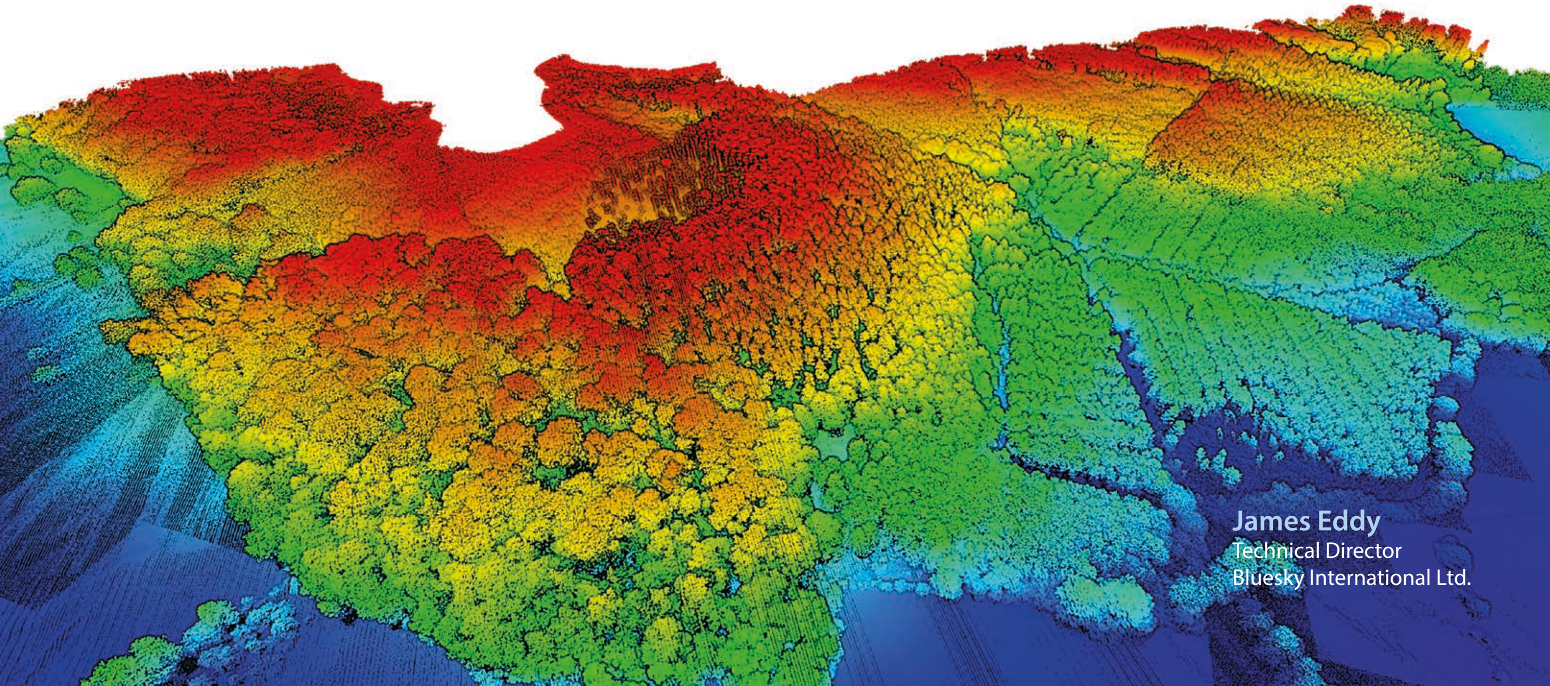
White Paper: **LiDAR Applications**

"You'll be amazed what you can do with LiDAR"

Abstract

Airborne LiDAR is the most rapid and efficient method of accurately measuring the height of the earth's surface and objects on it. This white paper is aimed at the non-expert to explain what LIDAR is, how it works and what the applications are for the resulting data. LiDAR is often perceived as just a method of creating a terrain model, but it is far more than that, and for many applications it can save time and money by reducing fieldwork or more manual methods. The paper gives several examples of how LIDAR can be applied across a range of sectors and disciplines. The use of LiDAR is only set to increase over the coming years, and will be commonplace as a de facto method of measuring both urban and rural landscapes.



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White Paper: **LiDAR Applications**

Executive Summary

This paper is aimed at providing the reader with an introduction to an evolving technology of measuring the height of land using lasers mounted on an aircraft. The technique is known a LiDAR (sometimes referred to as light detection and ranging) and is now widely acknowledged to be the most rapid and efficient method of measuring large areas of terrain and landscape, in both urban and rural areas.

The paper is aimed at the non-expert and presents a brief overview of the technology, the data, and most importantly, it focusses on the wide range of applications in which LIDAR is now a critical tool. The aim is to demonstrate to the reader that LiDAR is not just for creating "terrain models", but has wider and far-reaching benefits, which encompass several disciplines. It therefore has a wider use than expected across multidisciplinary organisations, including local authorities, civil engineers and environmental consultants. One data supply can have multiple uses and it has become an increasingly essential component in many applications from flood mapping, urban modelling, construction, infrastructure planning to archaeology.

This white paper discusses Airborne LiDAR, what it is, the science behind it and why it has become essential to many mainstream applications.

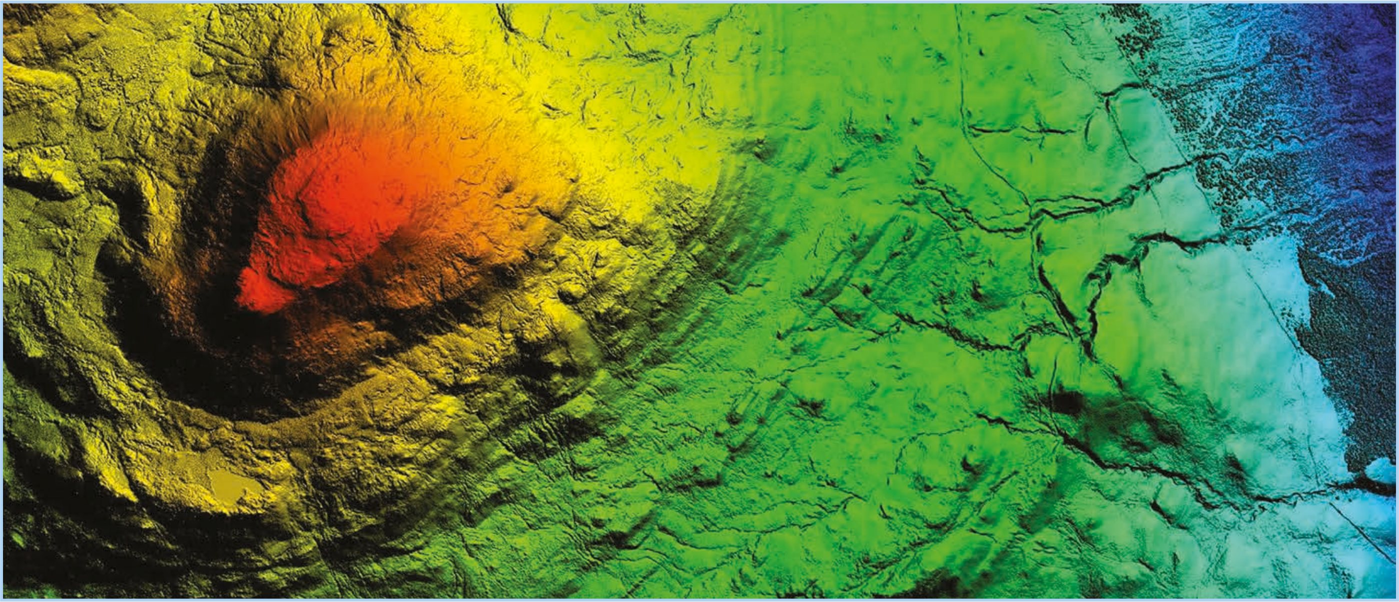

Figure 1 *- Airborne LiDAR (Isle of Skye)*

Introduction - What is LiDAR?

LiDAR (Light Detection and Ranging) was conceived in the 1960s for metrological purposes, soon after the invention of the laser in the 1950s. A laser is a device that generates an intense beam of constant light, of a fixed wavelength. Over the past ten years there has been a proliferation in the use of LiDAR sensors, regularly used in both airborne and ground surveying, as well as in many other sectors, including surgery, cutting, guidance, and measuring. This has been accompanied by an increase in the awareness and understanding of LiDAR in previously unrelated industries as the application of LiDAR has been adopted. Lasers themselves are very accurate in their ranging capabilities, and can provide distances accurate to a few millimetres.

An airborne LiDAR system is made up of a single laser with a receiver. The laser produces an optical pulse (a beam of light) that is transmitted towards the ground, reflected off the ground or an object it hits, and returned to the receiver. The receiver accurately measures the time of travel of the pulse from its start to its return, and the intensity of the light returned. With the pulse travelling at the speed of light, the receiver senses the return pulse before the next pulse is sent out. As the speed of light is known, the travel time can be converted to a range measurement. The LiDAR combines the laser range (i.e. the distance), laser position from GPS, and laser orientation from an inertial measurement unit (IMU), accurate x, y, z ground coordinates can be calculated for each individual laser pulse. The IMU measure the attitude of the aircraft (i.e. the roll, pitch and yaw) to a very high degree of accuracy. The LiDAR sensor collects a huge amount of data and a single survey can easily generate millions of points totalling several terabytes of data.

Airborne lasers can work at up to 500Mhz, which means it can fire up to 500,000 pulses of light per second. Modern LiDAR systems can record multiple returns from the same pulse. If a beam hits a tree, for example, some of the beam will hit a leaf and send a reflection (or return), the rest of the beam will continue down sending returns from other leaves and branches, eventually hitting the ground, and reflecting off that. This is known as the last return. By evaluating the time differences between the multiple return signals the system can differentiate between buildings and other structures, vegetation, and the ground surface. This process is used to remove surface features to produce "bare earth" models (DTM) and other enhanced data products. For example it is also possible to do selective feature extraction, such as the removal of trees and other vegetation to leave just the buildings.

The initial LiDAR data can be further enhanced using additional post processing, some of which can be automated and some are manual. Further processing utilises the multiple return signals from each laser pulse. By evaluating the time differences between the multiple return signals the post processing system can differentiate between buildings and other structures, vegetation, and the ground surface. This process is used to remove surface features to produce bare earth models - Digital Terrain Models (DTM), and other enhanced data products. For example, it is also possible to do selective feature extraction, such as the removal of trees and other vegetation to leave just the buildings.

As LiDAR is what is known as an active sensor, in other words it emits its own light pulse, it can be operated in the day or night and therefore are more opportunities to capture the data unlike aerial photography which relies on daylight.

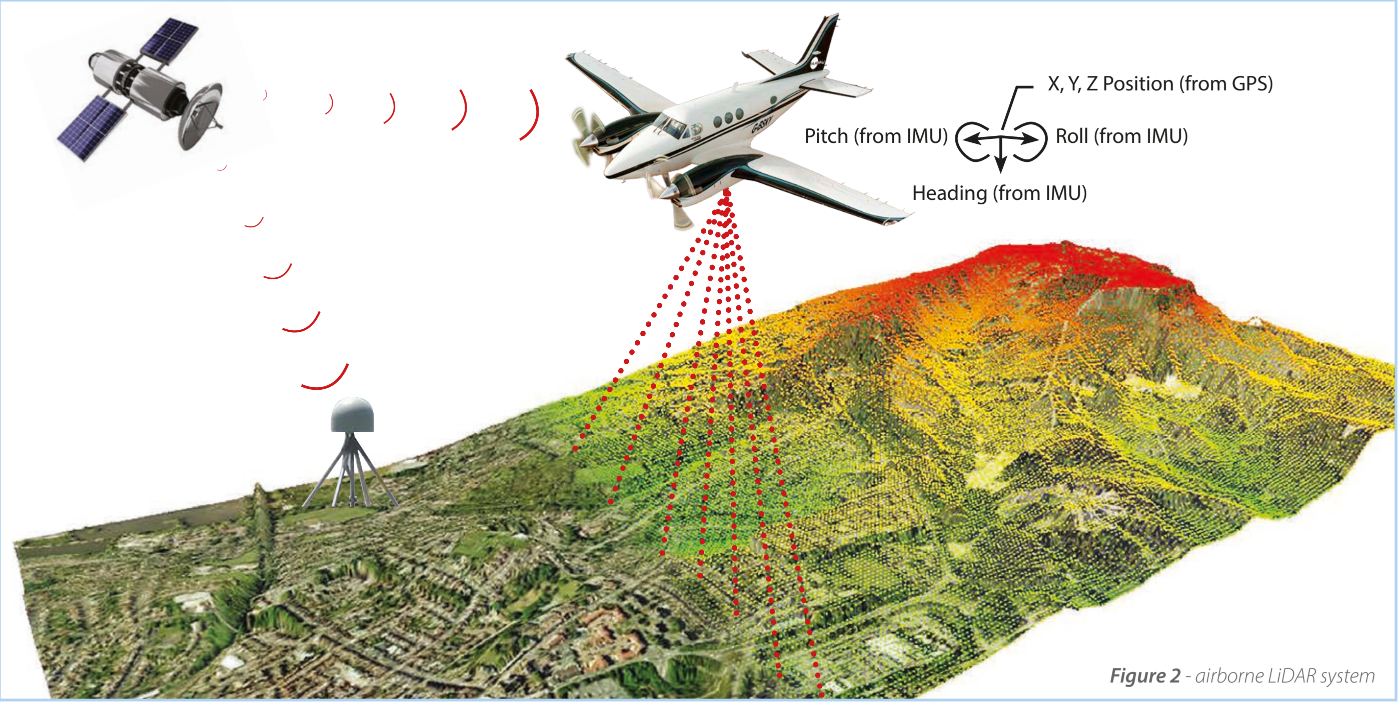

***Figure 2** - airborne LiDAR system*

LiDAR Data

As discussed above, the LiDAR system records a series of three dimensional points, to create what is known as a point cloud. A point cloud is simply a virtual "cloud" of points in 3D space. If you imagine a 3D shape with the surface covered in enough points to replicate the shape of the object. Point clouds are intended to represent the 3D external surface of an object, for airborne LiDAR this is the surface of the earth. For modern airborne LiDAR is accurate to within about 10cm of its actual position.

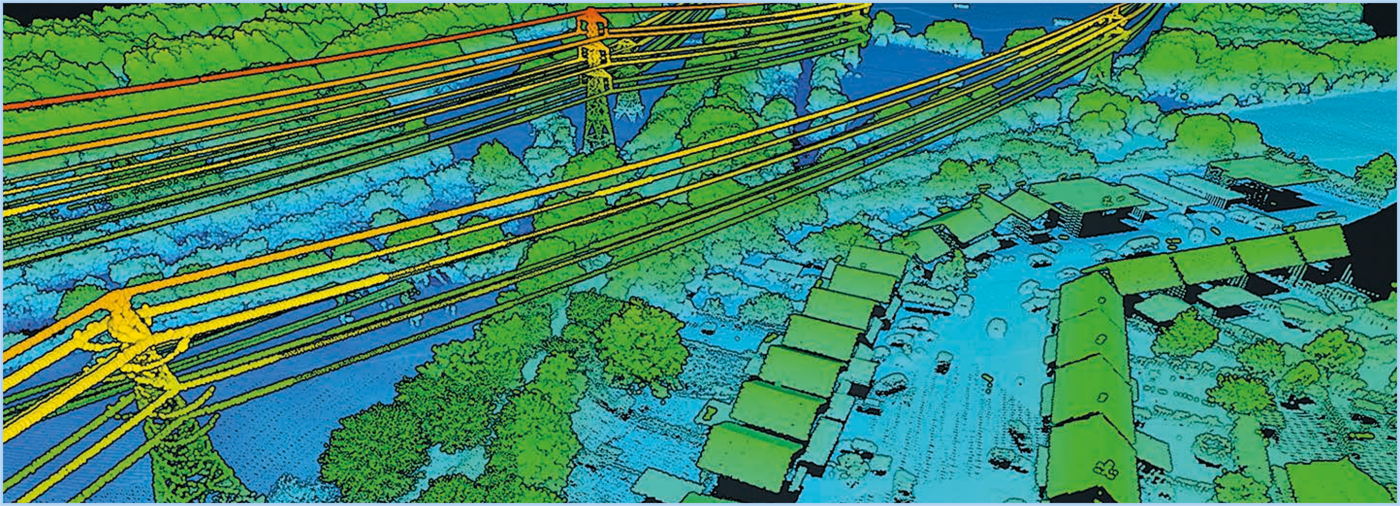

Figure 3 *- Example of LiDAR point cloud.*

Point clouds need specialist software to view and work with, therefore the point cloud is often converted to a 3D grid, with regularly spaced pixels, for example:

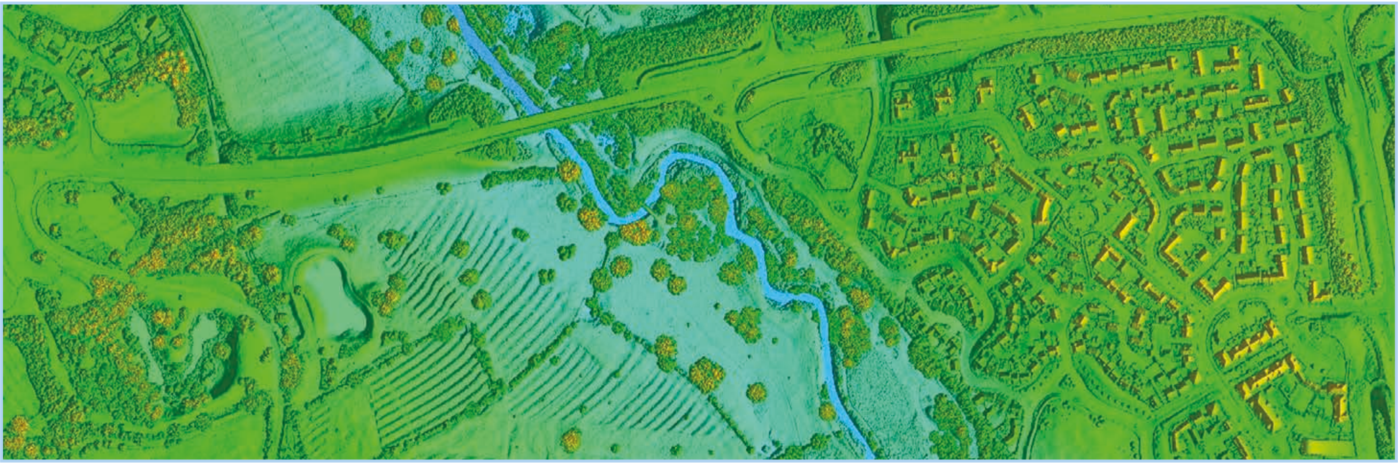

Figure 4 *- The image above shows an area as a Digital Surface Model (DSM), which contains the buildings and vegetation. Such objects are removed in the DTM during the data processing stage*

Airborne LiDAR Applications

LiDAR is very easy to work with to create data products that meet a wide range of needs. The simplest form of data acquired from LiDAR is an ASCII format file-containing x, y, and z coordinate data. This coordinate data corresponds to the geographic 3-D position of an actual LiDAR return. The return and associated coordinate could be the position of a return off the ground, a building, a tree, or any other object that the laser beam has hit and been reflected from. The data can be imported into a variety of software, including GIS (Geographical Information Systems), CAD and other more specialist software for use in many applications, some of which are highlighted here.

Flood Modelling

Features such as buildings, constructed river banks or roads have a great effect on flow dynamics and flood propagation. Only high-resolution input data can solve the purpose that relates to the systems topography as well as to the identified features. Frequent urban flooding has been observed in many parts of the UK over the past decades and an urgent need is identified to improve and increase our modelling efforts to address the effect model input data has on the simulation results. Even differences of a few tens of centimetres can mean a lot in loss calculations in urban areas. LiDAR has brought this level of detail to the industry allowing for much more accurate flood prediction models to be created.

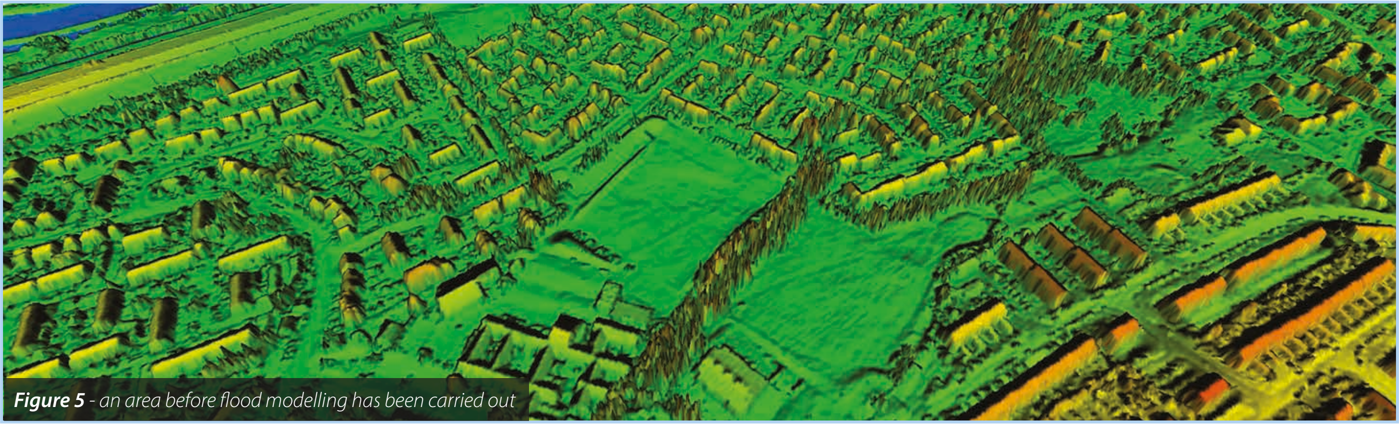

Figure 5 *- an area before flood modelling has been carried out*

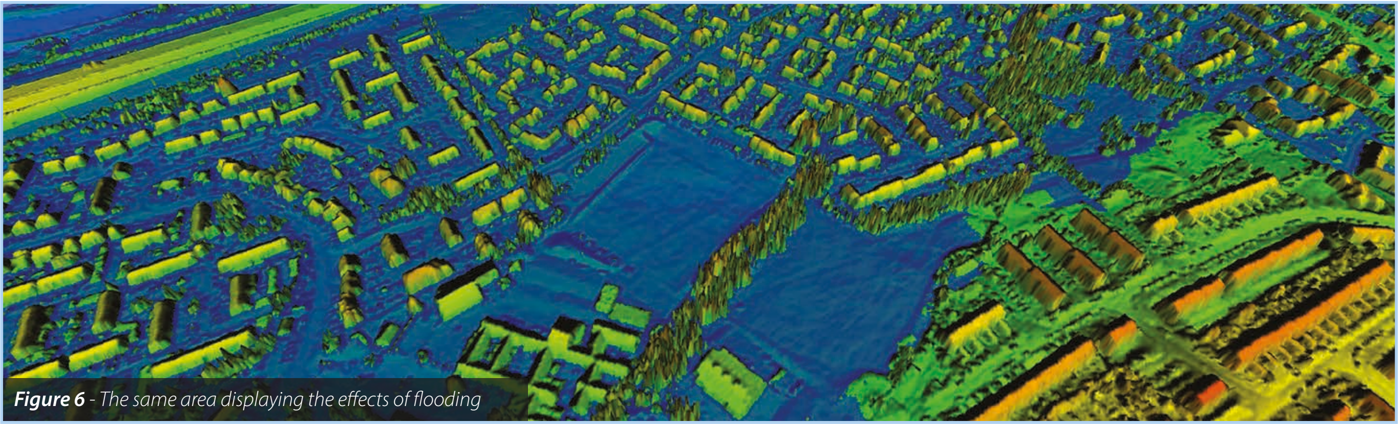

Figure 6 *- The same area displaying the effects of flooding*

The Flood and Water Management Act 2010 and Flood Risk Regulations 2009 designated the Unitary and County Councils as Lead Local Flood Authorities. Duties include the recording of the condition of flood risk management assets to ensure that any degradation in condition is recorded and dealt with to ensure protection is maintained where possible. With such widespread flooding, LiDAR is the most efficient method to assist Lead Local Flood Authorities in the assessment of changes in manmade or natural features. LiDAR data can also be incorporated into relief, rescue and flood simulation software to provide advanced topographical information for risk assessment.

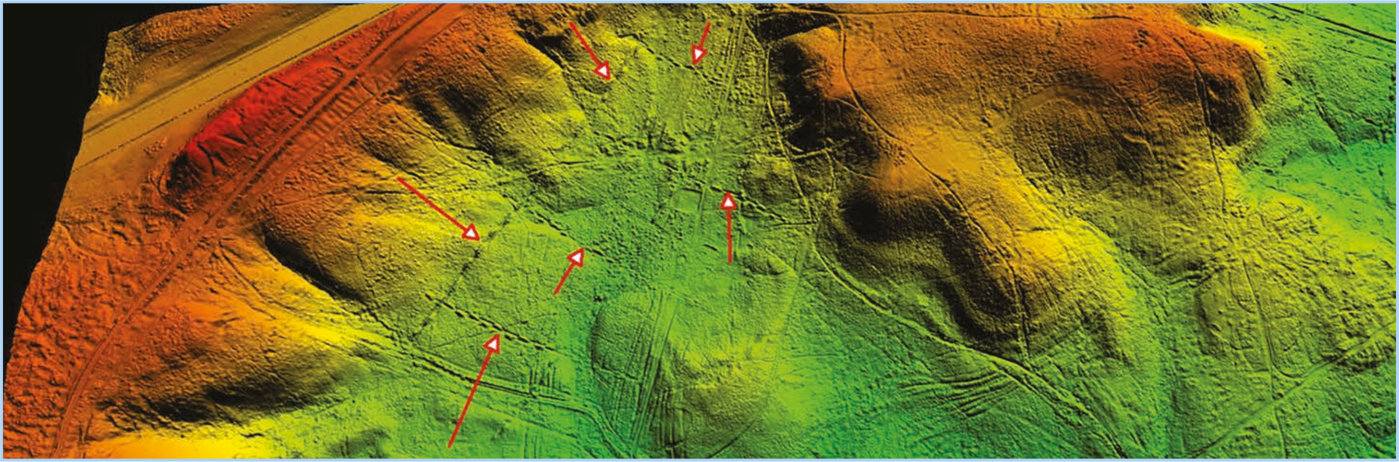

Figure 7 - *A key application is flood defence work. Existing users have uncovered previously unknown ponds and bunds buried deep in the undergrowth within woodlands which they are repairing to attenuate flooding. Note the Iron Age fort in the bottom left corner*

Arboriculture, Forestry Management and Planning

Accurate information on the terrain, tree heights and densities is critical to tree managers, foresters and natural resource managers. LiDAR is unique in its ability to measure the vertical structure of forest canopies and individual tree crowns. As well as mapping the ground beneath the forest, LiDAR is able to predict canopy bulk density and canopy base height. Both of these factors can be used for, amongst other things, canopy fuel capacity for use in fire behaviour models. LiDAR surveys allow large scale surveys to be taken with a level of cost-effectiveness not previously available. Another use of LiDAR is the measurement of peak height to estimate the root expanse. This is a valuable tool for insurers when considering houses in particular areas. Knowing the proximity of trees and invasive species to property, overhead power cables and other infrastructure is an increasing application. It is also increasingly being used to identify habitat corridor gaps, significantly reducing costs in comparison to large scale manual surveys.

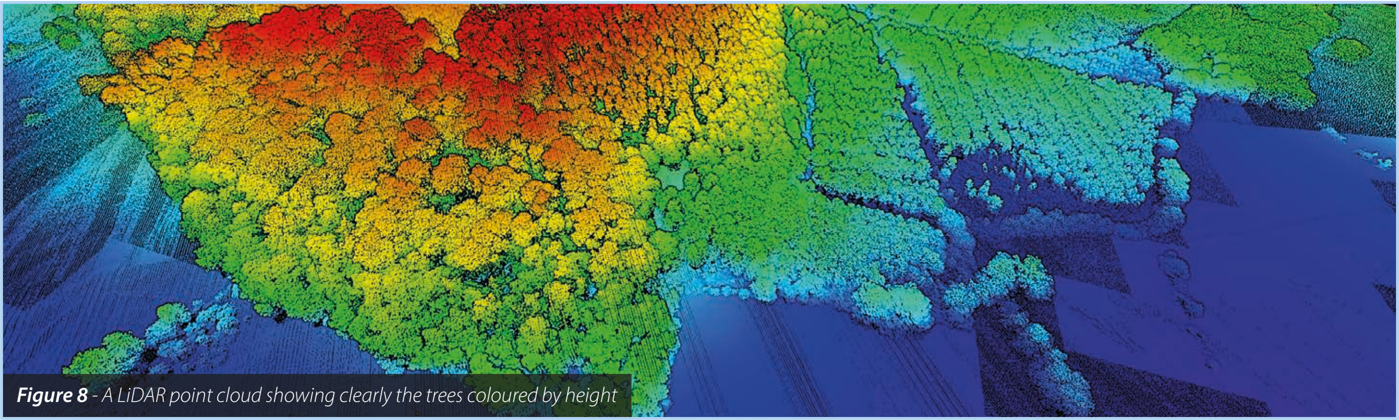

***Figure 8** - A LiDAR point cloud showing clearly the trees coloured by height*

Urban Planning

Urban, city, or town planning is the discipline of land use planning which explores several aspects of the built and social environments of municipalities and communities. LiDAR data, when combined with digital orthophotos, can be used to create highly detailed Digital Surface Models and eventually Digital City Models. Using specialist software it is also possible to create estimated surface models of buildings from the original LiDAR data. This technology allows large area models to be created in a very short space of time. Accurate digital models are required today for many applications including Telecommunication and wireless communication (for calculating line of sight), disaster planning, air and noise pollution modelling and infrastructure planning. Combined with GIS, LiDAR can also help identify areas not previously mapped such as new buildings and extensions not captured on base maps. Slough Council for example have used their LiDAR survey to update their data - they were astounded to find a significant amount of previously unknown new buildings and extensions. Identification of these additions are critical for the emergency services and building inspectors, as well as understanding the implications for local infrastructure. LiDAR data can also be used with GIS and CAD software to help planners and engineers to model various scenarios for calculating the best outcome of a proposed construction, such as a new highway or development.

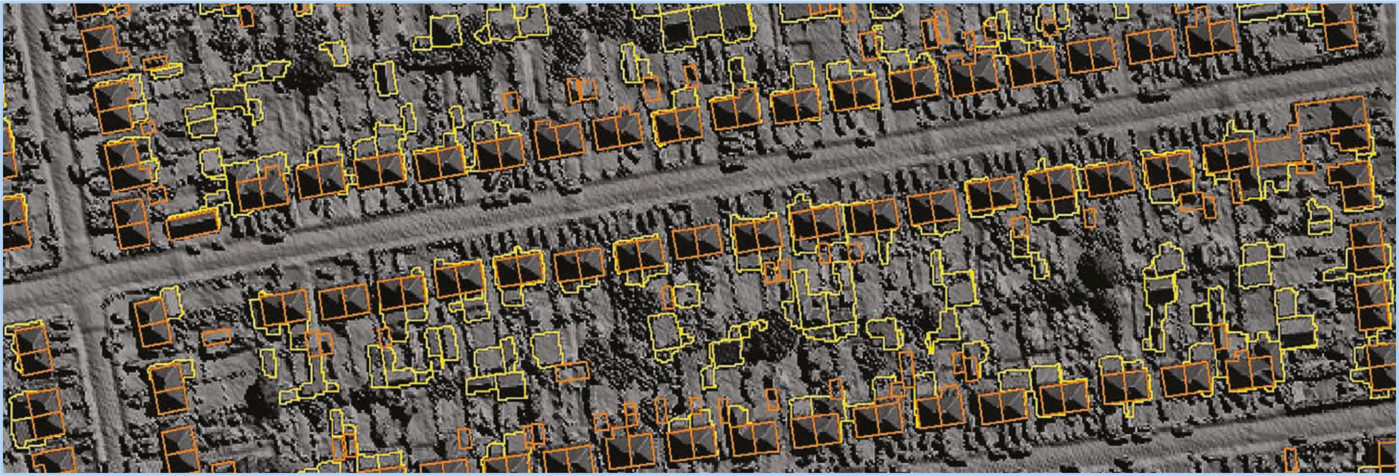

Figure 9 *- LiDAR can detect unmapped buildings: the orange are the mapped buildings and the yellow shows all buildings that do not appear to have been mapped*

Figure 10 *- Visualised LiDAR data with aerial photo draped over to demonstrate urban planning*

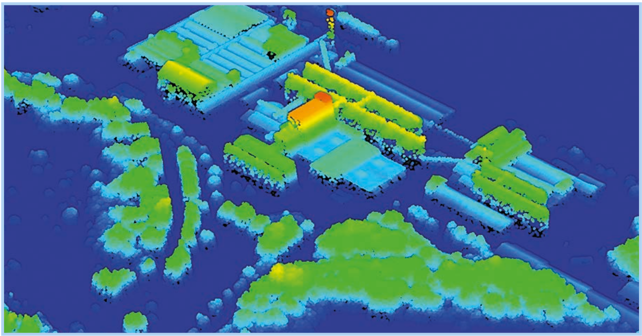

Figure 11 *- LiDAR coloured to show the relative height of buildings and trees*

Corridor Mapping

The built landscape is made up of a network of routes, which comprise transport or utilities forming corridors across the countryside. These corridors require very specific management, and high density LiDAR is now for many practitioners the main data source for this management.

Transportation corridor mapping to support engineering planning and change detection of road networks requires high spatial resolution and high scale engineering mapping accuracy. Airborne LiDAR data can be used to capture large amounts of data over large areas and ground based LiDAR can be used to add a greater amount of detail in specific areas. This method allows the most cost-effective process for site-specific LiDAR capture.

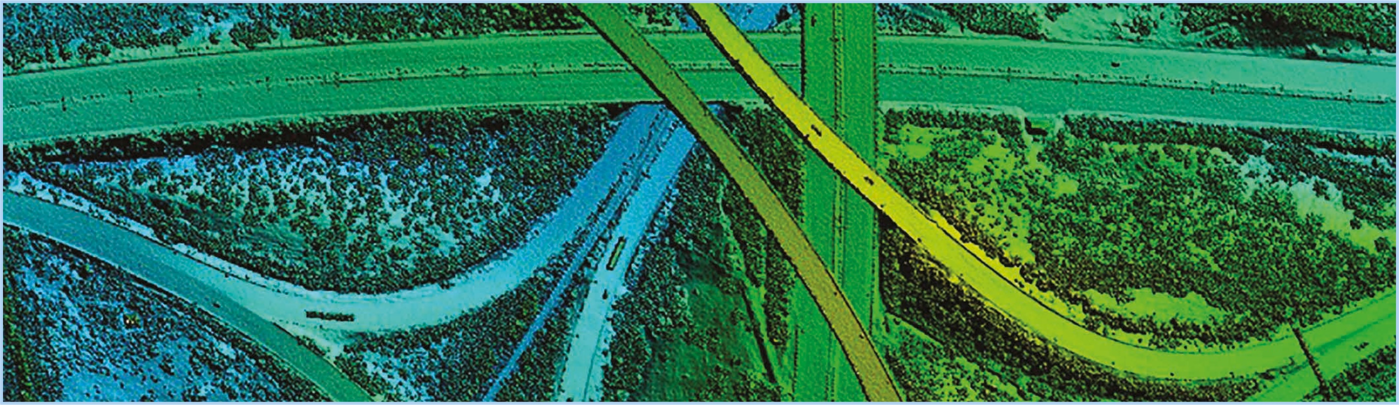

Figure 12 *- LiDAR of a major motorway junction*

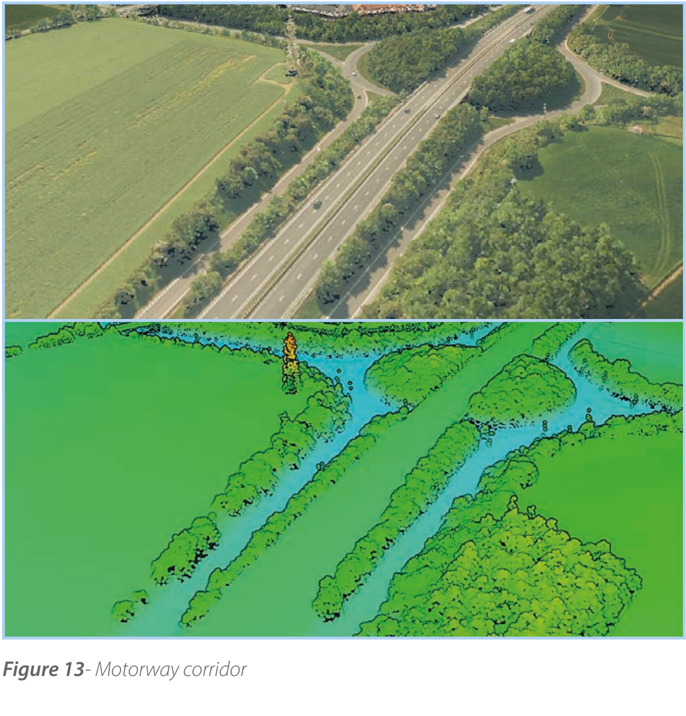

Figure 13*- Motorway corridor*

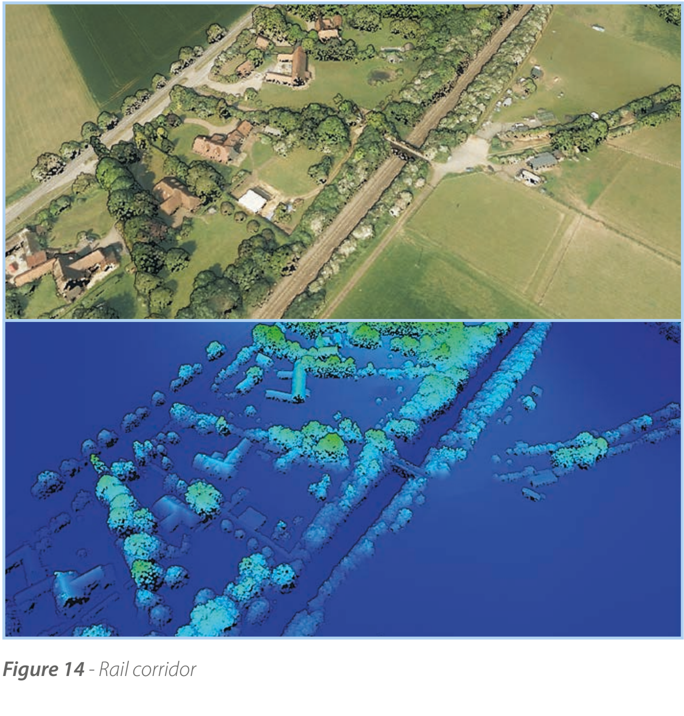

Figure 14 *- Rail corridor*

Power Lines

Power transmission line surveys are also regularly undertaken using LiDAR, where vegetation overlap and potential damage can be accurately assessed and targeted. Very high density LiDAR allows the detection of individual power lines and components making up the pylons, which can be used to measure the sag of lines (catenary) and even the individual insulators.

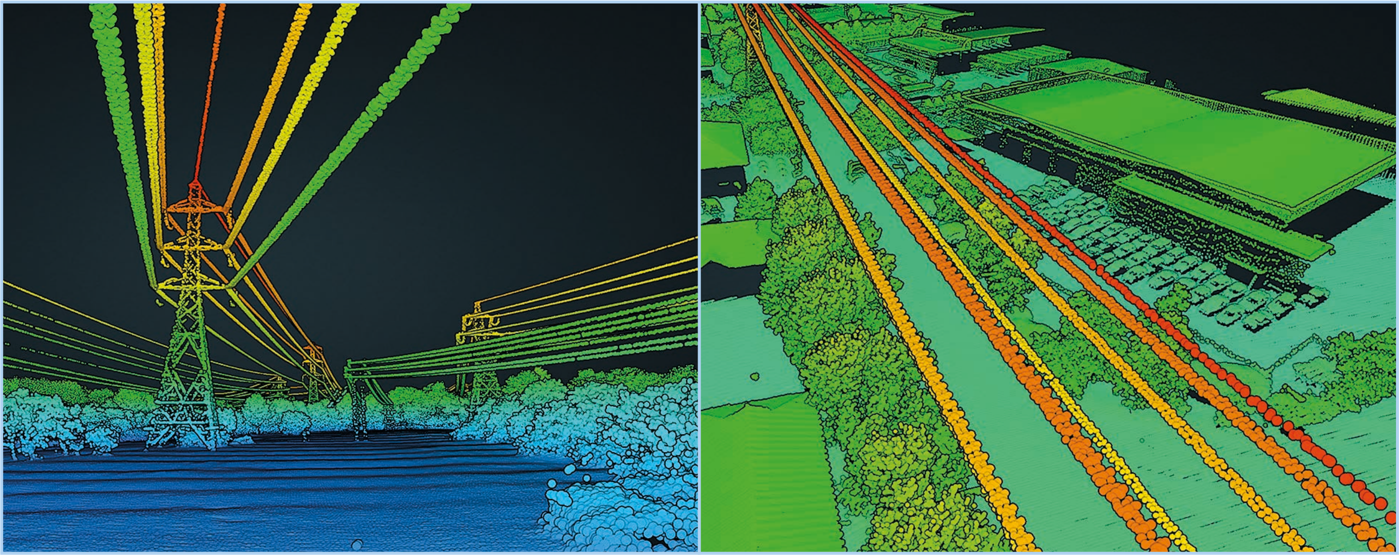

Figure 15 *- Point clouds of high voltage powerlines*

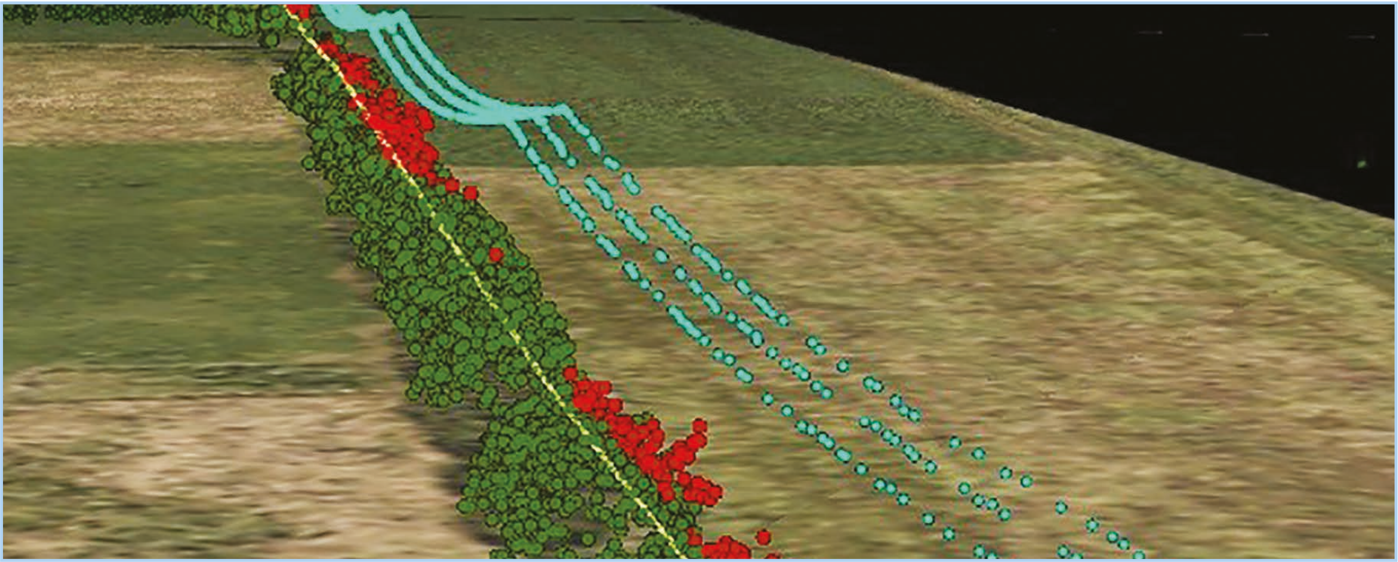

Figure 16 *- Point cloud data of powerlines showing proximity to trees*

Quarries, Minerals and Waste (Volumetrics and Exploration)

LiDAR can be used to survey land to see its suitability for mining and quarrying, as well as give an accurate indication of environmental impact. LiDAR's high accuracy also means that a quick survey can be undertaken that will give precise volumetric measurements for existing quarries and waste materials within a few centimetres. The same method can be used to measure stockpiles of coal and other such materials.

Figure 17 *- Visualisation of LiDAR of a quarry with aerial photography*

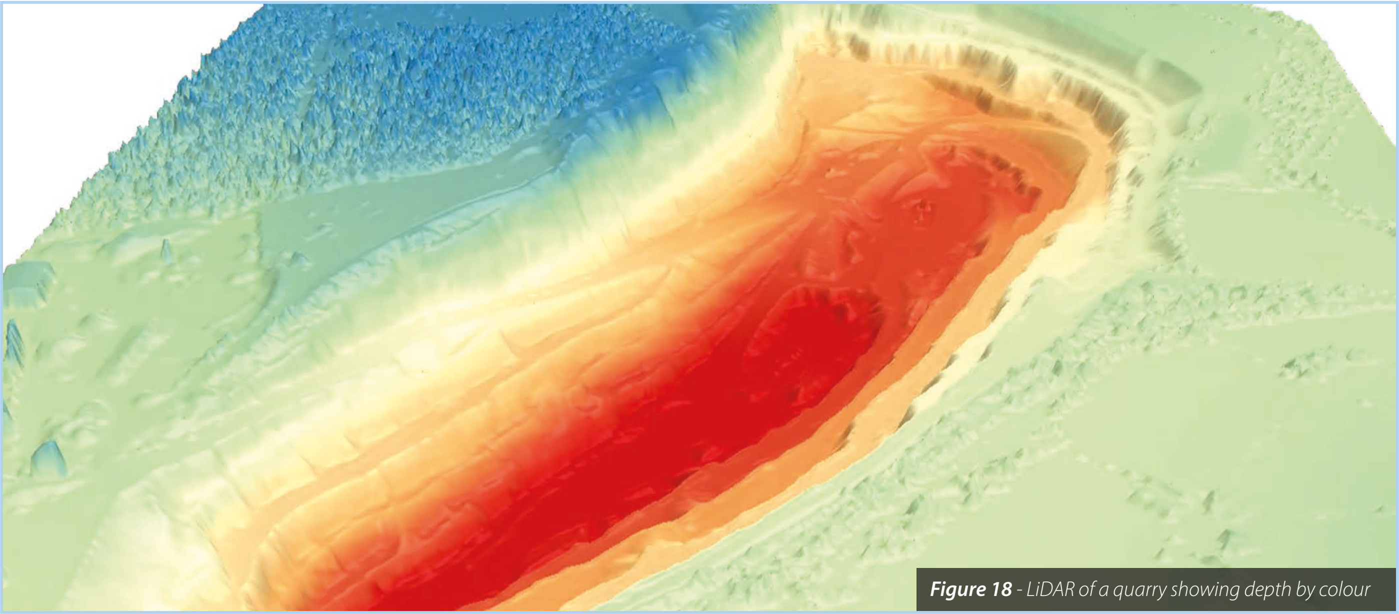

Figure 18 *- LiDAR of a quarry showing depth by colour*

Archaeology

LiDAR is increasingly used in the field of archaeology including aiding in the planning of field campaigns, mapping features beneath forest canopy, and providing an overview of broad, continuous features that may be indistinguishable on the ground. LiDAR can also provide archaeologists with the ability to create high-resolution Digital Elevation Models (DEMs) of archaeological sites that can reveal micro-topography that are otherwise hidden by vegetation which can be integrated into a Geographic Information System (GIS) for analysis and interpretation. Beyond efficiency, its ability to penetrate forest canopy has led to the discovery of features that were not distinguishable through traditional geo-spatial methods and are difficult to reach through field surveys. In the UK this has led to the discovery of many new important archaeological features including roman roads, forts and Iron Age enclosures and, even more recent history such as PoW camps and trenches.

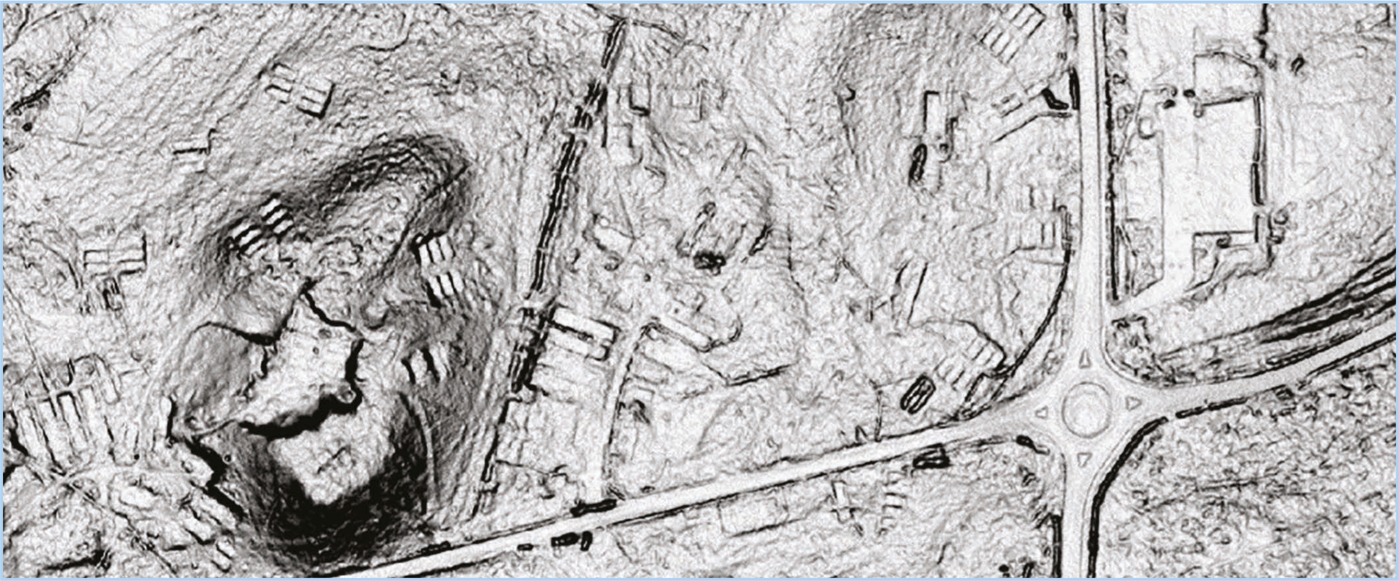

Figure 19 *- The LiDAR has revealed the building footprints of an old PoW camp enabling an exercise in recording some local history with older citizens*

Figure 20 *- World War One practice trenches are clearly visible in this LiDAR*

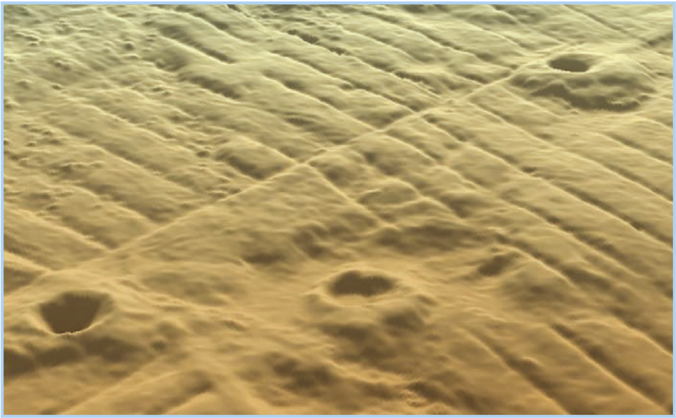

Figure 21 *- Old pit heads are clearly visible in this area of moorland in LiDAR*

Mapping and Cartography

Traditionally maps have been created from aerial photography and ground survey, but more recently LiDAR's high resolution and accuracy has enabled it to be used in the creation of maps. If the LiDAR has been classified then this can assist in road, building and vegetation identification and subsequent mapping. The 3D aspect of LiDAR makes it especially suitable for mapping terrain models, including complex mountain topography or in wetlands and other restricted areas. Other topographical data can be derived from LiDAR such as high-resolution contour maps, or maps of buried features such as pipelines. Mapping from LiDAR is in several countries becoming the standard method.

Figure 22 *- An example of how mapping extracted from LiDAR data can look*

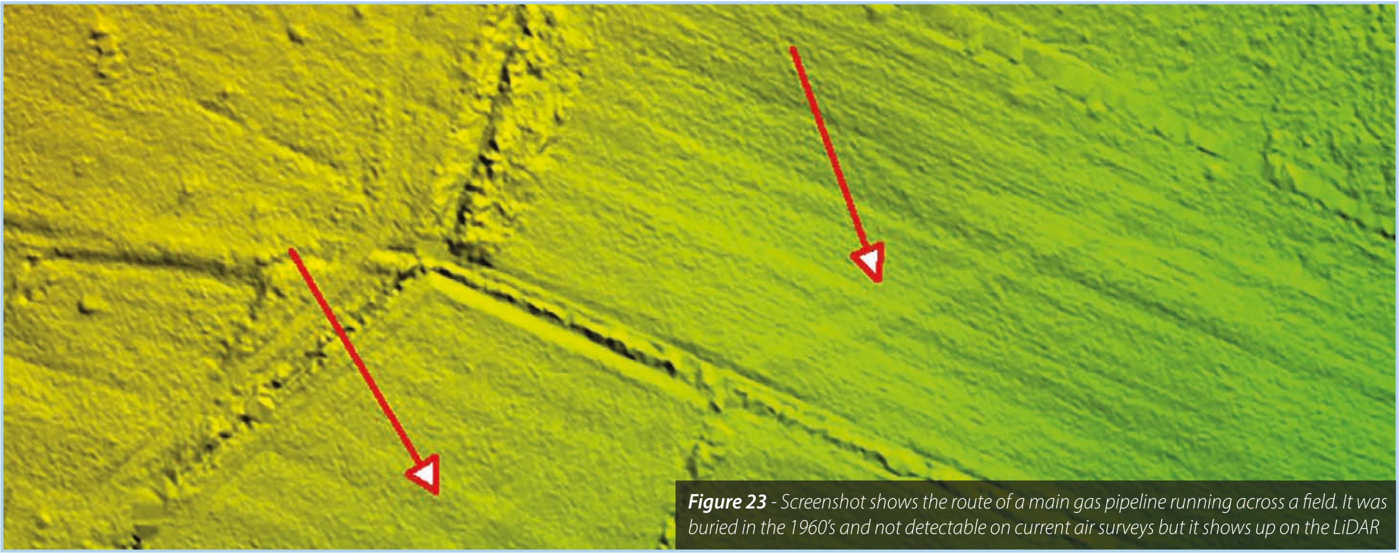

Figure 23 *- Screenshot shows the route of a main gas pipeline running across a field. It was buried in the 1960's and not detectable on current air surveys but it shows up on the LiDAR*

Renewable Energy

Renewable energy is a relatively new sector that has benefitted from LiDAR. Proposed wind farms are now often modelled using LiDAR during the planning stage, with the same data also used for public engagement to demonstrate the impact on the environment to the general public. As the LiDAR contains the shape of the land, trees and buildings, wind can be accurately modelled, so the turbines can be placed in the most effective and aesthetic location.

The solar industry is also beginning to benefit from LiDAR. The exact shape, slope and aspect of individual roofs can be very accurately measured for every roof across an entire city. The useable area can be then determined along with shading from nearby trees and buildings. This information, combined with annual solar radiation information is used to calculate the annual solar yield and potential return on investment. The entire solar potential can be determined for a city at a fraction of the cost of a full survey.

Figure 24 *- using LiDAR every suitable roof and the useable area has been identified*

LiDAR is also being used for the identification and yield calculations of ground based solar farms. The information within the LiDAR allows for quick estimations as the slope, aspect and shading of a field can be determined.

Coastline Management

LiDAR enables surveys to be taken of the coastline give great insight into the land/sea interface. This gives a snapshot of the coast at specific time intervals; combining multiple datasets over many years can give a valuable insight into occurrence of coastal erosion and deposition. Modelling of coastal change is the precursor to the planning of coastal defences and infrastructure; LiDAR is quickly becoming the gold standard for this preliminary work. In addition the detail of sensitive habitats such as sand dunes and salt marshes offer a powerful tool for coastline ecology and management.

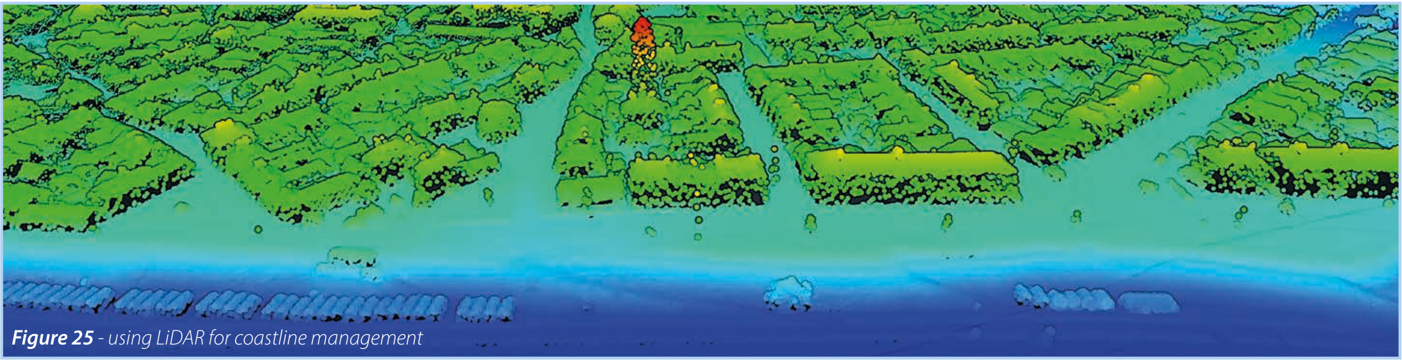

Figure 25 *- using LiDAR for coastline management*

Viewshed Analysis

The environmental impact of new development is key to the planning process, and one of the key factors is visibility. LiDAR can be used for assessing the visibility from and to new developments in a 3D environment, from new housing to wind farms and roads to warehouses.

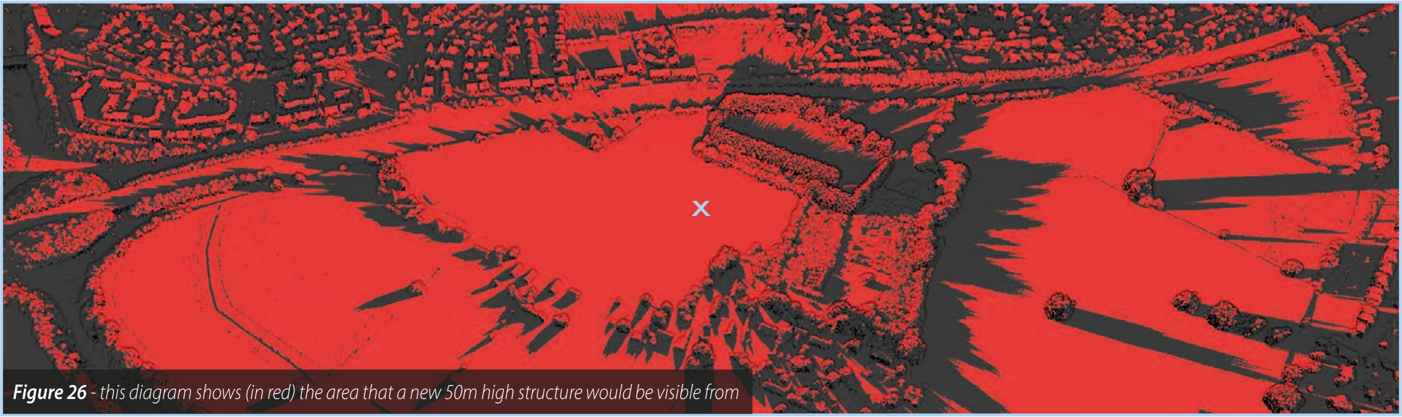

Figure 26 *- this diagram shows (in red) the area that a new 50m high structure would be visible from*

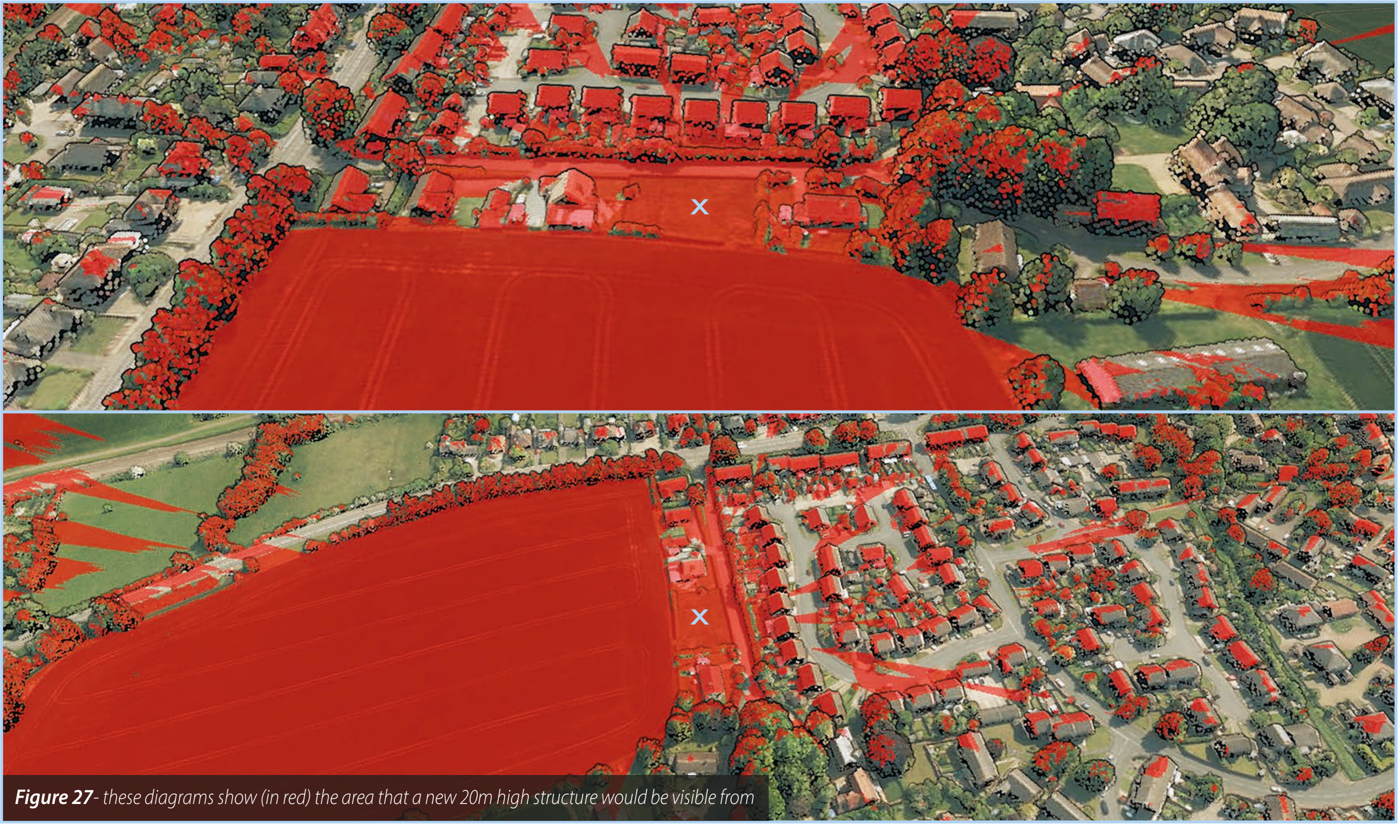

Figure 27 *- these diagrams show (in red) the area that a new 20m high structure would be visible from*

Shading Analysis

As mentioned above LiDAR contains all objects on the earth's surface which allows the data to be used for shade modelling. This is useful for the solar industry, as well as in the planning stage of new developments for shadow analysis.

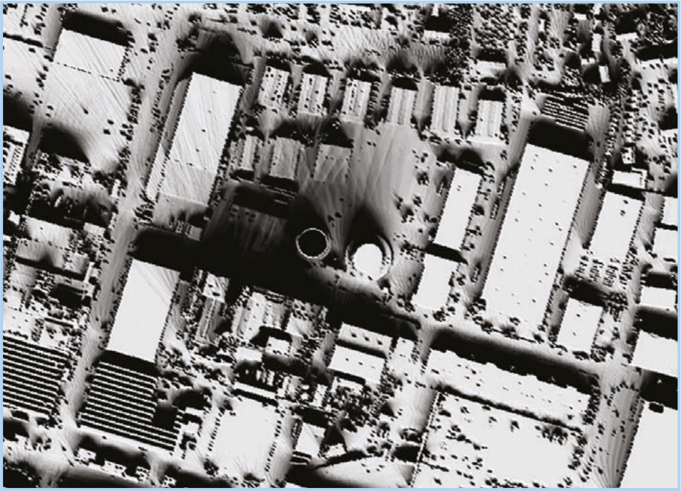

Figure 28 *- average shading in January*

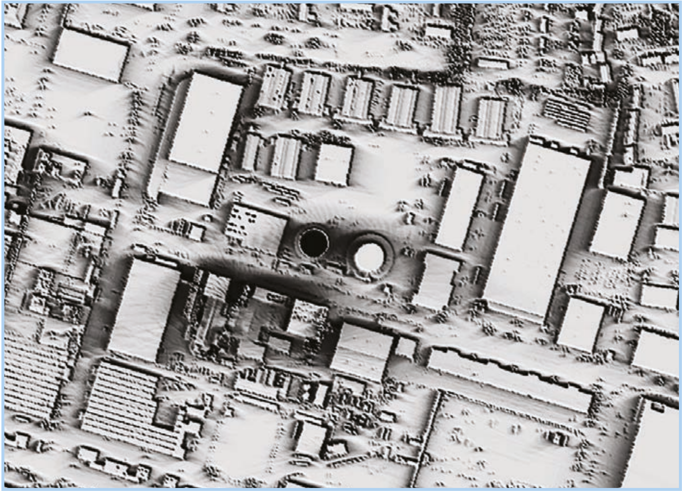

Figure 29 *- average shading in July*

Conclusion

The incredible accuracy and detail of LiDAR makes it an essential component of many applications that help inform local authorities and other land management organisations in their areas of responsibility. One LiDAR data supply can have multiple uses across many departments ranging from flood mapping, urban modelling, renewable energy, construction, infrastructure planning to archaeology. These multiple applications make LiDAR an incredibly cost-effective way of providing highly accurate base data across all departments of the Local Authority in a single flight. Regular flights will provide an unprecedented indication of change and risk, essential in assessing local authority policies.

The use of LiDAR within a wide scope of organisations, including Local Authorities is growing rapidly as the uses and data handling are becoming more understood. It is predicted that LiDAR will become as widespread as other geographic information such as mapping and aerial photography in the coming years.

It is often perceived as a very expensive data source, which was the case several years ago, but as with most technologies this type of data is becoming more affordable, particularly when it can be applied across so many disciplines.

LiDAR is a rapidly changing technology. The power, speed and accuracy of the sensors is ever increasing, and the scope of application will inevitably increase in line. We will perhaps see airborne LiDAR become as commonplace as aerial photography, with countries undertaking national surveys. Already some EU countries do have national LiDAR coverage, with more to follow. It is exciting time in to be in aerial survey.

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