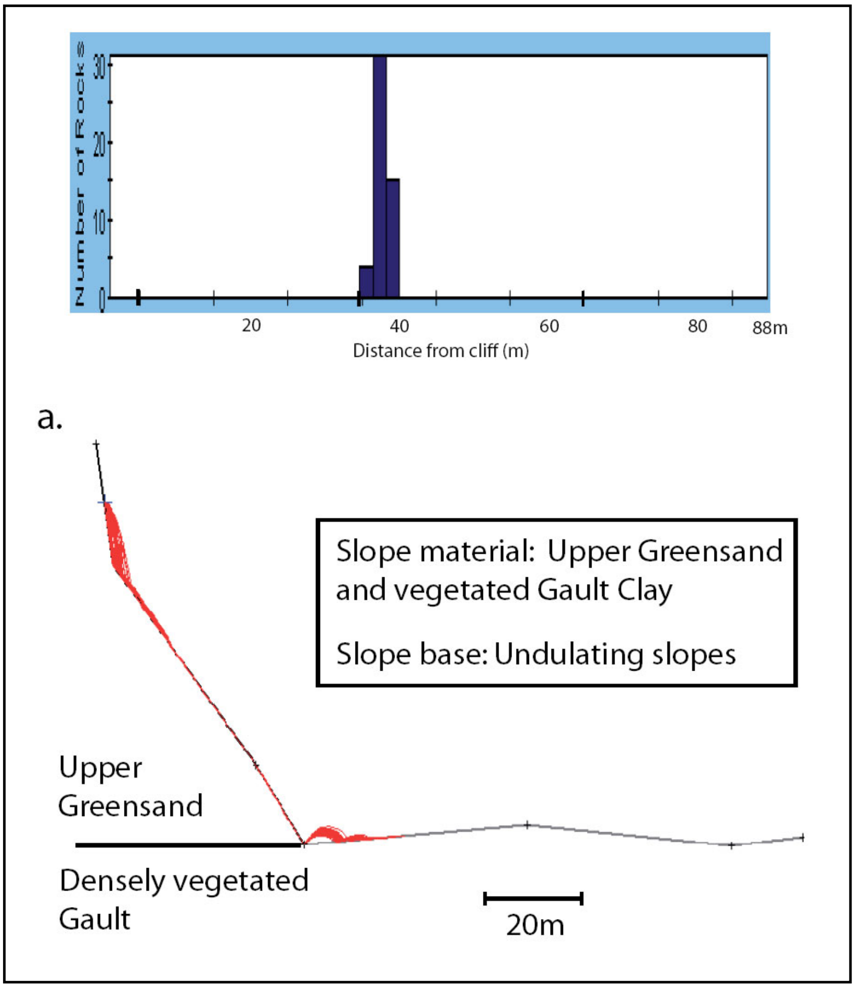


Figure 5. Results of rock fall simulations using *RocFall* for falling rocks from the face at scan locations 1 and 2. Scenario shows blocks falling from scan location 1 onto undulating vegetated ground. The cliff profile and block size have been derived from the laser scanning data.

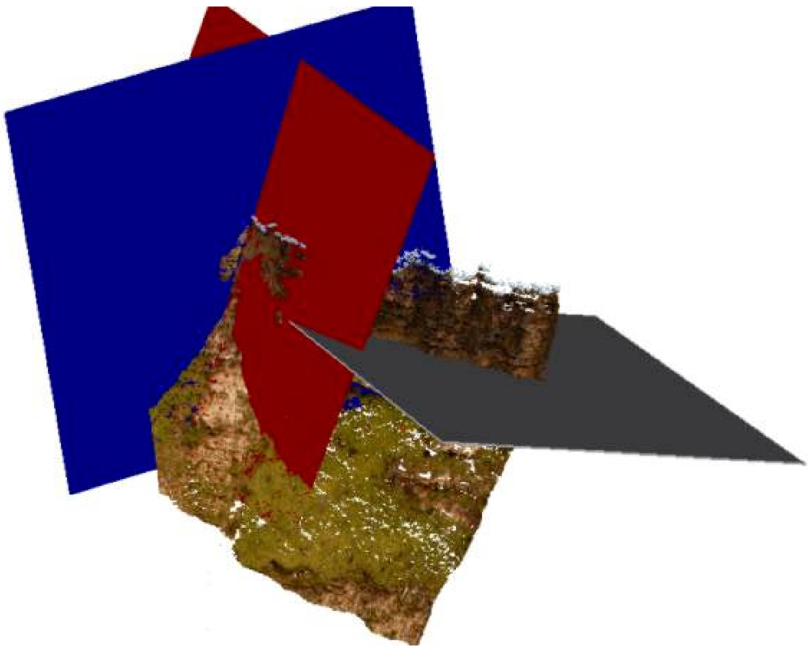


Figure 6. Discontinuity estimation for bedding and major joint sets in the Upper Greensand outcrop at the Blackgang end of the Gore Cliff using plane fitting functions with *RiSCAN Pro* software.

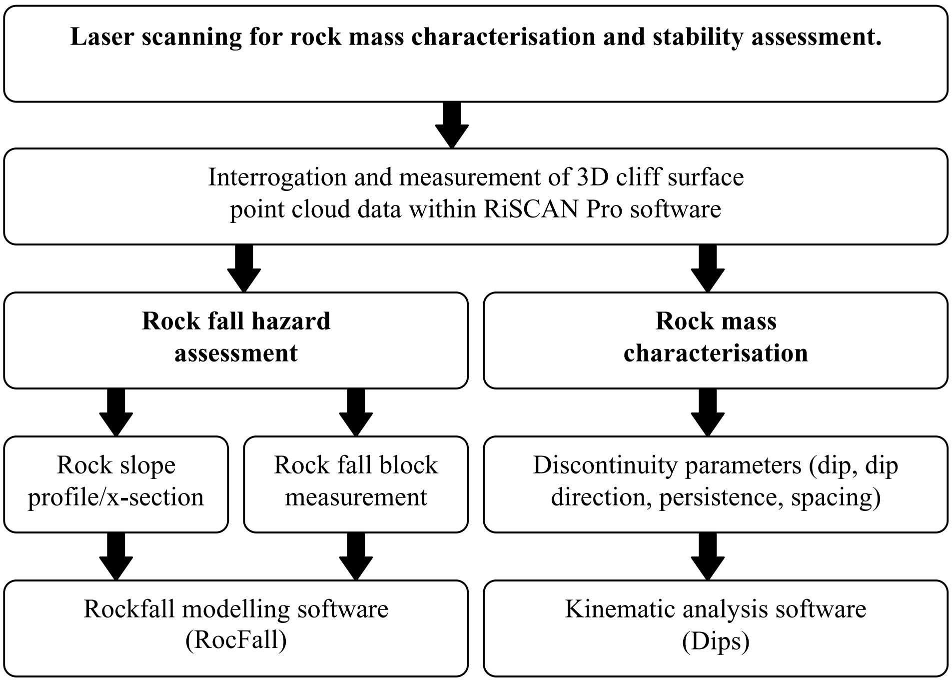


Figure 7. Terrestrial laser scanning work flow for rock fall hazard assessment and rock mass characterisation applications.

CONCLUSIONS

Laser scanning provides a tool for the determination of a range of rock mass parameters that may not be possible due to safety or access problems. The type of information includes discontinuity data such as persistence, dilation and roughness; and estimates of the dip and dip direction of discontinuities in the rock face. Figure 7 details a typical workflow for a rock mass characterisation and stability assessment. The laser scan represents a rapid means for collecting accurate high-density surface model of a rock face and software (such as *RiScan Pro*) allows rock mass characterisation measurements to be made using the point cloud data. The laser scan data generates an accurate representation of the rock surface and allows interrogation of the surface using measurement tools and planes. Such analyses can include block size measurement and cross section derivation for use in rock fall modelling applications. Point cloud (x, y, z) can be resampled and exported to other standard gridding and contouring packages such as *Surfer*, to GIS and image processing systems, for example *Ermapper* the software used to derive Figure 2. Discontinuity data derived from the laser-scanned data can also be used for further numerical analysis using *DIPS* or other discontinuity process software packages. The laser data significantly represents an accurate model of the rock mass at the time of scanning and can therefore be used to generate dynamic time change models that can highlight the more active and hazardous components of the cliffs and slopes being measured. Subsequent surveys can reveal movements through time-series analysis of the laser scan epochs (subject to stable scanning base station conditions). The laser scan model represents a time stamped image of the rock face and can provide the basis for planning appropriate remediation and mitigation strategies, whereby the scan provides a detailed map of rock mass on which areas requiring attention can be highlighted.

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