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1. INTRODUCTION

Static Terrestrial 3D Laser scanning technology has matured to the extent that it is considered a viable engineering capability and there are a number of departments within Eskom that perform static terrestrial laser scanning on a regular basis. It is thus a requirement that terrestrial laser scanning should be formally established and controlled with the required standards.

This document outlines the standards to be applied in the use of the technology in Eskom.

2. SUPPORTING CLAUSES

2.1 SCOPE

The scope of this standard is static terrestrial 3D laser scanning technology and its application in the Eskom environment.

2.1.1 Purpose

The aim of the document is to provide the required standards around the use and application of Static Terrestrial 3D Laser Scanning technology in an Eskom context.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions.

2.2 NORMATIVE/INFORMATIVE REFERENCES

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.

[2] National Key Points Act, Act No 102 of 1980

[3] 240-54179170: Technical Documentation Classification and Designation Standard

2.2.2 Informative

[4] 240-75884558 – Standard for Metadata for Spatial Datasets

[5] GSA BIM Guide Series 03 (www.gsa.gov/bim)

[6] ASTM Standard E 2544-08, “Terminology for 3D Imaging Systems,” ASTM International, West Conshohocken, PA, www.astm.org.

[7] Greaves, T. and Jenkins, B. [2004], “Capturing Existing Conditions with Terrestrial Laser Scanning: A Report on Opportunities, Challenges and Best Practices for Owners, Operators, Engineers/ Construction Contractors and Surveyors of Built Assets and Civil Infrastructure,” Spar Point Research LLC, Danvers, MA.

[8] Terrestrial Laser Scanning Specifications, CALTRANS Surveys Manual, California Department of Transportation, 2011.

2.3 DEFINITIONS

Term	Definition
3D Laser Scanning	3D Laser Scanning is a non-contact, non-destructive technology that digitally captures the shape of physical objects using a line of laser light. In other words, 3D laser scanning is a way to capture a physical object's exact size and shape into the computer world as a digital 3-dimensional representation. This technology could also be associated with close range stereo photogrammetry. Close range photogrammetry similar to this technology but uses variety of cameras to obtain topographic images at a define distance
Calibration	To set-up and confirm the measuring accuracy of a device, according to a prescribed standard.
Cloud-to-Cloud Scan Registration	In Cloud-to-Cloud scan registration neither targets nor special features are processed into modelled vertices. Instead, clouds are aligned to each other by selecting three or four "common points" within the overlap area of each cloud. These common points are selected to be physically close to representing the same point within each overlapping scan. Special software is then used to align the entire surfaces of the overlapping scan clouds to each other. This method is appealing because it reduces the need for placing targets in the scanner's field-of-view and scanning/surveying them. In the right conditions, "cloud-to-cloud" registration can provide amazingly accurate overall results. Rather than relying on a dozen or so target-based points for network adjustment, cloud-to- cloud registration may literally be taking advantage of a best fit based on hundreds of thousands of points.
Control Survey Network	A 3D Laser scanning registration methodology similar to traditional surveying. A control network is established for the site/building/ structure and then each individual scan is tied to the control network as an independent task. The scans are registered "to each other" only in a relative sense, based on how well each scan is individually tied to the control network. If one scan is not tied into the control network well (and the error is not related to the control network itself), then this one bad tie-in has no effect on the other scans being tied to the network. In this scheme, there is no need to worry about overlapping scans or even needing to have scans that are adjacent to each other (if the project doesn't require it). In a sense, this method represents the most traditional way of registering. It's familiar to surveyors and, if executed properly with the right tools, is sound methodology. All of the usual survey guidelines apply to extending control inside or outside the network. Also referred to as a "Coordinate Frame" or "Project Co-ordinate Frame".
Datum	An engineering **datum** used in geometric dimensioning and tolerancing is a feature on an object used to create a reference system for measurement. In engineering and drafting, a **datum** is a reference point, surface, or axis on an object against which measurements are made.

Term	Definition
Extracted Features	Where it is not always practical to place targets (or enough targets) within a scanner's field-of-view, extracted features from the laser scan are used to align multiple scans. (A tall building or structure, for example, may be virtually inaccessible for placing targets on high points. However, certain specific features, such as a pointed corner or an edge of steel, may be visible from multiple scans. Such a corner or edge can be scanned at high density, just like a target.) Using special software, corner scan data can be converted into a model and corner coordinates can be extracted. These corner points or vertices can be treated just as formal targets are treated to register adjacent scans to each other. This method is generally less accurate than target-based methods, but suffices for certain projects.
Geo-referencing	In 3D Laser Scanning data processing, this is the standard process of tying scan data (or any survey data) to the relevant control/coordinate systems. Coordinate systems may be state plane, local area, site-specific, plant-specific, etc. On many projects, both registration and geo-referencing are done, *i.e.*, scans are tied to each other and the registered set of scans is tied to control. It's common, even with relocation of a scanner around a site/structure, to supplement high-definition survey data with other measurement tools/methods. For example, utilities not directly visible to the scanner are commonly surveyed conventionally. These points are later merged with the high-definition survey results to comprise the full survey.
Handheld Laser Scanners	Hand-held laser scanners create a 3D image through the triangulation mechanism described above: a laser dot or line is projected onto an object from a hand-held device and a sensor (typically a charge-coupled device or position sensitive device) measures the distance to the surface. Data is collected in relation to an internal coordinate system and therefore to collect data where the scanner is in motion the position of the scanner must be determined. External tracking often takes the form of a laser tracker (to provide the sensor position) with integrated camera (to determine the orientation of the scanner) or a photogrammetric solution using 3 or more cameras providing the complete Six degrees of freedom of the scanner.
Levelling	Also known as surveying; to level all heights out; to get a reading as if there is no difference in heights or contours on the sites. Levelling is done on every scan position. The cameras can now auto adjust the height. The camera has to be levelled with the inclinometer.
LiDAR	Light Detection and Ranging. It is a rapid airborne laser scanner used to measure ground, building and tree heights. LIDAR (Light Detection And Ranging) uses ultraviolet, visible, or near infrared light to image objects and can be used with a wide range of targets, including non-metallic objects, rocks, rain, chemical compounds, aerosols, clouds and even single molecules. A narrow laser beam can be used to map physical features with very high resolution.

Term	Definition
Panoramic Image	A panoramic image is any wide-angle view of a physical space. Spherical panorama images (that incorporate a full 180° vertical viewing angle as well as 360° around) must be made by stitching multiple images. Stitching images together can be used to create extremely high resolution gigapixel panoramic images.
Raw Scan Data	3D laser scanning data exported from the 3D imaging system and not processed and/or altered in any way.
Registration	In 3D Laser Scanning work, this is the process of merging multiple scans *with each other* in correct, relative 3D geometry within a single coordinate system. In commercial practice, it's rare to sufficiently capture a site or structure with a single 3D laser scan. It's either too large to be captured with one scan or key parts of the site/structure are obscured from the line-of-sight of the scanner's first set-up. Hence, the scanner or scan head must be physically moved into a second location or orientation to capture parts of the site/structure obscured in the first scan. This process is repeated until all of the site/structures to be scanned are captured.
Resolution	All point clouds are made up of hundreds of thousands or even millions of points. Resolution is usually measured in millimetres (or microns) and is the smallest possible distance between any two given points within your point cloud. Therefore, the higher the resolution (points are closer together), the more points you need to visualize the same model. But also, the higher resolution, the more detail there is on the model.
RGB	RGB (red, green, and blue) refers to a system for representing the colours. Red, green, and blue can be combined in various proportions to obtain any colour in the visible spectrum. Combining red, green, and blue light is the standard method of producing colour images on screens, such as TVs, computers, monitors, etc.
Scan Target	Special scan targets that are placed within the scanner's field-of-view. Each target is scanned at high density. These scans are then processed with special software to extract their centre point locations (X, Y, Z). Two scans that share identical sets of targets can be registered to each other. A network of scans linked by targets can similarly be registered, typical for civil projects.
Spatial resolution	The space between the individual measurements in the scan
Spherical Point Cloud Viewer	This is a published viewer that allows point clouds to become accessible to any PC-user in the organization. Typically the only software required is a free applet in a web browser. These viewers allow the user to view the point cloud from the central position of each laser scan in a Google Street View-like environment. Navigation between scan positions is direct-hotlink based and there is facility for simple measurement and mark-up for sharing of information. The spherical point cloud viewer is derived from the original point cloud. If the point cloud is coloured according to a spherical photograph captured from the same position (see below), then data in the viewer can be coloured accordingly. If the data is not coloured from the image then a natural grey-scale tone is applied giving a black and white photograph effect in which the shades are derivatives of the return intensity of the laser.

Term	Definition
Station (Scan-Stations)	The place where the scanner is placed from which to conduct the relative surveys.
Time of Flight 3D Laser Scanning	In a time of flight scanner a pulse of light is emitted from the scanner. The time it takes for the pulse to travel from the scanner to the object and back is measured allowing the scanner to calculate the distance. The key benefit to this type of scanner is longer range scanning. The down side of this type is that they do not collect as many points. Currently they collect about up to 50,000 points per second. Hence the position of each point where the pulse hit the object or reflected back can be determined by using trilateration technique.

2.3.1 Disclosure Classification

Controlled Disclosure: Controlled Disclosure to external parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
2D	Two-Dimensional
3D	Three-Dimensional
CAD	Computer Aided Design
GTE	Group Technology Engineering
MP	Mega Points
CFD	Computational Flow Dynamics
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning system
IMU	Inertial Measurement Unit
LiDAR	Light Detection and Ranging
O&M	Operations and Maintenance (Plant Asset Lifecycle phases)
PCIS	Point Cloud Information System
PCM	Process Control Manual
STLS	Static (Stationary) Terrestrial Laser Scanning
TSSS	Total Station Survey System

2.5 PROCESS FOR MONITORING

The required quality control and auditing processes will be implemented and invoked on regular intervals to measure adherence of the organisation to the requirements put forth in this standard.

2.6 RELATED/SUPPORTING DOCUMENTS

[9] 240-109606436 Static Terrestrial Laser Scanning Work Instruction.

3. STATIC TERRESTRIAL 3D LASER SCANNING STANDARDS

The requirements and standards for 3D Laser Scanning are outlined below.

3.1 ACCEPTED APPLICATIONS OF STATIC TERRESTRIAL 3D LASER SCANNING TECHNOLOGY

The following are deemed accepted areas of application for 3D scanning technologies in Eskom Holdings:

- Validation of plant asset creation projects (verification and validation of "as built" plant to 3D design models).
- Environmental Impact Assessments/Studies.
- Feasibility Studies ("Fit for purpose" studies).
- Site Lay-out and Arrangement Planning and Design.
- Plant refurbishments and modifications.
- Design Base Modifications (Management of Changes toand approved or existing Design Base).
- 2D/3D layout and arrangement drawing generation (including detail drawings)
- Reverse engineering and Design Base Back-fit activities.
- FEA Simulations (3D model creation/preparation).
- CFD Analysis (3D model creation/preparation)
- Compliance monitoring (Component geometric design compliance)
- Process piping, pipe hanger and pipe support surveys
- Deformation and monitoring surveys
- Material/Component Wear Surveys and Surface Reconstruction
- "As Built" surveys.
- Forensic and/or Incident Investigations (Evidence Capturing)
- Maintenance and Project Activity Execution Planning/Requirements Validation*
- Safety and operational training*
- Emergency Preparedness planning and management*
- Training*.
- These items are generally deployed on the point cloud spherical viewer for this purpose and add the most value when it is delivered to the Client in this viewer and enabled in an information Portal environment.

3.2 LASER SCANNING DATA CLASSIFICATION & GENERAL DATA MANAGEMENT

- All 3D laser Scanning data and information generated on behalf of Eskom will, as a minimum, be classified as Level 3 (Controlled Disclosure) information. This is based on the fact that scanning will take place in plants and sites considered to be National Key-points in terms Act 102 of 1980. This is the minimum classification – based on client requirements, it can be re-classified to Level 2 if applicable. All documentation generated shall comply with: 240-54179170 Technical Documentation Classification and Designation Standard [3].
- In the case of Nuclear plant, the data will by default be classified as Level 2 information (Confidential) due to inherent risks involved in accidental sharing of highly classified site information and data. Based on client requirements, it can be re-classified to Level 1 (Top Secret) if needs be
- All 3D laser scanning data and information of Eskom sites shall be stored in a non-public, password protected information management environment.
- Any record copies of 3D laser scanning data, required for legal purposes must be safeguarded against unauthorised use or loss for the term of retention specified. (In general, as this data is considered part of the design base information set, it should be kept for the life of the power

station, unless otherwise specified by legislation).

- Where external service providers render the 3D laser scanning service to Eskom, a written agreement of Information/Document Disposal must be provided upon contract completion and handover of project deliverables. A period of no more than 12 months will be allowed post-contract completion for such disposal (in order to allow post-scanning support services in cases where there are data read-ability issues or data conflicts).
- Although scan data of an area of plant may become superseded by later scans taken after a modification, the earlier scan data-sets never become obsolete (and as such may not be destroyed). The original scan is still the most precise and detailed record of what existed beforehand, which may become valuable for various reasons such as identification of equipment now hidden, damage claims, deformation analysis, general asset management queries etc. Therefore superseded scans may not be deleted, and should be retained for the life of the plant for trace-ability and audit-ability.

3.3 SCAN DELIVERABLES, TOLERANCES AND QUALITY

The Scan tolerances and quality shall be defined in line with the project objectives. Based on the level of detail required the following deliverables, tolerances and scan resolution is specified:

Detail Level	Area of Interest	Deliverable description	Tolerance (mm)	Minimum Resolution/ Point Densities (mm x mm)
Level 1	Total Project area – Large earth works/site	Point Cloud	± 51	152 x 152 (Recommended) 500 x 500 (Average) 3500 x 3500 (Max Allowable)
	Total Project area – Smaller earth works/site or sub-set of a site (plant area)			152 x 152 (Recommended) 350 x 350 (Max Allowable)
Level 2	Building or System (Low Detail)	Plan Elevation Surface model Point Cloud	± 13	25 x 25 (Recommended) 50 x 50 (Average) 350 x 350 (Max Allowable)
	Building/System (High Detail			5 x 5 (Recommended) 35 x 35 (Average) 50 x 50 (Max Allowable)
Level 3	Floor/Level	Plan Elevation Point Cloud	± 6	5 x 5 (Recommended) 13 x 13 (Average) 35 x 35 (Max Allowable)
Level 4	Room or object/ component/ artefact in the room (General layout)	Surface Model Point Cloud	± 3	13 x 13 (Recommended) 35 x 35 (Average) 50 x 50 (Max Allowable)
	High Density Room or Areas, object/ component/ artefact in the room			0.5 - 1 (Recommended) 3.5 x 3.5 (Max Allowable)
Level 5	Surface Measurement (wear or damage at surface level) Resolution will depend on spec and application	Point Cloud Surface Model Mesh or Triangulated Models	± 1 (or smaller)	0.04 x 0.04 (Recommended) 0.05 x 0.05 (Average) 0.35 x 0.35 (Max Allowable)

Note:

- Point cloud tolerance - the distance between two points in a point cloud as compared to the true distance between the same two points in the actual scene should be less than or equal to the specified tolerance.
- The resolution of the scan is of utmost importance when scanning high detail plant areas, equipment or component detail (e.g. like those contained in substations or plant valve stations). In

those cases, the scan detail should be sufficient that the conductors and the clamps should be identifiable and can be modelled in detail.

- When selecting the resolution, the accuracy should not be more than 30 mm (ideally 3 mm) and the number of shots not less than 6 shots per point, ideally 8 shots per point (Default setting 4 shots).
- The registered point cloud data shall be reduced in size (e.g. to filter out "noise" and/or redundant data) to the maximum possible extent, without compromising data quality, accuracy and resolution of the 3D model.

3.4 SCANNING PROJECT DELIVERABLES

The following deliverables are required are as a minimum:

1. Scope of Work as per Paragraph 3.1
2. Safety Plan per Paragraph 3.2.2
3. Laser Scan Field notes Paragraph 3.2.5 which shall include as a minimum:
    - The Scanner used to perform the scan
    - Scan project datum and control network that is established and the methodologies employed to control dimensional accuracy
    - The floor/site layout plan showing scanner scan positions and target locations
    - Scan Logbook
    - Any other pertinent survey and scanning information
4. Raw Pointcloud data.
5. Registered/Processed Pointclouds.
6. Pointcloud Registration Quality Report, extracted from the registration software used.
7. 3D and other Digital colour photos, linked to each 3D Scan-point.
8. If part of the Scope of Work, 3D modelling, drafting and design (CADD) Software files in the required format.
    a) Integrated Truview Pointcloud portal for the scope of work delivered (if specified as a requirement).

3.5 STATIONARY TERRESTRIAL LASER SPECIFICATIONS

Description	Specification
Level compensator should be turned ON unless unusual situations) require that it be turned OFF.	Each set-up
Minimum number of targeted control points required.	A *minimum* of two (2) targeted control points, are scanned at high density for stationary laser scanners set-up in a level orientation, using a dual-axis compensator, occupying, back- sighting, and fore-sighting control points with known X, Y, and Z coordinate values. When known control is not occupied, back-sighted, and foresighted, a *minimum* of four (4) targeted control points are required for each set-up.
STLS control and validation point surveyed positional local accuracy.	H ≤ 9.1 mm V ≤ 6.1 mm
Strength of figure: α is the angle between each pair of adjacent control targets measured from the scanner position.	Recommended 60º ≤ α ≤ 120º
Target placed at optimal distance to produce desired results	Each set-up
Control targets scanned at high density	Required
Measure instrument height (when occupying control) and target heights	Yes
Check position of instrument and targets over occupied control points	Begin and end of each set-up
Be aware of equipment limitations when used in rain, fog, snow, smoke or blowing dust, or on wet pavement.	Each set-up
Distance to object scanned not to exceed best practices for laser scanner and conditions - Equipment dependent	Manufacturer's specification
Distance to object scanned not to exceed scanner capabilities to achieve required accuracy and point density.	Each set-up
Observation point density	Sufficient density to model object.
Overlapping adjacent scans (percentage of scan distance)	5% to 15%
Maximum measurement distance to meet vertical accuracy standard for horizontal (pavement) surface measurements	79.28m
Minimum measurement distance	Manufacturer's specification
Registration of multiple scans in post-processing	Required
Post-processing software registration error report	Required
Independent control validation points (confidence measurements) to confirm registration	Minimum of three (3) per scan

3.6 3D LASER SCANNING REGISTRATION METHODS

The Control Survey network method is preferred for scanning of long straight project scopes, e.g. conveyor belts, roadways, railways and site surveys of large areas.

The following methods are acceptable for merging multiple 3D laser scans of a project together, listed in order of preference:

- Targets
- Cloud-to-Cloud Registration
- Extracted Features (low accuracy projects).

Regardless of merging method chosen, all these scans MUST be Geo-referenced and tied to the Control Survey Network. It is also accepted that based on the complexity and scope of a laser scanning work request, that a combination of above methods may be required.

3.7 BEST PRACTICES TO BE IMPLEMENTED ON 3D LASER SCANNING PROJECTS

1. A High accuracy survey of all scan targets shall be done. To ensure highly accurate, high definition surveys of substations and power plants, only the most accurate total stations should be used to capture this data. No densification control is allowed beyond secondary scan points.
2. Only scan targets recommended by the 3D Laser scanner vendor should be used. Make-shift targets are not allowed due to the risk for accuracy. Scanning of the laser target should be done at high density, i.e. 1.5 mm point-to-point spacing.
3. At least four (4) scan targets should be placed for each scan, with the norm between 5-6 scan targets. The service provider should add more for redundancy in areas where there is potential risk of target scan quality not being acceptable.
4. In cases where “cloud-to-cloud” scan registration will be used, good 3D –geometry needs to be confirmed (e.g. buildings are good candidates due to their geometry).
5. An overlap of at least 15% is recommended between adjacent scans for areas where multiple scans will be required to capture all the information. For accurate scan processing a minimum of 30% overlap is required, unless this is not achievable.
6. Where possible, “on site” quality assurance (QA) checks should be performed on scans to identify potential problems with data or quality. It is recommended that ad hoc checks be performed with a total station to scan several targets and compare the data findings with that obtained with the laser scanner.
7. A Control Survey network needs to be configured for all scan projects. Control can be established using GPS units or by tying into and existing local datum if that is preferable/ prescribed. Inside of plants, a local co-ordinate system will be used that is referenced off the site’s 3D model or Site lay-out drawing(s). Where a site 3D model exists, the Control Survey network co-ordinates must be aligned exactly with the 3D model co-ordinate system.
8. A control network must be of an order of accuracy higher than what it is being used for. It is recommended that each point in the network be referenced to at least two, preferably three, surrounding permanent objects or points by measurement of angle, distance, and height. The project coordinate system and vertical datum must be stated and all existing control used as the basis for the scanning control network must be listed and described, including who published them.
9. The scanning work is to be done on a **suitable and repeatable co-ordinate system** either established or re-established on site based on existing infrastructure.
10. At least 4 well spread **permanent control points** should be placed on each level of a plant, preferably inter-visible with at least one other, and a list of these co-ordinates, with descriptions is to be delivered with the scans.
11. The survey control should be **consistent throughout the plant** (or unit) to a standard deviation of **5mm**. This can be relaxed to a figure of 10mm between units on the same plant.
12. The plant should be covered with an average spacing of 5mm between dots and with **sufficient density** of dots to facilitate the creation of 3D solid models from the point cloud, including the modeling of pipes 50mm diameter. Note that this is not an indication that 3D solid models

should be produced, but rather that the data will be sufficient for that purpose should the decision be made to do so.

13. The total XYZ **positional accuracy** specification of the scanner used should be equal to or better than 5mm standard deviation at a range of 25m, and 10mm within 50m (if applicable and agreed to on the Project).

3.8 LASER SCAN DATA STORAGE ARCHITECHTURE

The required Point Cloud Information System (PCIS) infrastructure should be in place to manage all laser scanning and pointcloud information assets created in and for Eskom.

As a minimum, a PCIS server shall be implemented with approximately 20 Tb of storage base. Capacity will double each year depending on the scope and volume of 3D laser scanning projects undertaken.

As a minimum, the following meta-data shall be stored on all 3D laser scanning datasets:

- File name of the raw data
- If a re-scan or subsequent scan, the revision schema for the system should be enabled
- Date of capture (into PCIS)
- Scanning system used (with manufacturer's serial number)
- Service Provider company name
- Site/Project name
- *PBS Information (Plant Tag/system unique number (if known))*
  Survey number (if known)
- Scan number (unique scan number for this survey)
  Total number of points
- Point density on the object (with reference range)
- Environmental conditions (temperature, humidity and other key weather conditions during scanning that influenced scan quality (outdoor scanning)

3.9 3D LASER SCAN DATA STORAGE

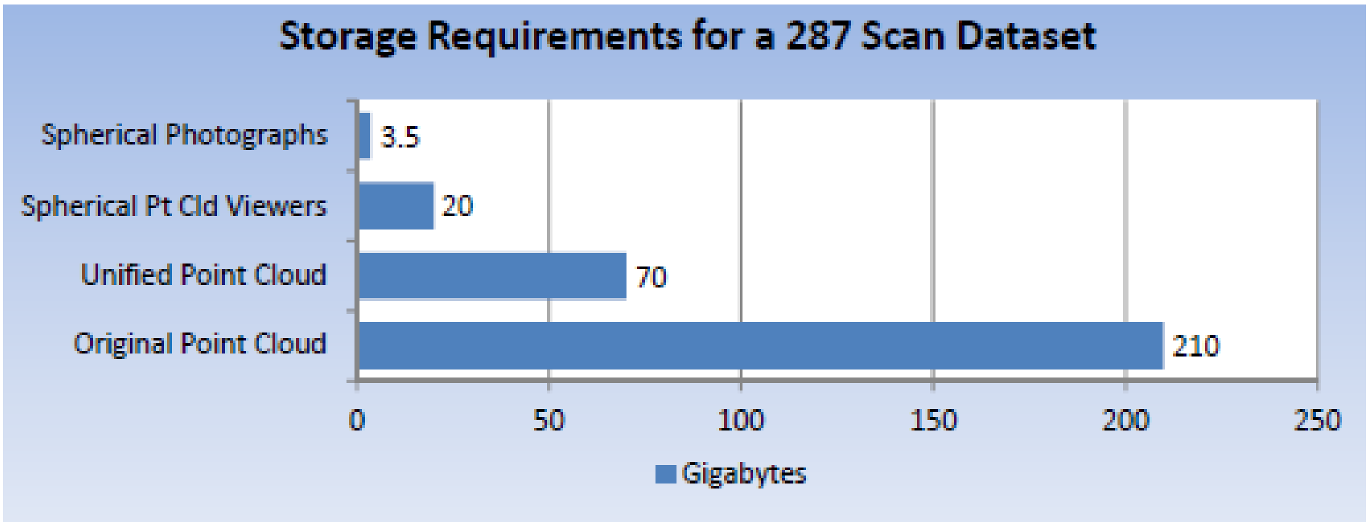
3D Laser scanning shall be managed as a design base information asset, subject to all Group IT controls and measures in place to ensure data quality and integrity in line with the CARAT principles.

Sufficient data storage capability shall be provided to store both the raw 3D scan files as well as the processed, integrated point cloud files. Raw scan file sizes are generally 2-4 GB in size, depending on the scan quality. Processed point cloud file of the same raw data is between 10-15 Mb in size. Data storage requirements should be based on these guiding values, multiplied by the number of anticipated scans.

Group IT should implement the required access control, disaster recovery and back-up procedures to ensure that the data asset is suitably managed and maintained over its lifecycle.

3.10 3D LASER POINTCLOUD DATA STORAGE

The graph below indicates the typical storage requirements for a typical scan dataset (based on about 287 scan sets):



All 3D laser scanning information shall be stored centrally in an access controlled database. Issuing of information around 3D raw laser scan data (or pointclouds) should be done from this central repository; with an administrator level user ensuring that the latest approved revision of the data set is issued for use.

4. AUTHORISATION

This document has been seen and accepted by:

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5. REVISIONS

Date	Rev.	Compiler	Remarks
July 2019	Draft	AB Haupt	Draft for review
September 2019	0.1	AB Haupt	Approved Final Draft Document after Review
September 2019	1	AB Haupt	Final Document for Authorisation and Publication

6. DEVELOPMENT TEAM

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