Client Guide to 3D Scanning
-and-
Data Capture

BiM
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Executive Summary

This brief summary page discusses the scope and applicability of this client guide.

Key client questions addressed in this section:

- Why (and when) should I use 3D scanning technology?
- What is the value proposition for 3D scanning technology?

Laser scanning is a broadly applicable technology for a number of industries. Adoption in the architecture, engineering, and construction (AEC) sector is comparatively nascent, however, and the potential benefits during project development and for operations and maintenance of existing assets have not been fully realized by clients (procurers of 3D scanning services). This document attempts to bring clarity to this issue by 1) outlining the potential client benefits and the value proposition of 3D scanning, 2) analyzing the process for applying scanning throughout all project phases, and 3) identifying key client challenges to successful application of the technology. Ultimately, the guide will address how 3D scanning technology integrates with a building information modelling (BIM) approach, in support of the broader objectives of the United Kingdom (UK) BIM Task Group.

A common misconception of 3D scanning technology is that it is simply an incremental technological advancement of surveying, providing a safer, richer, and more rapid method of spatial data acquisition for surveying applications. While this is certainly one application of 3D scanning (and a very important one), the technology brings myriad opportunities to clients/owners, project managers, and engineers to monitor, assess, and analyze physical data captured from the environment. In addition to saving time and money to perform the same tasks with traditional methods, 3D scanning affords decision-makers with a revolutionary tool to evaluate existing conditions, assess construction progress, perform structural and cultural assessments, record as-built conditions, and manage large asset portfolios. In many ways, 3D scanning lays a solid foundation for the overall improvement of information management on projects and asset management programs.

In this guide, a variety of applications and their associated processes will be presented, with a focus on identifying the key challenges for clients looking to procure 3D scanning services for capital projects and facilities management applications. The key areas of application classified in the guide are 1) rapid urban scale mapping and modelling, 2) infrastructure and portfolio asset management, 3) site monitoring and assessment, and 4) structural analysis and inspection. For each type of application, the guide will focus on appropriate equipment and processes, with advice on establishing goals and functional requirements for procuring 3D scanning services. The process of delivering these services, from procurement to handover, will be discussed to help readers understand what applications are relevant for different phases of a construction project. Finally, applications for existing asset portfolios will be examined, with a focus on streamlining operations and maintenance, and reducing facilities management costs.

As the equipment and service costs of laser scanning continue to decrease, the opportunity for leveraging 3D scanning in the AEC sector will become even more tangible. Many owners have already realised significant value from the application of 3D scanning, and ultimately this technology will surely change the way that many AEC professionals work. In anticipation of this development, this guide prepares owners, asset managers, service providers, project managers, and engineers for an integrated approach to the application of 3D scanning, and lays the groundwork for further research and investigation into the broad application and standardisation of this promising and beneficial technology as part of a holistic BIM approach.
### Graphical FAQ

Use this graphical representation of frequently asked questions (FAQ) to navigate to a specific section of the document to get a quick answer to a common question. This table also helps readers to understand the scope of the guide. Click on a box to navigate directly to section of the guide that addresses the question.

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why (and when) should I use 3D scanning technology?</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>What is the value proposition for 3D scanning technology?</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>What is 3D scanning technology?</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What equipment and measurement methods are used for 3D scanning?</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How do 3D scanning technologies compare with traditional methods of data capture?</td>
<td>X</td>
<td>X</td>
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<tr>
<td>What are the different ways that 3D scanning can be applied to my projects?</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>How can 3D scanning be useful for new construction projects?</td>
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<td>X</td>
<td>X</td>
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<td>X</td>
</tr>
<tr>
<td>How is 3D scanning applicable to renovations, rehabilitations, and tenant improvements?</td>
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<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>How can 3D scanning be applied to improve operations and maintenance of my existing assets?</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>What is the process for using 3D scanning?</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How are 3D scanning services procured?</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>What are the key considerations for managing field activities?</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>What types of deliverables can be created with 3D scanning?</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How is the quality of 3D scanning deliverables assessed?</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>What are the legal concerns in procuring 3D scanning services?</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>How can I ensure the quality of the deliverables from service providers?</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>How does 3D scanning technology integrate with a BIM process?</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Have more BIM questions? Appendix 9 of the BIM Working Party Strategy Paper should provide answers.
Section 1: Terminology and Technology

This introductory section establishes a vocabulary to discuss 3D scanning, and explains the basics of how 3D scanning works. Also addressed in this section are comparisons with traditional surveying and a discussion of 3D physical measurement approaches.

Key client questions addressed in this section:

- What is 3D scanning technology?
- What equipment and measurement methods are used for 3D scanning?
- How do 3D scanning technologies compare with traditional data capture?

1.1 3D scanning basics

1.1.1 History and comparison with traditional methods of measurement

Background and history

Laser ranging systems have been in use in a variety of industries for decades, with the first patented instruments appearing as early as the late 1980’s. 3D scanning was first applied in the Architecture, Engineering, and Construction (AEC) industry in the 1990’s with the market debut of the first integrated commercial systems for 3D scanning9,18 and since then the growth in industry has been rapid and profound. Early adopters found value in industrial plant applications to capture existing conditions, where poor existing documentation and complex equipment made retrofits and maintenance difficult.

Speed and quality has increased rapidly since that time, mirroring the increases in data storage and processing speeds over the same period. These developments, in fact, have directly influenced the advancement of 3D scanning technology by making post-processing fast and more powerful.

Client value

The client value proposition for 3D scanning is not simply bringing efficiencies to existing surveying methods. 3D scanning provides owners with a powerful toolkit to accomplish previously unattainable measurement goals, and creates a solid foundation for improved asset information management in general (see all benefits in Section 2: Applications and Benefits). 3D scanning is a supplement to, not replacement for, the traditional total station. In fact, a common method for establishing a control network is to use a total station (control networks help to link scans together, and are discussed in Section 3.1.3 Pre-planning). As scan speed and quality increase, cost of hardware and labor is also decreasing, making the value proposition for using 3D scanning technology for AEC applications clearer than ever.
1.1.2 Measurement methodology

**Distance measurement**
Scanning systems primarily capture the physical position of a target object, represented as a series of points (forming a “point cloud”) typically in Cartesian coordinates (XYZ). This is accomplished by comparing the emitted and returned light pulse, and determining the value of the target object in relation to the position of the scanning instrument (see Section 1.1.3 Equipment Basics for an overview of different scanning instruments). The scanner calculates the position by measuring the angle of the scanner assembly (scanner head and reflector) and the time of light travel (measured directly as in time-of-flight scanners, or indirectly, as in phase- and light-based scanners).

**Color and intensity**
The scanner also records a measure of return energy (represented as an intensity value) from the surface which is a function of the target surface characteristics and the ambient light conditions. Most scanners have the ability to determine the colour of the each point by using a camera (can be built-in or separate), which is represented by the commonly used RGB (red, green, blue) value scale. Because scanners are optical systems, only what the scanner can “see” is captured, thus scanners cannot go through walls or other obstructions (these create “shadows” in the point cloud where no data is captured). In fact, the integrity of the physical data is dependent on the environmental conditions during acquisition, as is of course the intensity and colour data, which varies depending on the light conditions.

**Point clouds**
Measurement values are represented with file formatting that expresses the position, intensity, and color of each individual point in the point cloud. Ultimately, the data can be encoded in a variety of point cloud file formats (ASCII, PTS, LAS, E57, etc.), which use some variation on the XYZIRGB position-intensity-colour scheme. Several hardware and software vendors have proprietary point cloud that can readily be converted depending on the needs of the client. It is often prudent for clients to specify the file formats of deliverables based on the end use of the data with existing information management systems. Clients may consider using a standard archiving format that is non-proprietary, such as the ASTM E57 File Format for 3D Imaging Data Exchange to ensure conformance to project needs.

**Mobile/aerial systems**
Mobile and aerial scanning systems, where the scanner is mounted to a vehicle in motion during the measurement process, capture additional data about the movement of the vehicle to compensate for the motion. A Global Navigation Satellite System (GNSS) detects the position and velocity of the scanner, an inertial measurement unit (IMU) detects the attitude rate and acceleration of the scanner. This information is stored and processed during the data acquisition process, and then the processing software outputs a point cloud file with the adjusted physical positions, allowing project teams to very quickly capture data from the physical environment without having to mobilize equipment several times. Additional data such as the environmental conditions during the time of data capture, as well as calibration and service provider data, may also be linked to the dataset. Mobile and aerial scanning are quickly becoming the standard method for creating digital city models, documenting networks of road, tunnels, or powerlines, and other large scale infrastructure measurement initiatives.
Measurement accuracy
A number of factors affect the accuracy of the point cloud data, including instrument capabilities and calibration, and quality control measures. Environmental conditions that affect the integrity of the data include surface reflectivity, the angle between scanner and target (angle of incidence), and the range to the target object (the laser beam diverges with distance, so measurements further from the instrument are less accurate). 3D scanning service providers are experts at controlling for these sources of error, thus it is crucial to establish functional performance requirements prior to field acquisition so the optimal instrument, scanning position(s), and acquisition times can be negotiated with the service provider to achieve the highest quality deliverables. A number of general rules of thumb apply, however, that clients should be familiar with to ensure proper development of functional performance requirements.

How can higher accuracy be achieved?

- Instrument accuracy
- Angle of incidence to target
- Number of scanning locations
- Number of control points (or artifacts)
- Number of quality control measures
- Frequency of instrument calibration

+ Distance to target
- Surface reflectivity
- Scanning speeds

= Accuracy

Figure 3- General rules of thumb for achieving higher accuracy
1.1.3 Equipment basics

The table below compares and contrasts traditional methods of physical data capture with 3D scanning systems. The table concisely describes common scanning systems, in comparison with traditional surveying instruments.

<table>
<thead>
<tr>
<th>Traditional Instruments</th>
<th>3D Scanning Instruments†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td></td>
</tr>
<tr>
<td>Photogrammetry</td>
<td>3D scanning</td>
</tr>
<tr>
<td>Surveying</td>
<td>3D scanning</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td></td>
</tr>
<tr>
<td>Terrestrial</td>
<td>Terrestrial Mobile</td>
</tr>
<tr>
<td>Aerial</td>
<td>Aerial</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>$$$$$$$</td>
</tr>
<tr>
<td>$</td>
<td>$$$</td>
</tr>
<tr>
<td><em><em>Maximum Range</em>†</em>*</td>
<td></td>
</tr>
<tr>
<td>n/a</td>
<td>4-6km</td>
</tr>
<tr>
<td>up to 1km (with prisms)</td>
<td>120-190m</td>
</tr>
<tr>
<td>1km</td>
<td>1km</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;10cm (aerial)</td>
<td>3mm</td>
</tr>
<tr>
<td>1mm</td>
<td>2mm</td>
</tr>
<tr>
<td><strong>Method of measurement</strong></td>
<td></td>
</tr>
<tr>
<td>Common reference</td>
<td>Time of travel for laser</td>
</tr>
<tr>
<td>points between images</td>
<td>pulses between emitter</td>
</tr>
<tr>
<td>Wave phase difference</td>
<td>and receiver</td>
</tr>
<tr>
<td>(via reflector)</td>
<td>Wave phase differences</td>
</tr>
<tr>
<td></td>
<td>(Continuous Wave)</td>
</tr>
<tr>
<td></td>
<td>Single flash pulse</td>
</tr>
<tr>
<td></td>
<td>detected on a focal</td>
</tr>
<tr>
<td></td>
<td>plane array (FPA)</td>
</tr>
</tbody>
</table>

| Field of View (vertical) |
|--------------------------|--------------------------|
| 30°                      | 90°                      |
| *depends on lens         | *manual rotation         |

| Field of View (horizontal) |
|-----------------------------|--------------------------|
| 360°                        | 360°                     |
| *depends on lens            | *manual rotation         |

*Approximate achievable levels. Very dependent on equipment and methodology.
†Instruments commonly used for AEC applications. Triangulation and interferometry scanners not addressed here.
Section 2: Applications and benefits

This section of the guide focuses on identifying applications and benefits of laser scanning technology. The following guidelines will establish types of 3D imaging applications, discuss the approach for different applications, and clarify to what phases of the construction lifecycle each applies.

Key client questions addressed in this section:

- What are the different ways that 3D scanning can be applied to my projects?
- How can 3D scanning be useful for new construction projects?
- How is 3D scanning applicable to renovations, rehabilitations, and tenant improvements?
- How can 3D scanning be applied to improve operations and maintenance of my existing assets?

2.1 Approach to applying 3D scanning

2.1.1 Cost-Benefit tradeoff - determining return on investment

When directly compared with traditional surveying systems to perform traditional surveying activities, laser scanning can be cost-prohibitive in terms of equipment costs, mobilisation costs, and processing time. However, 3D scanning systems provide a wealth of data compared with a total station, and thus the discussion of return-on-investment (ROI) is more complex, and depends on the application. 3D scanning does much more than bring efficiency to existing processes; it affords new ways to analyze, measure, assess, and monitor that must be evaluated in terms of the value provided to the client. Depending on specific needs, clients may find that for more technically challenging or complex projects it is simply not possible to use traditional surveying approaches and equipment to meet the functional performance requirements. A trusted service provider is essential in guiding clients to understanding these tradeoffs and acting accordingly.

KEY 3D SCANNING BENEFITS FOR CLIENTS

- Capturing existing conditions with high resolution
- Identifying errors with 2D as-built documentation
- Reducing client risk for renovation/rehabilitation projects
- Reducing need for physical site visits and inspection
- Assessing structural integrity of assets
- Monitoring and recording construction progress
- Recording cultural and historical facilities and artifacts
- Facilitating better information management on projects

Figure 4- Examples of 3D scanning benefits

2.1.2 Managing expectations

Achievable goals

One of the most common sentiments from service providers is that clients can have unrealistic expectations about the possibilities afforded by laser scanning technology. While 3D scanning systems truly signal a paradigm shift in industry, the technology does have limits, and a catch-all approach to all applications does not exist. On the other hand, 3D scanning is at a stage of development in industry when expectations can be inflated, as isolated success stories are overemphasised and consistent performance is lacking, leading to a high number of failures. A key purpose of this guide is to support clients in establishing reasonable, achievable goals, and ultimately, to realise these goals in partnership with qualified service providers.

Clarity and purpose

Clients need to make themselves aware of both the potential and limitations of this technology and instruct professional, qualified service providers accordingly within the scope of an agreed and understood specification. The client should never be confused about what they are actually receiving as a deliverable, and the invitation to tender is the contractual vehicle to articulate details about the functional performance requirements of the deliverables (see more about scanning deliverables in Appendix B: Deliverables). Clients should also note the significant additional time required during post-processing to produce meaningful deliverables that conform to the client’s requirements. It may be prudent for clients to consult with surveying and BIM professionals to seek guidance on vetting service providers and evaluating performance qualifications (see more about working with service providers in Section 3.1.2 Procurement- Partnering with Service Providers).
2.1.3 Technology and process alternatives to 3D scanning

3D scanning is a powerful tool, but is it always the right choice for the job at hand? Alternatives to laser scanning are generally cheaper, but the tradeoffs may not be worth it from a client perspective. It is certainly important, however, for clients to understand their options. Quality service providers have a wealth of experience in this area and should be consulted for making technology choices.

<table>
<thead>
<tr>
<th>Technology alternatives to 3D scanning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand / Manual Measurement</td>
</tr>
<tr>
<td>Useful for only the simplest measurements</td>
</tr>
</tbody>
</table>

- **Manual/hand measurements**: While it might seem comical to compare a tape measure with something as advanced as 3D scanning systems, clients should avoid resorting to 3D scanning where simpler measurement tools may be capable of doing the job for lower cost. When the accuracy of the data really matters, however, this option is unlikely to deliver measurements that can be used with confidence.

- **Total station (Electronic Distance Measurement [EDM])**: Modern, reflectorless total stations are capable of achieving extremely accurate measurements, and are the most common way to set up a control network in preparation for 3D scanning efforts. In and of themselves, total stations are excellent for measuring distinct points of interest within the environment, but are slow and cumbersome for recreating existing conditions and 3D objects in any meaningful way. More likely to be a supplement, rather than an alternative, to 3D scanning.

- **Digital photogrammetry (and photography)**: The most likely candidate for alternatives to larger-scale laser scanning efforts is likely digital photogrammetry, a photo-based sensing system commonly used for aerial mapping and development of aerial imagery. Close-range photogrammetry is more suitable for smaller objects, especially if complex, but may be an alternative to AEC applications of 3D scanning depending on a variety of factors. Currently, a number of industry solutions for using consumer-level photography to recreate existing conditions are emerging, although the accuracy achieved varies wildly depending on the data capture methodology the camera quality, and the reconstruction software. Most simply, basic digital photography taken during the scanning effort can provide a narrative record of the work which can be easily referenced later (ref. EH guide). Many scanning systems have cameras built into the scanner that capture high resolution imagery, and the accompanying photography is an extremely valuable supplemental asset to clients.

- **Global Navigation Satellite Systems (GNSS)**: Typical for large areas, GNSS data capture (i.e. captured using a GPS device) provides a viable for alternative for some large scale aerial 3D scanning applications and for actually positioning 3D scanning systems, but the number of points it might be practical to collect is likely limited compared with other alternatives.
2.2 Types of applications

It is important for procurers of scanning services to understand the benefits, limitations, and potential applications of the technology. This section of the document categorizes the main types of AEC applications of 3D scanning, with a focus on the potential benefits for each area of application. Clients should consider that many 3D scanning data sets can be used for a variety of different applications - one of the many benefits of 3D scanning is that the data sets can be serve as a physical record, and thus may be used for a variety of applications throughout the life of a facility and beyond. It is important to consider and plan for these myriad uses prior to procurement.

2.2.1 Rapid urban-scale mapping and modelling

City-scale data
Over the past decade, a number of large-scale implementations of 3D scanning have been undertaken for urban-scale mapping and modelling. Urban-scale scanning systems use mobile (vehicular), fixed wing, or helicopter mounted 3D scanners to capture the environment in 3D while in motion. Long-range scanners can capture highly accurate data for entire urban or rural areas, and provide significant advantages over digital photogrammetry in interpreting ground surfaces and features that are occluded by trees or other obstacles. Mobile mapping systems, supported by 3D scanning technology, permit the collection of high-precision imagery and distance measurements while traveling at normal highway speeds, providing speed and safety advantages over total stations which may require traffic closures and can pose a safety risk to field staff. A common application of mobile mapping systems is to capture large roadway networks, which is substantially faster and safer than a total station. The captured data can be used to assess the condition of the roadway or embankments to identify maintenance needs or safety risks, and can be integrated with a GIS facilities management system to serve as an interactive record of large roadway asset networks. In addition, 3D scanning makes it easier to create models of entire cities, as terrestrial or mobile data of building facades can be combined with aerial data to achieve better coverage of the target area. Features of the environment, including buildings, roads, and other assets, can be extracted from the point cloud automatically. This valuable data provides myriad advantages for improving asset management, operations and maintenance planning, urban planning, public outreach, and programming for capital projects.

Figure 6- 3D scanning allows rapid data acquisition at an urban scale (Image Courtesy of Autodesk)
The future of rapid data capture

Although not yet ready for mass production, autonomous driving systems have been developed that allow cars to navigate roads without any driver input that utilize 3D scanning technology. These systems incorporate a 3D scanner and a GPS system to assess vehicle position, while an on-board computer integrates the position data with data captured by radars, an IMU, and other sensors to pilot the vehicle. Specific to construction equipment, a number of researchers have also identified applications for flash LiDAR-based systems for real-time object detection, collision avoidance, and other safety applications on construction sites. While still in early implementation, these developments have major implications for transportation planning as well as the use of construction equipment on site.

2.2.2 Infrastructure and portfolio asset management

The use of 3D laser scanning has revolutionised data collection, and creates a platform for using BIM by capturing the existing built environment in 3D. The ability to provide quick, accurate detailed data in 3D has transformed its use in particular for refurbishment and retrofit projects, as well as for new construction. The technology also has key applications for asset management, including operations and maintenance of large infrastructure projects or asset portfolios. The ability to obtain accurate complete coordinated data in congested, confined and sometimes dangerous environments has lent its considerable use in a variety of industries. The application of laser scanning in this area has been shown to bring a number of benefits such as improved safety by reducing exposure to hazards and confined spaces which are of significant concern for roadway and power infrastructure assets. In addition, professionals have the ability to access data about the facility remotely without having to visit or access the site. This central repository of asset data is enhanced by greater information available that is made available with regard to clash detection and improved design understanding, which can enable better designs and reduced rework in the field. A key benefit of 3D scanning is the ability to swiftly collect valuable and relevant information at any scale. Kinetic and mobile mapping systems are more commonly being used on large-scale civil and city mapping projects resulting in considerable time and cost savings by reducing road or rail closures or using restricted time allowances.

2.2.3 Site monitoring and assessment

Monitoring is a key activity on construction jobsites to ensure worker safety, to track the movement of resources, and to understand the progress of construction. Its application during the construction stage is particularly poignant to site monitoring both in terms of design to as-built comparisons, progress assessment, clash detection, all the way through to continuous movement or excavation monitoring. Either by using the point cloud data or subsequently the 3D model, accurate scenarios or 'what if' analyses can be applied to support project goals, whether through the use of 4D modeling or by comparing different scan data sets to allow calculations and comparisons. 3D scanning can also be used to create a highly accurate physical record of either a completed construction project or a job in progress, which can be useful during operations or during litigation.
In addition to providing value during the construction phase, 3D scanning has also been used to assess sites of natural disasters, traffic accidents, and crime scenes. A multitude of scenarios exist where laser scanning is being applied for analysis, from the inspection of foundation excavations, volume calculations, and monitoring coastal erosion. Laser scanning has increased accuracies in damage assessment as a preemptive measure or to record post incidents both terrestrially or via aerial systems\textsuperscript{15}. An increased area of application is forensic analysis, whether this is associated with incident or damage assessment. The portability, speed and capability of remote measurement makes it entirely feasible to use this technology both before incidents at known high risk locations or as part of incident recording and investigation, and it has become an essential tool for police and forensic departments. The ability to capture a road accident or scene of crime rapidly in considerable detail allows the site to be cleared and further assessment, reconstructions, visualisations to be made away from the site. In some cases, scanning has been used prior to any incident to assess risk, such as disaster assessments and examination of areas at risk of flooding\textsuperscript{15}. Potential flood risk areas has been facilitated by using aerial scanning systems, and long range terrestrial systems are now capable capturing increasingly large areas for use in areas such as flood assessment planning.

2.2.4 Structural analysis and inspection

Terrestrial laser scanning has proven to be very effective for structural assessment. An important consideration for structural applications is the selection of the equipment and the optimal placement of scanning locations based on current site conditions, which may require careful planning to ensure worker safety and complete data acquisition. Scanning can significantly reduce the time required to assess critical infrastructure, such as roadway bridges, by reducing the amount of point measurements that must be taken with traditional methods. After data acquisition, a number of different analyses of the physical properties of structures can be assessed with currently available commercial software.

The ability to collect data remotely, quickly and with an immense level of detail, particularly in complicated and restrictive environments, has contributed to the significant adoption of 3D Laser Scanning for heritage recording of the structural and architectural aspects of cultural landmarks and historic buildings. Stakeholders have combined the use of hand held, terrestrial and arm scanners to record everything from archaeological artifacts to world heritage sites. Further, the ability to combine the techniques of photogrammetry with laser scanning technology has enhanced its use within this industry and afforded new ways to capture physical characteristics. Task applications include archive recording, archaeological excavation, structural or condition monitoring, restoration, digital reconstruction, interactive displays or virtual tours, interpretation of archaeological features, and spatial analysis\textsuperscript{1}. 

![Figure 8- Scanning can be used to perform quick damage assessments safely, such as the building collapse shown in this photograph (Image courtesy of Plowman Craven)](image)

![Figure 9- Scanning can be used for monitoring structural integrity. This image shows results from analysis being reported using a colour-coded point cloud (Image courtesy of City of London Corporation)](image)
Section 3: Process

This section of the guide describes the process for procurement, planning, field activities, processing, and application of 3D scanning. In addition to a description of the flow of information from start to finish, a number of topics such as quality control, sources of error, and proper planning will be discussed.

Key client questions addressed in this section:
- What is the process for using 3D scanning?
- How are 3D scanning services procured?
- What are the key considerations for managing 3D scanning field activities?
- What types of deliverables can be created with 3D scanning?
- How is the quality of 3D scanning deliverables assessed?

3.1 Breakdown of the 3D scanning process

3.1.1 The first step in the process- establishing goals and functional requirements

If the typical project commanded unlimited time and resources, it would make sense to employ 3D scanning at every step of project development. Because this is not often the case, it is important to consider the budgetary resources available for addressing a given problem, and to develop a concrete set of goals prior to procuring 3D scanning services. As defined earlier in the guide, functional performance requirements ultimately will dictate the equipment type, mobilisation strategy, service cost, and what service provider will be used. Because of this importance to the overall success of a 3D scanning application, it is a crucial first step in the process that must not be ignored or hastily completed. Arguably the most predictable reason for dissatisfaction on delivery is due to unclear performance requirements that force service providers to guess and assume about the intent of the effort, which leads to unsatisfactory performance, technological skepticism, and inadequate assessment of risk. A strategy for mitigating this result might be in asking questions like the following prior to procurement of services:

- What is the detailed goal that you are trying to achieve with this effort?
- What are the budgetary constraints for solving this particular problem?
- What type of deliverable is needed to achieve the goal of the effort?
- What local qualified and experienced service providers can perform this service?
- How will the point cloud data set or other deliverables be used in the future?

3.1.2 Procurement- partnering with service providers

Currently the procurement of 3D scanning services is subject to very little standardization or regulation. Clients should consider the state of an emerging technology, like 3D scanning, to educate themselves and their organizations about the promise of the technology for providing project or business value before they begin the procurement process. This consideration should be evaluated within the context of the AEC industry and the client’s appetite for taking risks related to technological innovation and their experience in dealing with similar efforts. Particularly relevant to asset management applications where the procurement process involves work on multiple facilities or large asset networks, a cautious...
approach to partnering with service providers will reduce the business risk of technological business decisions and increase the chances of client success.

The majority of 3D scanning procurement contracts will take on one of two forms (see Section 4.1 - Procurement considerations for more information):

1) an asset manager or owner contracting directly with a 3D scanning service provider or
2) an asset manager or owner contracts with a general contractor (GC) or design consultant, which subcontracts with a 3D scanning service provider

The former will be most common for larger programs involving mobile/aerial scanning or multiple terrestrial mobilisations. The latter will likely be more aligned with new construction or rehabilitation/renovation project applications. Although both contractual vehicles come with their own challenges, both may require clients to engage a third-party consultant to develop the invitation to tender and assist with evaluating service provider expertise. Consultants will also be helpful in understanding the level of effort required in post-processing to develop specified deliverables, which has a major impact on time and cost and is often underestimated by clients.

**How can a client lower risk exposure on 3D scanning investments?**

-early service provider engagement -clarity of functional requirements -experience of service provider -proven successes on similar projects -quality control measures + -prescriptive requirements -unclear client directives -systemic / organizational barriers = risk exposure

### 3.1.3 Pre-planning

To reduce the need for costly rework, field activities for 3D scanning efforts should be carefully planned ahead of time in collaboration with service providers. Prior to data acquisition in the field, clients should conduct pre-planning meetings with the selected service provider to discuss the measurement objectives, security or access constraints, mobilisation strategy, and the details about the control network:

- **Measurement objectives** - A clear and concise scope of the scanning effort should be established in this stage with a detailed list of the measurements to be taken, the measurement resolution and level of detail, the required accuracy for each (which may not be the same), and the required file format for deliverables. While the scope should be clearly established in the contract, the service provider may advise the client on different measurement goals that may achieve functional performance requirements quicker and cheaper during this stage.

- **Security and access constraints** - Ensuring unhindered access for service providers is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas. For government buildings and other sensitive security areas, escorts or additional security clearance should be organised prior to field acquisition to ensure the service provider is not delayed. The client will likely bear responsibility if these issues delay the work, so clients should be cognisant of the issues service providers may face on site. Any security issues with the acquired data should also be established clearly before processing, so service providers can organise secure data storage and transfer to protect sensitive information. Any issues related to worker safety during scanning should also be addressed at this stage.

- **Mobilisation strategy (scan plan)** - The expertise of the 3D scanning service provider is essential for establishing the mobilisation strategy. 3D scanners are optical instruments, and thus data sets can include “shadows” where the target is occluded, making the set incomplete. In addition, because the accuracy of the data decreases with distance (due to laser beam divergence), some measurements may not achieve the required resolution of the target object. These considerations will drive how many scan locations (for terrestrial applications) or what routes are
taken (for aerial and mobile applications). Clients may wish to engage an experienced third-party consultant to discuss mobilisation strategy with the service provider, as most clients will not have relevant experience in this area.

- Control network details- Control networks increase the level of confidence for subsequent data queries, quality assessments, and inferred measurements from the data set, and are an essential part of the planning process. Control networks can take on a variety of forms, including 1) the use of temporary objects within the scanning area (e.g. “targets”), 2) the use of permanent or semi-permanent fixtures within the scene (e.g. thermoplastics or fixed controls for periodic scanning), or 3) artifacts within the scene with known dimensions (e.g. spheres or other geometric primitives). The control network also serves to align the data to larger scale mapping networks (coordinate systems), a process called georeferencing (find more in the Appendix A: Terminology). The scanning software recognizes the objects within the scene and uses the information to align scan data to known controls that have been measured with other equipment, such as a total station. Some clients may wish to develop requirements for the accuracy of the control network.

3.1.4 Acquisition- capturing the physical data

Terrestrial data capture
The method of data acquisition is fundamentally different between terrestrial laser scanners (TLS) and mobile/aerial scanning systems. Intuitively, tripod-mounted terrestrial scanners are more common for smaller projects (involving one or a few facilities) where the focus is on the capture of facility features, such as architectural features, utilities, equipment, or structures. Mobile and aerial applications are more common for extensive networks of assets, or for recreating existing conditions at a lower resolution for urban planning or asset management. Furthermore, aerial applications using a fixed wing aircraft or helicopter will require careful aircraft path planning for large-scale mapping initiatives (often called “swath mapping”). Because of the drastically different capabilities of these systems, it is important for clients to understand the general measurement principles of each method to understand which approach is more appropriate to meet functional performance requirements (see figure on next page).

Mobile/aerial capture
For mobile and aerial applications, a scanner (typically a rotating mirror system with very high data capture rates) mounted on the vehicle captures existing conditions as it moves, and an Inertial Measurement Unit (IMU) equipped with a GNSS antenna (e.g. GPS) records the geospatial position of the scanner. The processing unit then adjusts the sensed distance measurements based on the motion of the scanner, and returns a series of adjusted measurements in a single coordinate frame. This differs from the data capture schema of terrestrial scanners, where the scanner is manually relocated to several different positions, then each captured scan is registered in a single coordinate frame using known points in a control network.

Measurement validation
During or immediately following acquisition, it is often prudent to take supporting measurement that can be used to validate the quality of the data set upon processing. Such measurements could be captured using manual measurement (e.g. tape measure) or using an optical instrument such as a total station. These measurements should include horizontal, vertical, and diagonal measurement to provide more confidence in the data set. Spot checks based on corroborating measurements may assist in validating quality but should not be considered a catch-all solution for ensuring data quality. For critical measurement goals, some clients may consider requiring multiple scans of the same target area to provide redundancy to the survey.

3.1.5 Processing / interpretation- understanding the physical data

Because the acquisition of the point cloud data is only the beginning of the process of answering the original research questions, it is likely prudent for the client to remain engaged with the service provider during the processing stage. The analysis required to answer client questions may involve work provided by the service provider (especially for Turnkey BIM contracts), but many clients will choose to use other stakeholders to perform the analysis or even accomplish it in-house. In addition to the physical data required, any additional metadata or project data specified in the contract is provided to the client by the service provider during post-processing.
During processing, the service provider will register the scans in a common coordinate frame using the control network, and any noise or unwanted data will be removed from the data set (called “filtering”). If any issues are encountered during this stage such as missing data, inadequate point/surface accuracy, or poor target resolution, remobilisation may be required. The contract should explicitly define how these costs will be incurred, although responsibility will likely fall on the service provider assuming the contract language is clear and definitive. Clients should keep in mind that substantial effort is involved in processing the point cloud data to extract something meaningful, and the large amounts of data produced can put a substantial burden on a client’s data management systems and IT infrastructure.

### 3.1.6 Application / delivery- functional application of captured data

Following data processing, the service provider will turn over the data to the client in conformance with the established file format specifications for point cloud and/or 3D model deliverables. If data storage specifications are included in the proposal, then the client will need to verify that the data provided conforms to these specifications following delivery and prior to payment for services. Many clients may desire to include some type of integration of the data with current systems, especially if the service is for existing assets in a portfolio. This process should be clearly defined in the proposal so service providers fully understand the integration requirements prior to delivery. Clients may wish to engage a third party consultant to monitor this process. Clients should be aware of the data storage costs and any logistics in maintaining the data, as point cloud files and 3D models can be quite large, and may reach over hundreds of gigabytes for larger efforts. In addition, hardware and software upgrades may be necessary to handle the deliverables provided. Clients must also specify the format of delivery, which commonly include CDs, portable hard drives, or web downloads and access. It is also important to ensure conformance to file naming conventions and handover processes defined in PAS 1192.

Reference the following page for a graphic demonstrating the process steps and deliverables involved.
Figure 11 - 3D Scanning process and deliverables

Looking for information about 3D scanning deliverables? Try Appendix B
Section 4: Procurement

This portion of the guide discusses legal and liability concerns, from establishing performance specifications for service providers to assessing quality of scanning deliverables.

Key client questions addressed in this section:

- What are the main components of an effective service procurement?
- How can clients ensure the quality of deliverables from scanning service providers?
- What are the legal issues associated with procuring 3D scanning services?
- Who is liable for errors and consequential problems associated with 3D scanning data?

4.1 Procurement considerations

4.1.1 Implications for procurement compared with traditional methods

The procurement of surveying services is usually a pretty straight-forward business. The deliverables are clear and the standards of service are well understood. However, the increasing adoption of 3D scanning and the application of BIM for buildings and infrastructure will likely result in the much broader sharing of data between project parties. BIM Protocols have already been drafted to allow for the sharing of data as part of the design and construction process. Whilst the nature of professional services (e.g. design, surveying, construction management) may not change markedly, the use of outputs including data will, and procurement processes need to provide for this.

On this basis, the procurement of 3D laser scanning services can continue to be based on the current best practice methods and agreements. Clients can be reassured that general principles of supplier selection and contracting will continue to apply. However, due to additional processes involved in the production of 3D outputs, and different ways in which surveys and other outputs might be used, some elements of procurement will differ from the purchase of traditional surveying services. The main differences stem from the type and format of final deliverables possible through 3D scanning. Compared to traditional surveying methods, where 2D drawings are usually the only product received by the client, 3D laser scanning generates a raw data set that can be transformed and converted into a range of formats including 3D surface data or a BIM Model (see more about Deliverables in Appendix B). These conversions may be provided as part of the original surveying commission, or may be undertaken by the client or another data user. The original data may be incorporated into models produced by third parties, or used as the basis for BIM work by others.

Procurement and appointments need not only to reflect the increased complexity of the service provided, but also the wider use of the data provided as part of the service. The two key areas for action are the following:

- Clients should assure themselves of the competence of their supplier as a means of risk mitigation
- Clients should ensure that agreements allow for the re-use of survey data, and that appropriate protections for originators and users are put in place

4.1.2 Definition of client requirements

The clear definition of client requirements is a prerequisite for a successful procurement. Clients should aim to fully clarify their expectations, especially with regards to the content, level of detail, format and accuracy of survey required. Potential and intended uses of the survey should also be described by the client, as service providers are well positioned to understand which formats and standards will be most appropriate to meet the clients’ needs. A well drafted Request for Proposal (RFP) should result in a proposal specifically tailored to the project that will assist the client in making an informed supplier selection.

This Guide advocates a functional performance approach to specifying client requirements rather than a prescriptive approach. Clients should clearly state the purpose(s) of the survey and data together with a clear summary of the ways in
which the material will be used in the future. Potential service providers will tailor appropriate solutions according to that future use, considering following issues:

- scale (laser scanning resolution)
- accuracy (density) of data
- level of detail
- parametric detail
- point tolerance
- technical equipment and processing standards required

A sample wording for a performance specification is set out below, describing the scope, format, use and deliverables taking a functional approach to performance requirements:

‘We require a laser scan survey of a multi-level site with a single storey building, associated ground level structures and a below-ground basement. The intention behind the required laser scan is to provide a 3D building information model of the building which accurately reflects the current layout. The level of detail and structure of the model should allow flexibility for more detailed modelling at a later date. All building structures and fabric to include facades, roofs (upper and lower surfaces) and structures, all rooms within buildings (including offices, staff rooms, shops, cafés, plant rooms). Doors and windows shall be shown, but architectural details such as architraves, mullions etc are not required. The following deliverables are required: point cloud data and Engineering building information model in [the specified format]’

This approach contrasts with a traditional prescriptive performance requirement where the client would typically enumerate the actual elements of work required from the surveyor. For example:

‘The survey will be undertaken at a scale of 1:100, will constitute semi-connected survey…will identify all walls, columns, stairs, doors and windows and will show a floor to ceiling height in each room…”

In addition to discussing the scope of the project in detail, clients should provide an indication of type and format of records which the service provider will need to deliver as well as future formats in which data will be used. Possible examples of deliverables may include the following (find more on deliverables in the Appendix B):

- registered point cloud
- georeferenced point cloud
- 2D drawings
- 3D surface data
- Rendered 3D object model
- Animated visualisations
- BIM model in a defined or Open BIM model format

As previously stated, clients are advised to make use of the experience of professional service providers and supply them with sufficient information regarding the intended functional performance of the survey. In common the other RFPs, the submission should include details of the supplier’s capability and management systems etc. These will require careful evaluation, as the services may be under development, and levels of capability will vary between suppliers.

Figure 12- This image shows a scan of the Queen Victoria Monument in front of the Buckingham Palace in London. This data was used to create a detailed 3D surface model to be used in coordination with the Queen’s Jubilee celebration concert (Image courtesy of Robbie Williams Productions)
4.2 Evaluating qualified service providers

4.2.1 Experience and qualifications (competence)

Currently in the UK, there are no special licensing requirements for performing 3D scanning services. Although surveying firms, BIM consultants, and turnkey BIM service providers are all subject to the obligations of professional conduct, the barriers to entry for this market are very low. Thus, it is prudent for clients to understand the importance for establishing valid qualifications and relevant experience for 3D scanning service providers. One of the best ways of doing this is simply by reviewing experience on past projects. Clients may wish to delegate this to a third-party consultant who is more qualified to objectively review the relevance of past project work and to establish the competence of the service provider in providing similar services. In general, identifying projects that have been successfully completed on time and on budget for a similar project scope is the first step in the process. Understanding measurement and post-processing quality, in addition to simple client satisfaction, is also crucial. A number of factors relating to service provider experience should be assessed, including:

- **Track record and past experience** – examples of previously undertaken 3D scanning commissions, established experience in using traditional methods of surveying, willingness to disclose examples of prior work, availability of references from previous clients and reputation in the industry are all good guides to competence and capability
- **Technical capability** – evidence of familiarity with a variety of software/hardware, ability to achieve high levels of accuracy required during measurement and readily available, wide technical base of tools, equipment and processes appropriate to functional performance of a survey will demonstrate technical capability
- **Internal capacity** – evidence of training and development in provision of 3D scanning services, internal capabilities and programme capacity to enable timely delivery are key criteria
- **Information exchange standards** – well developed standards for electronic information exchange will be necessary for frequent transfers of 3D data and survey deliverables. These standards and the skills to work to them are evolving. Suppliers should be able to demonstrate familiarity with the application of open standards such as IFCs (Industry Foundation Classes).

Clients may also wish to conduct detailed interviews in coordination with a third-party consultant to ensure the experience of service providers is valid and relevant prior to formal issuance of the RFP.

4.2.2 Technical requirements

The large size of 3D point cloud files, sometimes running into terabytes, will require processing capacity, bandwidth, IT back office and archiving capabilities. It is imperative for clients to understand the supplier’s capabilities with regard to security and capacity of IT systems and archives. At minimum, suppliers should be able to demonstrate capacity in the following areas:

- Hardware
- Bandwidth and file transfer capability
- In-house security including dedicated workstations if required
- Security, back-up processes and service agreement standards for archive
- Ability to deliver the information in the format specified
- Ability to collaborate effectively (e.g. working to PAS 1192-2 standards)
- Quality control process – the availability and quality of specific standards and processes for 3D scanning and post-processing quality assurance should be an important selection metric. These processes may be associated with equipment calibration and verification.

As with all commissions, an effective working relationship is the key to excellent service. The combination of a clear brief and appointment, capable supplier and effective team working in a collaborative manner will go a long way to delivering the expected outcome.
4.3 Context of procurement

Before describing the details of the agreement, it is useful to clarify how a client will procure a surveying service and how this might affect the nature of the agreement. Depending on the project type and the ultimate use of the data, these agreements may take on different forms.

4.3.1 Client contracts directly with 3D scanning service provider

The most common arrangement has a client contracting directly with a 3D scanning service provider. This is the optimal approach for clients who own existing assets, require a range of survey deliverables and will benefit from individually tailored contracts. In addition, rights, liability and confidentiality issues can be structured in anticipation of the uses of the data and the parties involved. A client contracting directly with a service provider is the simplest and most often used arrangement.

One issue with the direct contract approach is that the client may find themselves providing the survey and the data to third parties for inclusion in their work. It is difficult to encourage third parties to rely on this data without some form of risk transfer. Clients may find it better to include the survey as part of a wider commission (e.g. delivered as a sub-contract to the design lead) in order to manage this risk.

4.3.2 3D scanning service provided through an existing agreement

In this instance, the employer will state the requirement for 3D laser surveying as part of the wider service requirement. For example, a lead designer or main contractor could be made responsible for procuring the services and ensuring the quality of 3D scanning deliverables as part of their service. The employer will be an end user of data, and appropriate rights, liabilities and confidentiality arrangements will have to be in place to enable the client to make wider use of the information. An example of this arrangement will be when an employer will require 3D scan or model as part of the ‘as-built’ deliverables of a construction contract. Where a survey is commissioned as part of a design commission, the appointment should allow for the use of the data by other consultants, contractors and other third parties. The next section considers how provisions for the use of the survey and data can be incorporated into an agreement.

4.4 The agreement

The client guide provides a general overview, and clients are advised to seek professional legal advice when drafting agreements to ensure a clear description of the services to be provided.

4.4.1 General terms

When drafting an agreement, clients should anticipate that the documentation will place particular focus on the following items:

- Definitions of new, 3D scanning related, terms used in the Agreement. These should be clear and unambiguous. The CIC BIM Protocol provides a good example of a set of additional, data orientated definitions
- A clear statement of functional performance of the survey i.e. the explanation of specific purposes for undertaking the survey and acquiring data
- Specific provisions for obligations, rights and liabilities of parties associated with the use of the survey and associated data
All technical requirements which were previously addressed in the RFP and constitute an essential element of services should also be included in the agreement, typically as an appendix. Some service providers may have prepared templates enumerating these requirements which may be appended to the Agreement. An appendix should address the following elements:

- Type and format of final deliverables required (2D drawings, 3D model, readiness for integration with BIM, additional metadata like supporting imagery, environmental conditions, the field acquisition, the processed point cloud)
- Required exchange format for deliverables
- Accuracy of data required namely scanning resolution, overall point density, point tolerance, precision and quality control
- Level of detail required
- Technical standards that should be adhered to

4.4.2 Obligations, rights and liabilities

Obligations
Obligations, rights and liabilities are the key elements of an agreement, setting out what the parties have to do, their entitlements and the extent to which a party is responsible for the consequences of errors or omissions in their work. A well drafted agreement is necessary to enable managed use of the data by the client and other parties and to provide appropriate limits to consultants’ liabilities. Services agreements will include an express term which obliges the service provider to deliver work to a defined standard, typically defined in terms of skill and care. Typically no change to the wording will be required. Service providers may request a qualification related to ‘reasonable endeavours’ if the service requirement is highly complex or involves a high degree of dependence on input from 3rd parties. Ideally this qualification should avoided – particularly where absolute accuracy is required.

Rights
Under most agreements, the service provider retains the IP associated with their work and grants the employer a licence to use the work for a range of purposes. For example, an employer would have the right to use the survey for their own purposes but might not have the right to give the survey to a purchaser of the asset without an additional agreement. Agreements can include provisions for rights such as licences for a range of defined participants to have a licence to use information for defined purposes. If a survey is produced as part of a wider design and construction project for example, then licences might be granted to project team members to use the survey in connection with design and construction only. Licences are important on projects where data sharing is encouraged, as participants are increasingly required to demonstrate that they have permission to use data sourced from 3rd parties. The licence is a convenient way of allowing for data use, although both the third parties and the uses need to be defined (often quite generally) in the agreement. If there is no licence, then the data cannot be used without breach of copyright – an important IP protection for the surveyor. A typical licence will permit the transmission, copying and use of the data in connection with a defined project, and will also permit the granting of sub-licences.

Licences can also have limitations – such as limits on the alteration of the work without consent. If the surveyor is making use of information provided by the employer or by other project participants, then it is a good idea also to include licences which grant these rights to the surveyor. Limitations on the liabilities associated with the licence are discussed below.

Liabilities
Liabilities associated with a survey based on a scan should not differ from those associated with a measured dimensional survey, where the surveyor is potentially liable to the employer for the quality, accuracy and completeness of the survey. However, as discussed elsewhere, there is potential for survey data and the survey itself to be incorporated directly into the work of others. As a result, issues of liabilities to a wider group of participants need to be considered – mostly to promote the use of the data whilst protecting the employer and the originator.

Under current arrangements, employers will issue surveys to consultants working on their behalf, taking responsibility for their accuracy. Recipients of the survey information will rely on the fact that it has been produced to a professional standard, but unless third party rights provisions are being used, will have no contractual remedy with the originator should there be errors or omissions in the survey.

With a greater take-up of BIM, there is an increasing likelihood that consultants and contractors will want to use survey data for a wider range of processes. Users of the data may seek to establish not only a right to use the data, but also any liabilities that the originator might hold. At the same time the originator also seeks to place a limit on this exposure. Agreements will typically include limitations on liability related to modification, amendment, transmission, copying or loss.
Additional measures
Licences are effective where the identity of the 3rd parties and the purposes for which the information can be used can be defined in the agreement. Where parties and purposes cannot be defined in advance, other arrangements can be put in place in the agreement as follows:

- **Professional indemnity insurance** - Clients are advised to ensure that their service provider carries adequate Professional Indemnity Insurance (PII) cover through their agreement. The Survey Association requires that its members have cover for any one claim up to £500,000. Other institutions recommend higher levels of cover, albeit that the requirement should be proportional to the potential loss, which in the case of measured survey work is relatively low.

- **Third party rights** - the service provider accepts a wider ‘duty of care’ agreeing to the reliance on his work by named third parties. The third parties may use and rely on survey deliverables and the service provider will be liable to that party for errors. Although use of third party rights encourages the wider use of data and gives some protection to data users, the RICS recommends that its members should exclude third party rights from their agreements. Third party rights are similar to licences in that the party has to be defined up-front in the agreement.

- **Collateral warranty** - an additional agreement between a provider, such as a contractor, consultant or subcontractor (warrantor) and a third party (beneficiary) giving the third party the right to use survey deliverables. The warrantor remains liable for potential survey errors to the beneficiary. Collateral warranties are used in connection with other agreements such as the sale of an asset and can be established at any time. As data becomes more valuable, it is foreseeable that survey providers may be asked to sign up to these agreements.

4.5 Security, privacy and confidentiality

The capture of accurate, reproducible data through a 3D scan process can potentially trigger concerns around the management of confidential information held by the client and service providers. Non-disclosure agreements are commonly available, and the contract can also include appropriate wording in the agreement, such as:

“[Name of firm] shall during and after completion or determination of this Contract keep confidential and shall not divulge to any third party any information acquired or which become known to that firm through the provisions of Services.”

Other approaches to security and protection that can be defined through the selection process and agreement include:

- **Secure storage** – appropriate storage and archive facilities for both electronic and hard copy form of data will be an essential reassurance for data protection

- **Archiving processes** – limited access to archives and specific processes like destroying documents once delivered or destroying duplicates could be introduced

- **Limited number of potential data users**

- **Limited purposes for use** – clients should be particularly aware of potential marketing usage of 3D scans and point clouds by service providers and may wish to limit such use in their agreements

- **Defined security standards**

Parties are advised to evaluate their specific needs against potentially confidential character of data collected during 3D scanning and tailor their confidentiality agreements accordingly.
Section 5: BIM Integration

The final section of the guide discusses how 3D scanning integrates with a building information modelling (BIM) approach to project delivery. The section discusses the relation of 3D scanning to the UK BIM Maturity Model, COBie data drops, and additional point cloud-based deliverables.

Key client questions addressed in this section:

- How does 3D scanning technology integrate with a BIM process?
- How does 3D scanning relate to the UK BIM Maturity Model?
- How does 3D scanning relate to COBie data drops?

5.1 3D scanning across the BIM project lifecycle

5.1.1 BIM and 3D scanning

As mentioned at the beginning of this guide, it is clear that 3D scanning has much more to offer than simply improving existing surveying workflows. In fact, 3D scanning creates a foundation for a BIM approach by capturing existing conditions in a highly accurate, 3-dimensional format that can be used as a basis for developing project designs. In addition, 3D scanning can be used throughout the construction phase and at handover to ensure conformance to the design by checking the 3D scan data against the BIM. We also know that BIM is not just about design and construction, but rather the entire lifecycle. BIM does this by accomplishing the following:

- Improving assessments of existing conditions (existing data sets like record blueprints and drawings poorly represent conditions and can present liability issues to contractors)
- Maximizing productivity during construction by improving coordination with existing infrastructure and avoiding field discrepancies during the construction phase
- Validating construction quality during post occupancy and improving asset management strategies for clients owning large asset portfolios

Figure 13- 3D scanning can be the foundation of a BIM approach
By utilizing a formal approach to handover processes, clients can ensure that the data submitted by service providers can be managed according to the client’s existing processes and can integrate with current information technology systems. One method that supports this approach is storing or uploading data to the Common Data Environment (CDE) as defined in BS1192, which allows the file naming of the point cloud to follow the same convention as all other project or record documents. The PAS BS1192 section on handover processes states that the “effective transfer of structured information between the asset lifecycle stages produces significant value”¹⁶, and formal handover processes can enable this value by adhering to standard codes for drawing and model files that are defined in the document. The document defines a “PC” standard code for point cloud files which should be specified in the agreement.

Clients should be aware that scanning applications will vary depending on the project stage. Scanning prior to construction may be to establish existing conditions or for assessment of the project site and surrounding area, which will occur during the first three stages of construction as defined by the Construction Industry Council (CIC), including Brief, Concept, and Developed Design. Scanning may also be applied during new construction or for rehabilitation and renovation, during the Production-Installation phase of the project. This may be for progress monitoring, or the assessment of construction quality. A key application of scanning is for as-built recording, or assessment of project performance to support project guarantees during the As Constructed phase. And finally, during post-construction, or “In-Use”, scanning can be employed to record cultural or historical assets, for assessment for maintenance, or for streamlining operations and maintenance. The PAS document notes that “a Point Cloud survey shall be provided to verify the completeness of the as-constructed model.” The graphic below maps the different applications of scanning to the typical CIC project phase.

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**Figure 14- Applications mapped to CIC project stages**

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¹⁶ The PAS BS1192 section on handover processes states that the “effective transfer of structured information between the asset lifecycle stages produces significant value.”
Appendix A- 3D Scanning Terminology

A.1 Industry terminology- finding a common vocabulary

3D scanning and data capture encompasses a number of similar technologies, all of which can be considered optical 3D measurement techniques (or 3D imaging systems), which describes an optical instrument that captures physical data from the environment, either by speed/coherence of light or triangulation\(^2\) (not addressed in this document). Data captured by 3D scanners are usually referenced with known Cartesian (XYZ) coordinate systems, such as Global Navigation Satellite Systems (GNSS), Ordnance Survey (OS), or local project coordinates. A number of industry terms are used to differentiate the ways that data can be captured, processed, and delivered.

**3D laser scanner**- terrestrial, mobile, or aerial 3D range imaging device that uses a laser (light) to measure distance via time-of-flight, phase-based, or light-based detection. Common terms used in the AEC industry include:

1. **LIDAR** (Light detection and ranging)- a term commonly used for aerial scanners\(^2\)
2. **LADAR** (Laser detection and ranging)- commonly used for terrestrial scanners\(^2\)
3. **flash LADAR/LIDAR**- emission and detection of light using light arrays and an electro-optical device\(^2\)

**Photogrammetry**- Photo-based sensing using a digital camera, where high-resolution photos are “stitched” together using overlapping photographs\(^3\). Often uses special digital cameras called metric cameras, but can be accomplished with unordered photographs from consumer digital cameras\(^4\)

**Electronic Distance Measurement (EDM)**- The measurement principle of a total station. This surveying approach has been in use for decades, and relies on a reflected wave phase difference between emitted and return light pulses for measurement\(^5\).

**Point Cloud**- The most common 3D scanning deliverable. A data set consisting of points detected by the 3D imaging instrument, represented with Cartesian (XYZ) coordinates. Point clouds of varying accuracy can be generated from 3D scanning systems, digital photogrammetry, and many other sensing systems. For most scanning applications, a point cloud will be generated from multiple scans measured from varying positions in relation to the target object\(^1\).

**Metadata**- Supplementary data linked to the point cloud measurements (“the data about the data”); examples include 1) the scanner position and motion (e.g. sensed via an Inertial Measurement Unit), 2) 3D objects linked to project or enterprise information management systems, and 3) database links to geographic information systems (GIS). See Appendix B: Deliverables for more information on metadata.

A.2 Process terminology- physical measurement and data capture

Once the equipment has been selected, the process of physical measurement can begin. Before any field activities are conducted, the first step in the process is to establish goals for the specific application, with the key result being the development of functional performance requirements. The following introduces the vocabulary for discussing the process; more detail is provided in Section 3: Process.

**Functional performance requirements**- Requirements developed by the client prior to procurement or in partnership with service providers that explicitly state the purpose of acquiring the scanning data and provide measureable metrics by which to evaluate 1) the quality of the laser scanning deliverables and 2) conformance to the client goals

**Data acquisition**- This term describes the field activities associated with using the 3D scanning instrument’s optical sensor to detect the physical characteristics of the environment, typically in the form of individual points for each laser pulse, which form a point cloud.

**Processing**- Following acquisition of point cloud data in the field, service providers must process the captured data. This involves four key steps:

**Registration**- Nearly all objects and facilities require many separate scans to achieve full coverage. The first step of processing is to register all of the different scans into a common coordinate system, often accomplished using a control network of known points measured and marked independently (i.e. with a total station) prior to the
scanning data acquisition. For some applications, the scans need only be registered relative to each other, but often the scans must be oriented to an existing coordinate system, such as specific project coordinates or the Ordnance Survey (OS). This optional, supplementary activity is called **georeferencing**.

**Filtering**- In this step, erroneous or unwanted data is removed from the point cloud, such as vegetation, overlapping points, obstructions, outliers, etc. Because point cloud accuracy decreases with distance from the scanner, culling may be required to ensure the most accurate points for a given feature are used.

**Classification**- Because the point cloud data set only contains the position of the points and the position(s) of the scanner during data acquisition, it is often required to identify and "classify" different features from the data set, such as a ground surface, building facades, roadways, powerlines, or other key features. Another term used for this activity is **feature extraction** or **object recognition**.

**3D modelling**- Often integrated with classification, the optional step of creating surface meshes or 3D solids from point cloud data is becoming commonplace in industry. This step uses the point cloud data to develop a geometric data set that can be linked to additional metadata (the “I” in the term “BIM”) and used for additional analysis. More on this “scan-to-BIM” process can be found in Appendix B: Deliverables.

### A.3 Quality terminology- establishing functional performance

Every scanning deliverable has a **required accuracy**, which is the minimum accuracy to meet functional performance requirements. This guide advocates a functional performance approach, as opposed to a prescriptive approach, to establishing this number. Because the accuracy required can be based on the size of features to be extracted, construction tolerances, budgetary restrictions, or other constraints, it will likely be difficult to establish without partnership with service providers or by an industry expert consultant. At the heart of functional performance requirements and closely related to point density, required accuracy must be carefully negotiated with the service provider to ensure it is reasonable and attainable.

**Resolution of measurement**- the density of the coordinate measurements over the target area\(^1\), which is closely related to the overall **point density** of the dataset. The entire dataset may have a high point density (and a high overall resolution), but if the resolution of a specific target area (e.g. a building façade) is not sufficient, functional performance requirements may be impossible to achieve. Depending on the purpose of the scanning effort, the data set may have varying resolutions for different geographic areas. Another way to think about resolution is in driving the minimum “artifact” size, or the dimensions of the smallest recognizable feature in the dataset\(^8\). Service providers will often determine the resolution of measurement needed to achieve the required accuracy.

**Accuracy**- In technical terms, accuracy is the closeness in agreement between a measurement and its true value\(^2\). Of course, the process for establishing the “true value” is dubious, as any measurement can only be compared to other independent measurements with different instruments (i.e. with a total station). As such, there is some level of **uncertainty** for every measurement. Factors affecting accuracy of the data capture, and consequently the accuracy of the deliverable, include:

1. scanning system used (i.e. maximum achievable accuracy in controlled lab conditions)
2. environmental factors (e.g. temperature, relative humidity, atmospheric pressure)
3. target object/surface characteristics (e.g. surface reflectivity, angle in relation to scanner)
4. processing methodology (i.e. quality control measures used and independent validating measurements)

**Precision**- The term precision describes the closeness in agreement between independent tests, following identical methodologies. Precision, then, is a function of random error and is not related to the “true” value of the measurement\(^2\). In other words, a data set can be quite precise, while simultaneously being completely inaccurate.

**Quality control**- Evaluating the point cloud deliverables for conformance to the client’s functional requirements. Quality control measures include proper instrument calibration and using independent measurements to validate accuracy. During data acquisition, quality control is accomplished through the use of a **control network**.
Appendix B- Deliverables

B.1 Rich and meaningful data

File formats
For most applications, the point cloud produced by the scanner will likely be the means to a more data-rich end. Point clouds may be useful for visualization and basic analysis, but significant value can be realized by converting the point cloud data into a more usable format, such as a 3D model or BIM. Clients may also wish to have service providers develop deliverables from the point cloud such as 2D drawings to support design processes. It is very important to specify file formats for each deliverable, as many formats (e.g. ASCII) may not include all of the data desired, such as scanner positions or weather conditions during data acquisition. 3D model deliverables should be created using standard formats, such as IFC, or common exchange formats such as DXF to allow clients to retain as much data intelligence as possible at handover. Service providers are the best resource for understanding which formats are appropriate to meet functional performance requirements, and should be engaged prior to field acquisition to negotiate specifics.

Metadata
In addition to point cloud based deliverables, the client may also wish to require supporting imagery, environmental conditions, or additional metadata for later use. At project handover, often to meet requirements for client organizations (such as COBie data drops, see Section 5.2 Supporting the BIM Maturity Model), supplementary metadata may need to be provided. Examples include:

1. the field acquisition (e.g. date, scanning system used, environmental conditions)
2. the processed point cloud (i.e. number of points, point density)
3. the service provider (company name, facility/object being scanned, project information)

Clients should pay attention to how the data and supporting metadata is actually delivered, as data storage and management may present logistical challenges. Specific client business operations that use or reference point cloud data may have format requirements about which service providers are not generally aware, hence the importance of establishing requirements up front. Level of effort varies significantly for different types of deliverables, and may require additional field activities or post-processing to produce. Clients who engage service providers early can reduce risk exposure by fully understanding the data delivery process prior to field activities.

B.2 Point clouds

The most basic form of 3D scanning deliverable is the point cloud. Typically point cloud formats (e.g. ASCII) record the XYZ location of each point, along with the intensity and/or colour data (RGB value) for each point. Because of the high density of the measured points and the colour data linked to each point, point clouds often resemble high resolution 3D photographs. Although point cloud file formats support storage of additional sensing and environmental data, this data will be superfluous for many clients who are interested in primarily the physical and colour measurements of the facility. It is common for service providers to use this data for quality control purposes, which depends on the vendor proprietary hardware/software used for measurement. It may be prudent for clients to specify a common exchange format for deliverables (e.g. ASCII) so that the service provider can convert proprietary data to the correct format for use with the client’s information systems. For clients currently using 3D imaging data (e.g. as part of an asset management system), the client may wish to specify a proprietary format for delivery to ensure interoperability with current data management systems.

While there is currently no UK standard or specification for 3D imaging data exchange at the time of this writing, the American Society for Testing and Materials (ASTM) has developed standards for 3D imaging terminology and developing agency-specific requirements for procurement.

B.3 Web view and access

Figure 15- High density point clouds can resemble 3D photos
Many service providers are developing complementary services to clients that allow them to more easily access, view, and analyze point cloud deliverables. The primary form of this service is a secure, web-based tool with a graphical user interface that allows users to access point cloud data easily. Access may be provided through the cloud, or through a secure client server. Because point cloud datasets are often very large (>50 GB for large facilities), this type of service can be quite beneficial to owners. In addition to bringing ease to data management, substantial time and money can be saved by using the point cloud as a virtual project environment, eliminating the need to be physically present on site (which reduces travel costs and latency). Emerging solutions offer streaming point cloud capability, which allows users to access larger data sets on personal computers or mobile devices with better performance and without the need to download the entire dataset to begin viewing. In addition, a variety of markup tools are commercially available which can be used collaboratively to identify and fix issues. As more data storage moves to the cloud, this approach will likely become a much more common form of deliverable.

B.4 2D plans and sections- existing assessments

Although 3D deliverables are commonly delivered for many scanning initiatives, many clients are still interested in generating 2D drawings of the as-built condition of a facility for reference. This is especially common for structural analysis applications of scanning, where the purpose of the scanning effort is often to verify data integrity for an existing set of as-built drawings. Many of these data sets have very low reliability due to their age or quality, resulting in unknown or uncertain existing conditions that can burden clients with additional uncertainty and risk. To mitigate this risk, traditional 2D deliverables (e.g. plans, sections, elevations, details) can be generated directly from the point cloud data by taking virtual sections through the point cloud and generating a drawing. The surface accuracy of point clouds is extremely high, making this a superior method for reproducing existing conditions in comparison with a total station or manual measurement. Clients should be aware, however, that the processing required to create a traditional as-built plan set from a point cloud requires significant additional post-processing compared with a simple point cloud deliverable, so measurement goals should be clearly established up front to minimize costs.

B.5 3D surfaces and solids

Surveyors have long been developing 3D surface models (Digital Terrain Models [DTM] or Digital Elevation Models [DEM]) as part of the site survey. Traditionally these deliverables have taken the form of Triangular Irregular Networks (TINs), which is essentially a list of XY points with an elevation (Z) attribute captured using a total station. Because each XY point can only have one Z attribute, vertical surfaces cannot be represented in a TIN surface because a vertical surface contains two elevations for the same XY point. As such, TINs are mostly appropriate for ground surfaces, and are not useful for vertical buildings, cultural heritage, and other detailed assessments. Typically a DTM is generated to create traditional surveying deliverables like the project base map, although 3D scanning can accomplish this with much higher surface accuracy with less field time than a total station.

For most 3D scanning initiatives, especially for buildings, a surface mesh or solid model is more appropriate. Surface meshes are true 3D surfaces, and can be readily converted to 3D solid bodies. These formats are appropriate for all applications, and afford additional analysis to the project team because surfaces and solid bodies can be analyzed for volumetric properties, mass excavation staging, and other applications.

B.6 Building Information Models (BIMs)

The “I” in BIM

Whereas graphical models such as 3D surface meshes and 3D solid bodies can only capture the physical properties of the environment or of a given object, a building information model (BIM) has the capability to supplement this data with additional attributes. A BIM is a parametric model, which means that the objects in the model have intelligence embedded
and understand a variety of parameters and relationships that are defined by the project team. Categories of this “metadata” include the following:

1. Information gathered from the sensors during the measurement process (optical data, environmental data, etc.)
2. Relationships with other objects (e.g. associating a window object with the wall object that houses it)
3. Equipment and/or manufacturer data (e.g. associating the equipment model number, specifications, maintenance schedules, and other information with an equipment model object)
4. Design criteria (e.g. restricting the size of steel members, connections, and material types based on national standards or project specifications)
5. Business intelligence, such as operational or knowledge management information

Metadata may be automatically stored in the point cloud file format, or may be linked to the point cloud or the 3D model objects after the measurement process. BIMs offer virtually unlimited possibilities for integrating business intelligence with the project or asset management

Support systems
Because development of a BIM is a distinct activity from the acquisition and processing of laser scan data, it may fall under the purview of the engineering design team, architecture team, or third-party consultant rather than the 3D scanning service provider. However, many firms offer “scan-to-BIM” services, where the firm will perform all of the services required to deliver a complete parametric BIM as the contract deliverable. This option may not always be tenable or preferable depending on the project constraints. This integrated approach can be quite efficient because one stakeholder handles the entire process, but careful attention must be paid to the contract language to ensure that partnering service providers understand the risks and liabilities, as well as the performance requirements for this emerging service.
References

17. Randall (2011)- Construction Engineering Requirements for Integrating Laser Scanning and BIM
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