APPLICATION OF HIGH-RESOLUTION LASER SCANNING AND PHOTOGRAMMETRIC TECHNIQUES TO DATA ACQUISITION, ANALYSIS AND INTERPRETATION IN PALAEONTOLOGY

Bates, K.T.,[1,2,*] Falkingham, P.L.,[2] Rarity, F.,[2] Hodgetts, D.,[2] Purslow, A.[3] and Manning, P.L.[2,4]

[1]Computational and Evolutionary Biology Research Group, Faculty of Life Sciences, University of Manchester, Stopford Building, Oxford Road, Manchester, M13 9PT, UK, karl.bates@postgrad.manchester.ac.uk;
[2]School of Earth, Atmospheric and Environmental Science, University of Manchester, Williamson Building, Oxford Road, Manchester, M13 9PL, UK, peter.falkingham@manchester.ac.uk, frank.rarity@manchester.ac.uk, david.hodgetts@manchester,ac,uk, phil.manning@manchester.ac.uk;
[3]Z+F UK LTD, 5 Avocado Court, Commerce Way, Trafford Park, Manchester, M17 1HW, UK, tony.purslow@zf-uk.com;
[4]Department of Earth and Environmental Science, University of Pennsylvania, 254-b Hayden Hall, 240 South 33rd Street, Philadelphia, PA 19104-6316, USA.

*Corresponding Author

Keywords: Laser scanning, photogrammetry, palaeontology, dinosaur, modelling, geology.

ABSTRACT:

Integrated laser scanning and photogrammetry - remote methods of collecting three dimensional (3D) spatial and geometrical data - has to-date been under-utilized in palaeontology. Laser scanning provides a dense point cloud that represents a precisely sampled replica of an object's surface geometry. Integrating a digital camera into the scanning unit allows photographic images to be combined with these point clouds to produce interactive photo-realistic 3D models. The Differential Global Positioning System (DGPS) also built into the unit provides sub-metre global position information and allows data to be integrated with other georeferenced datasets. As a non-invasive method of attaining geometrically precise 3D digital models, these techniques enable palaeontologists to explore fossils and fossil sites on the desktop where an exceptional level of visualization can be combined with analytical facilities unique to the digital environment. 3D geological mapping using integrated laser scanning and photogrammetry has provided the necessary framework for interpretation of fossiliferous localities in the context of their 3D sedimentary facies, improving understanding of the stratigraphic and palaeoenvironmental context of fossil sites. High-resolution photo-realistic models also offer remote interactive access through virtual fieldtrips, and may contribute significantly to conservation and education at palaeontological heritage sites. Building on its use to model the 3D geometry of fossil dinosaur tracks, we have also recently used laser scanning to digitize skeletal mounts of theropod dinosaurs, producing scale models that have been used to examine the mass, inertial properties and locomotor mechanics of these animals.

1.0 Introduction

The fossilised remains of plants and animals (both trace and body) are inherently three-dimensional (3D) objects. The scale of these objects can vary from microns to many meters in size, from micro-fossils to vast dinosaur tracksites. Existing imaging and mapping techniques have been applied to recording such features, from scanning electron microscopy to standard field-mapping at the other end of the scale. The results from such traditional techniques are two dimensional (2D) representations of inherently 3D structures. The potential loss of key information, such as 3D form, volume and geometry, from traditional techniques has encouraged the application of new technology to allow the acquisition of more complete data-sets in palaeontology.

In this paper we provide a concise review of recent applications of digital imaging and surveying techniques carried out by the Palaeontology Research Group at the University of Manchester, including recent laser scanning in collaboration with Z+F UK. Our aim is to briefly outline work carried out to-date and highlight the advantage of a 3D approach to palaeontological research and documentation. For more detailed coverage of each topic the reader is referred to Fabuel-Perez et al. (2009), Wilson et al. (2009) and papers by Bates and colleagues (Bates et al. 2008a&b, 2009a-d).

2.0 Geological Mapping

This example case study adopts an integrated approach incorporating quantitative digital outcrop surveying and detailed field geology to investigate the exceptionally well exposed Oligo-Miocene tidal to shallow marine rift initiation Nukhul Formation, Suez Rift. Trace fossil assemblages, in conjunction with primary sedimentary structures, have been used for the interpretation and categorization of sedimentary facies (or environment of sediment deposition). Ichnology has also been applied as a means of recognizing and mapping stratigraphically important surfaces across the Nukhul half-graben basin

In-house software Virtual Reality Geological Studio (VRGS) provides a platform for the integration and manipulation of quantitative digital outcrop data (e.g. laser scanning) and conventional field-work approaches (e.g. facies analysis and logging) (Fig. 1). This provides continuous 3D outcrop coverage allowing multiple viewpoints and the correlation of key structural and stratigraphic features at multiple scales (<cm to >km).

The Nukhul half-graben models have been used to quantify and help understand subtle controls on early syn-rift facies distributions related to growth folds, fault propagation and fault segment linkage. The quantitative outcrop models also facilitate the development of accurate palaeogeographic, sequence stratigraphic and tectono-stratigraphic models. Such studies can also be applied to improve the palaeoenvironmental context of fossil sites.

3.0 Tracking Dinosaurs

To scientists fossil tracks have the potential to reveal important information about the taxonomic position, locomotor kinematics and behaviour of individuals as well as the composition, abundance and environmental range of past faunas. Trackways provide information not available from the study of body fossils alone, and are a particularly important source of data about paleobiodiversity during periods of earth history in which body fossils are rare.

High-resolution laser imaging provides a means to model the 3D geometry of fossil tracks in the field with high accuracy. This represents a considerable advance for the science of vertebrate ichnology in which traditional field methods suffer from a significant degree of abstraction and lack the resolution required to interpret tracks quantitatively. 3D models provide additional morphometric information and allow the application of new analytical tools unique to the digital environment. The method will enable fossil track morphometrics to develop into an iterative process that combines 3D visualization and multivariate statistical methods, blending qualitative and quantitative approaches and allowing track morphologies to be compared holistically.

Fumanya (Catalonia) is one of the most important Cretaceous tracksites in Europe, but has suffered significant erosion in recent years and the nature of exposure of the track-bearing

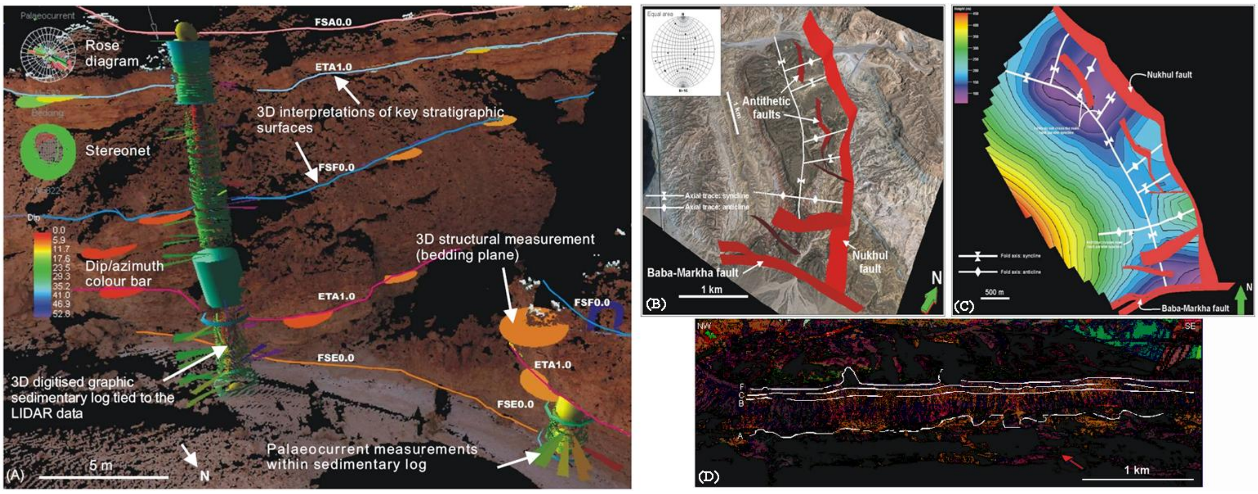

Figure 1. (A) Point cloud coloured by digital photos, providing a georeferenced framework for integrating field observations. (B-D) Fault models developed from 3D outcrop model. The stereonet shows poles to fault planes derived and (C) a structure contour map of key stratigraphic horizon generated for the Nukhul half-graben.

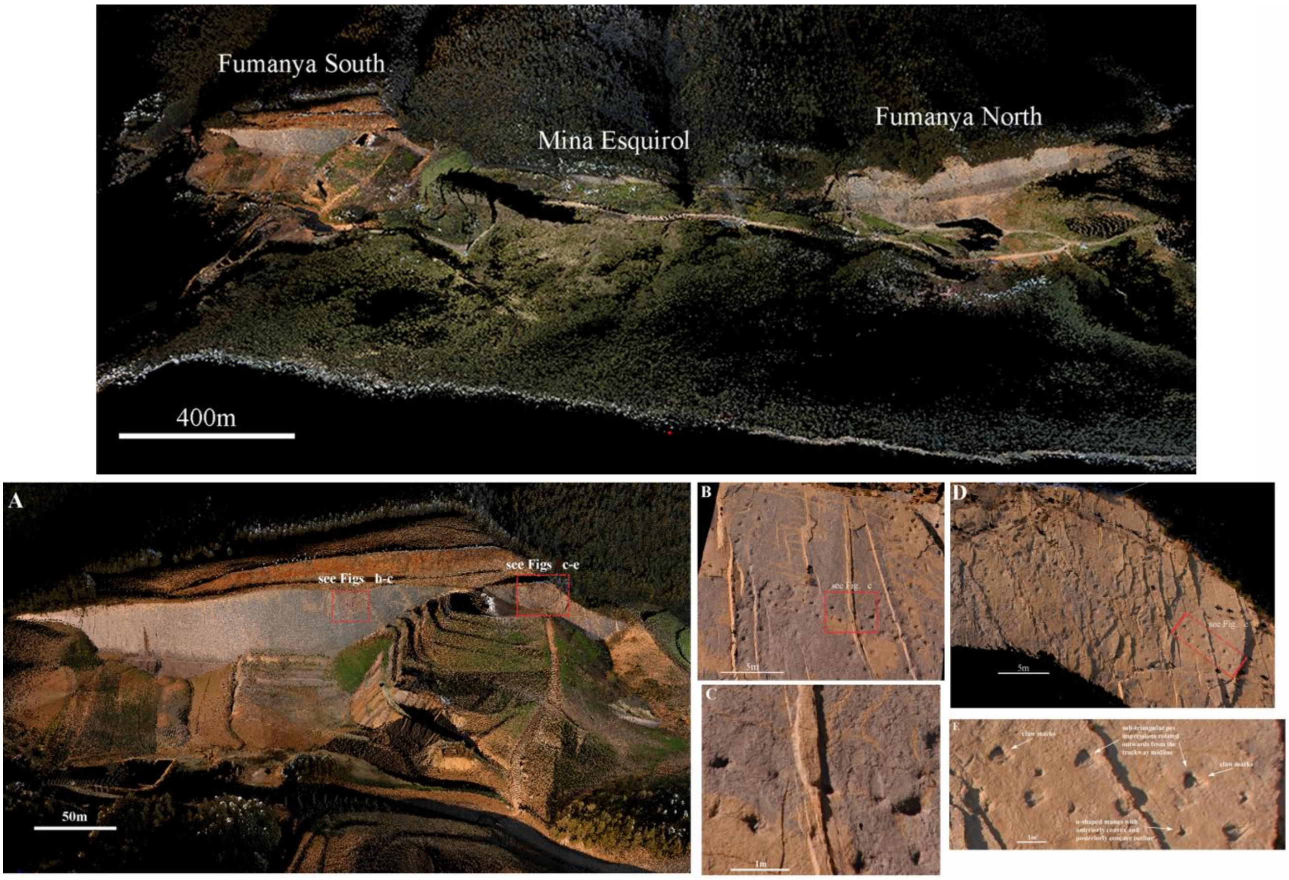

Figure 2. The Digital Outcrop Model above shows the Fumanya dinosaur tracksites in its surrounding 3D landscape and consists of a sequence of overlapping coloured scans that have been aligned and geo-referenced. In the field a 360^{o} scans and photographic panoramas were carried out in conjunction with smaller higher resolution scans of the track-bearing surface. The model can be viewed and manipulated (i.e. rotated 360^{o}, zoom in/out) as a single scaled 3D object. (A-E) High-resolution photo-textured scans can also be inserted with extremely high accuracy allowing areas of high scientific value to be viewed and interrogated in more detail. Modifed from Bates et al. (2008b).

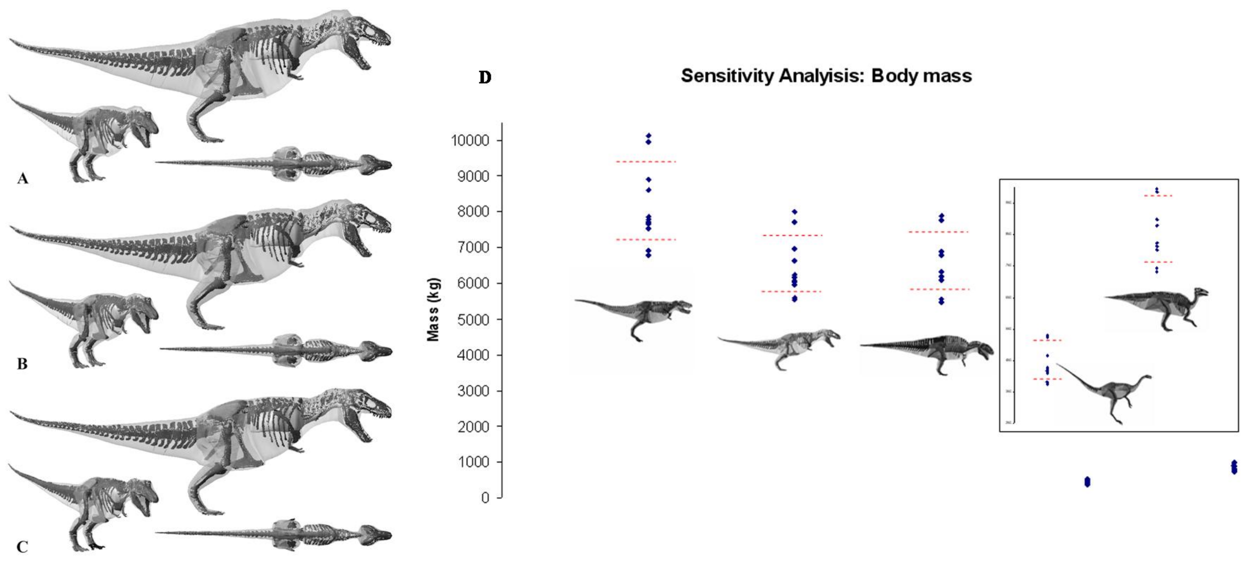

Figure 3. (A-C) A range of small to large volumetric reconstructions of *Tyrannosaurus rex* based a 3D laser scanned skeleton. (D) Range of body masses predicted for a range of theropod dinosaurs based on 3D computer volumetric models (from Bates et al. 2009a).

surface has hindered quantitative documentation of the ichnites. Using integrated laser scanning imaging and photogrammetry it has been possible to construct high resolution Digital Outcrop Models (DOM) of the tracksites (Fig. 2). Photo-textured DOMs are a powerful visualization tool and function as fully 3D interactive databases that preserve information about the site that would otherwise be lost to erosion. Laser scanning-derived DOMs have the potential to contribute profoundly to future geoconservation projects, particularly as a tool for rapid documentation and monitoring of heritage sites and promoting education and tourism, particularly through virtual fieldtrips.

4.0 Biomechanics

Laser scanning and Computer-Aided Design (CAD) software has been used to create volumetric models of a number of non-avian dinosaurs (Fig. 3). This allowed calculation of segment masses, centres of mass and moments of inertia for a best estimate reconstruction. Subsequently an extensive sensitivity analysis has been conducted in which the volumes of body segments and respiratory organs were varied in an attempt to constrain the maximum plausible range of mass values (Fig. 3b). The result is a wide range in actual mass and inertial values (3c), emphasizing the high level of uncertainty in such reconstructions. However, the centre of mass is well constrained below and in front of hip joint in each model.

5.0 Public engagement & education

Public engagement and the promotion of science to a wider non-academic audience form an integral role of the professional scientist in the 21st Century. The high level of public interest in palaeontology means that the earth's prehistoric past can provide an important medium through which to communicate information concerning contemporary scientific issues. Digital imaging and documentation techniques offer one means to achieve this feat, particularly as digital models of fossils can be effectively used to visually communicate what would otherwise be complex or technical information to a non-academic audience. In a previous paper (Bates et al. 2009d) we detailed two case studies in which digital data taken from our own research that had contributed to public engagement programmes and the use of fossils as an educational resource. Although currently in use, these examples are continually being developed and updated as the research progresses, illustrating the ease with which digital research data can be modified to suit a wider audience.

The eye-catching presentation and popularity of large enigmatic prehistoric animals like dinosaurs make 3D interactive models ideal for public engagement activities. A range of models have been used in a series of science open days at museums and schools as part of a dinosaur biomechanics exhibit (Fig.4). The sessions proved very successful, receiving a significant amount of interest from visitors of all ages. This success prompted the development of a stand alone interactive display that could be housed in a museum or on a website. One such interactive display has been developed based on an *Allosaurus* mount known as 'Big Al' and was developed specifically for the University of Wyoming Geological Museum (Wyoming, USA). Big Al represents one of the most complete dinosaurs from the Morrison Formation (Wyoming, USA), excavated in 1991 from the eastern Bighorn Basin near the town of Shell. Although the theropod *Allosaurus* has been known for over 100 years, Big Al has one of the most complete skulls and skeletons of this dinosaur. The skeleton is accompanied by a series of text- and image-based (photographs, illustrations) information boards that explore the palaeoecology of this animal and how it may be deduced from the physical evidence displayed in the fossil. This new interactive display allows visitors to answer for themselves 'How big was Big Al?' by selecting a number of possible body segment masses, according to how they think Big Al would have looked (Fig. 4). The values of our own best estimate reconstructions are provided to allow the user to compare results. Designed with Adobe Flash, the interactive display seamlessly integrates still images, text, and animations in a fully interactive manner. The nature of the software allows the application to be operated via a mouse or touch screen control, and is equally useable and effective as a museum gallery

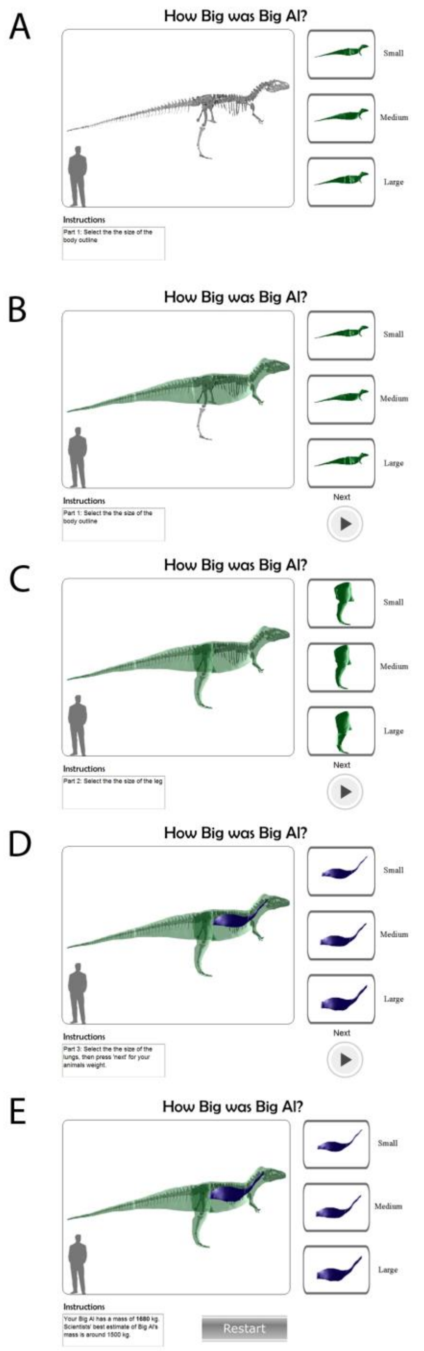

Figure 4. The 'How big was Big Al?' interactive body mass display, made in Adobe Flash. In a succession of screens the user is able to select from a range of different sized body, leg and respiratory volumes and until they have completely reconstructed Big Al. Each segment has a mass attached (using data from our own scientific publications) and the final screen reveals the body mass of Big Al based on their particular combination of chosen segment volumes.

exhibit, or via website delivery to personal computers at home (Bates et al. 2009d).

6.0 Conclusions

The application of remote sensing methods, such as laser scanning and photogrammetry, in palaeontology is still in its infancy and the full potential of these techniques has yet to be realized. Planned future applications include imaging large living animals to approximate mass properties, scanning body fossil excavations and the development of web-based 3D museum tours from laser and photogrammetric data.

References

Bates, K.T., Manning, P.L., Vila, B. & Hodgetts, D. 2008a. Three-dimensional modelling and analysis of dinosaur trackways. *Palaeontology*, 51, pp. 999-1010.

Bates, K.T., Rarity, F., Manning, P.L., Hodgetts, D., Villa, B., Oms, O. & Gawthorpe, R.L. 2008b. High-resolution LiDAR and photogrammetric survey of the Fumanya dinosaur tracksites (Catalonia): implications for the conservation and interpretation of geological heritage sites. *Journal of the Geological Society, London*, 165, pp. 115-127.

Bates, K.T., Manning, P.L., Hodgetts, D. and Sellers, W.I. 2009a. Estimating mass properties of dinosaurs using laser imaging and computer modelling. *PLoS ONE* 4(2), e4532 doi:10.1371.

Bates, K.T., Falkingham, P.L., Breithaupt, B.H., Hodgetts, D. Sellers, W.I. and Manning, P.L. 2009b. How Big Was „Big Al‟? Quantifying the effect of soft tissue and osteological unknowns on mass predictions for *Allosaurus* (Dinosauria:Theropoda). *Palaeontological Electronica* 12(3), 14A, pp. 1-33.

Bates, K.T., Breithaupt, B.H., Falkingham, P.L., Hodgetts, D., Matthews, N. & Manning., P.L. 2009c. Integrated LiDAR and photogrammetric documentation of the Red Gulch Dinosaur Tracksite (Wyoming, USA). In: S.E. Foss, J.L. Cavin, T. Brown, J.I. Kirkland & V.L. Santucci (eds), Proceedings of the Eighth Conference on Fossil Resources, pp. 101-103.

Bates, K.T., Falkingham, P.L., Hodgetts, D., Farlow, J.O., Breithaupt, B.H., O'Brien, M., Matthews, N., Sellers, W.I. & Manning, P.L. 2009d. Digital imaging and public engagement in palaeontology. *Geology Today*, 25, pp. 134-139.

Fabuel-Perez, I., Redfern, J. & Hodgetts, D. 2009. Sedimentology of an intra-montane rift-controlled fluvial dominated succession: The Upper Triassic Oukaimeden Sandstone Formation, Central High Atlas, Morocco. *Sedimentary Geology*, 218, pp. 103-140.

Wilson, P., Hodgetts, D., Rarity, F., Gawthorpe, R.L. & Sharp, I.R. 2009. Structural geology and 4D evolution of a half-graben: New digital outrcrop modelling techniques applied to the Nukhul half-graben, Suez rift, Egypt. *Journal of Structural Geology*, 31, pp. 328-345.

Acknowledgements

The work described here was largely funded by doctoral dissertation grants from the National Environmental Research Council (UK) to KTB (NER/S/A/2006/14101) and PLF (NER/S/A/2006/14033), with additional funding to KTB from the Jurassic Foundation and the Palaeontological Association Sylvester-Bradley Award. Z+F UK are thanked for their loan of the Imager 5006i for scanning dinosaur skeletons. Parts of this work were also funded by National Geographic and NZTV.