“Delivering Military Advantage through multi-national geospatial interoperability”

DGIWG 321

Point Cloud Standardization White Paper

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i. Executive Summary

This white paper is intended to provide recommendations and potential application profiles for point cloud data exchange by the defence community at different stages of data lifecycle: acquisition, modelling, encoding, dissemination and description.

It synthesizes the answers received from the “Questionnaire on Point Cloud Standardization Requirements” published and disseminated among DGIWG member nations in spring 2022 and proposes some potential work items for standardization that might be engaged to fit the identified needs of defence community.

ii. Contributing Participants

Nation	Parent organization
France (Lead Nation)	Institut Géographique National (IGN)
Spain	Cartographic Coordination Unit (SCC)
Sweden	Military Geographic Service
United States	National Geospatial-Intelligence Agency (NGA)
United Kingdom	United Kingdom Hydrographic Office (UKHO) and Met Office
Australia	Australian Geospatial-Intelligence Organisation (AGO)

iii. Document Points of Contact

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iv. Revision history

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04/08/2022	WD1	All	Document first writing from scratch
07/04/2023	WD2	3. References 6. “Format Presentation”	WD2 initialisation after P2 review in Utrecht. “Format presentation“ clause addition

Date	Edition number	Primary clauses Modified	Description
24/10/2023	WD2	6 Formats and Standards overview 7. Standardization work items proposal Annex A	WD2 review and modification after P2 discussions in Pont-à-Mousson (April 2023) and P2 virtual meeting (June 2023). Some modifications for formats and standards overview “Standardisation work items proposal” addition Some editorial changes to fit DGIWG format and styling rules. Some tools references additions
30/01/2024	Final Draft	3.1. Normative references 5. DGIWG answers to point cloud questionnaire 6.9. SIPC/MIPC Clause removal Table 9 - Work item proposals and standardisation needs	Addition of Australian use case Removal of SIPC and MIPC references. Editorial changes following last reviews at Garmisch Meeting (October 2023 and from AUS, GBR, FRA and USA.
05/12/2024	DGIWG Publication		Version for publication

v. Future work

This document aims to guide DGIWG member nations or clients in proposing new work items for point cloud standardisation based on scenarios outlined in clause 7 or alternative ones.

1. Introduction

With the development of LIDAR technologies for data acquisition by aerial or terrestrial means, many formats and software solutions have emerged to store and exchange the resulting point cloud data. Various uses already exist such as (among others): elevation data production, 3D urban city representation or virtual reality immersion. Point cloud data may come from many other sources, measuring devices and sensors and can represent (among others): Elevation data, Seismic data, Bathymetric data, Meteorological data, Fixed/Mobile consumer sensors (IoT), and may more types of data. These sources are captured by sounding devices, stereo imagery, etc.

Standardization for point cloud is increasing with older formats such as OBJ and PTX that are still in use, to more modern formats such as HDF5, LAS and others. LAS is a de-facto standard and the 1.4 specification was adopted as community standard by OGC in 2017. Cloud Optimized Point Cloud (COPC), which is a LAZ 1.4 file that stores point data organized in a clustered octree structure, may be the next point cloud standard that is brought under the OGC umbrella.

Currently, point cloud dissemination is not specifically handled by well-known OGC web service standards and technical solutions are developed to optimize access to point cloud data by chunking or tiling strategies.

Point cloud description by Metadata should be handled to have a consistent integration into a distributed architecture such as the DGRA.

This white paper is intended to provide recommendations and potential application profiles for point cloud data exchange by the defence community.

2. Scope

This white paper addresses potential standardization needs about point cloud data handling at different stages of data lifecycle: acquisition, modelling, encoding, dissemination and description.

It synthesizes the answers received from the “Questionnaire on Point Cloud Standardization Requirements” published and disseminated among DGIWG member nations in spring 2022 and proposes some potential work items for standardization that might be engaged to fit the identified needs of defence community on that subject.

3. References

3.1. Normative references

3.1.1. International standards

- **[DGIWG 114]** “DGIWG Metadata Foundation v2.0”
- **[DGIWG 116-1]** “Elevation Surface Model (ESM) Standardized Profile”
- **[DGIWG 116-2]** “Elevation Surface Model (ESM): GML Application Schema”
- **[DGIWG 116-3-1]** “Elevation Surface Model (ESM): Encoding Rules – Part 1: Core”
- **[DGIWG 116-3-2]** “Elevation Surface Model (ESM): Encoding Rules – Part 2: GeoTIFF”
- **[DGIWG 116-3-3]** “Elevation Surface Model (ESM): Encoding Rules – Part 3: GMLJP2”
- **[DGIWG 116-3-4]** “Elevation Surface Model (ESM): Encoding Rules – Part 4: NATO Secondary Image Format (NSIF)”
- **[OGC 17-030r1] “**LAS Specification 1.4 Format” – Community Standard
- **[OGC 17-014r8] “OGC** Indexed 3D Scene Layers (I3S) and Scene Layer Package (*slpk) Format” v1.2 - Community Standard
- **[OGC 17-014r9] “OGC** Indexed 3D Scene Layers (I3S) and Scene Layer Package (*.slpk) Format” v1.3 - Community Standard
- **[OGC 18-053r2] “**3D Tiles Specification v1.0” – Community Standard
- **[OGC 22-025r4] “**3D Tiles Specification v1.1” – Community Standard
- **[OGC 19-008r4] “**OGC GeoTIFF Standard v1.1”
- **[OGC 01-009] “**OpenGIS Implementation Specification - Coordinate Transformation Services v1.0”
- **[OGC 12-063r5]** “Geographic information - Well-known text representation of coordinate reference systems v1.0”
- **[ISO 19123:2005]** “Geographic information — Schema for coverage geometry and functions” (https://www.iso.org/standard/40121.html)
- [ISO 19115-1:2014] “Geographic information - Metadata – Part 1: Fundamentals” (https://www.iso.org/standard/53798.html)
- [ISO 19139-1:2019] “Geographic information - XML schema implementation - Part 1: Encoding rules” (https://www.iso.org/standard/67253.html)

3.1.2. National standards

- **[MEDIN]** discovery metadata Standard: https://www.medin.org.uk/medin-discovery-metadata-standard

3.2. Unstandardized Specifications

- **[LASZip]** "LASzip: lossless compression of LiDAR data" (Martin Isenburg): https://www.cs.unc.edu/~isenburg/lastools/download/laszip.pdf, Documentation: https://laszip.org/
- **[EPT]** "Entwine Point Tile v2.1". Specification: https://entwine.io/entwine-point-tile.html
- **[COPC]** "Cloud Optimized Point Cloud Specification v1.0": https://copc.io/copc-specification-1.0.pdf

3.3. Other related documents

- **[DGIWG 22-000]** "Questionnaire on Point Cloud Standardization Requirements"**:** https://portal.dgiwg.org/files/?artifact_id=72195

4. Terms, definitions, and abbreviations

4.1. Definitions

4.1.1. Point cloud

Collection of data points in 3D space
Note 1 to entry: The distance between points is generally non-uniform and hence all three coordinates (Cartesian or spherical) for each point must be specifically encoded.
[SOURCE: ISO 19130-2:2014, 4.51]

4.2. Abbreviations

ASPRS	American Society for Photogrammetry & Remote Sensing
AWS	Amazon Web Services
BGIC	Bundeswehr Geoinformation Center
CNES	Centre National d'Etudes Spatiales
COPC	Cloud Optimized Point Cloud
CSAR	CARIS Spatial Archive Raster
DBDC	Defence Bathymetric Data Center
DEM	Digital Elevation Model
DTM	Digital Terrain model
DSM	Digital Surface Model
EGI	Etablissement Géographique Interarmées
ESDIS	Earth Science Data and Information System
(E)VLR	(Extended) Variable Length Record
FOI	Totalförsvarets forskningsinstitut
GCP	Ground Control Point
GSF	Generic Sensor Format
GNSS	Global Navigation Satellite System
HLO	Helicopter Landing Officer
IGN	Institut national de l'information géographique et forestière
IMU	Inertial Measurement Unit
LIDAR	Light detection and ranging
MBES	Multiple Beam Echo Sounder
NASA	National Aeronautics and Space Administration
OAB	OGC Architecture Board
OGC	Open Geospatial Consortium
SAR	Synthetic Aperture RADAR
SBES	Single Beam Echo Sounder
SDB	Satellite Derived Bathymetry
SFTP	Secured File Transfer Protocol

UKHO United Kingdom Hydrographic Office
ZGeoBw Zentrum für Geoinformationswesen der Bundeswehr

5. DGIWG answers to point cloud questionnaire

5.1. Quantitative results

The « *Questionnaire on Point Cloud Standardization Requirements* » was published and distributed to DGIWG nations in March 2022. The first answers and use cases have been discussed during the Technical Panel (TP) Meeting in Taunton, May 2022, with a new deadline of June 2022 to provide new use cases and answers.

At the time this document written, eleven questionnaires were returned by seven different nations[1]:

- Four questionnaires returned by France:
  - LIDAR High Density civilian program by French geographic institute (IGN)
  - High Density maps for autonomous vehicles for the AI4Geo [2] program (Geosat)
  - Point cloud data from CO3D[3] project (CNES)
  - Point cloud data usages of the French Inter-Army Geographical Establishment (EGI)
- One questionnaire retuned by Spain representing, Army, Air Force and Navy usages of point cloud data
- One questionnaire returned by Sweden for the Swedish Defence Research Agency (FOI)
- Two questionnaires returned by Germany:
  - Kinematic Data Collection from BGIC
  - Usage of point cloud from ZGeoBw
- One questionnaire returned by Great Britain for the UKHO Defence Bathymetric Data Centre use cases
- One questionnaire returned by Czechia for national DTM production
- One questionnaire returned in December 2023 by Australia for Australian Geospatial Intelligence Organisation (AGO)

5.2. Qualitative results

The following sections synthetize the results of the point cloud management topics that the questionnaire covered.

5.2.1. Use case descriptions

The following use cases of point cloud data have been mentioned by the answering nations. They are often linked with elevation data (terrain or undersea) production but also with terrain characterization or change detection.

- CZE: Basic source for national DTM production;

[1] The answers to the questionnaire are available on the DGIWG portal here: https://portal.dgiwg.org/modules/files/details.php?m=files&artifact_id=72291
[2] https://www.ai4geo.eu/
[3] https://co3d.cnes.fr/en/co3d-0

- ESP/Army: Data capture (aerial or ground acquisition) for visualization service or 3D scenarios;
- ESP/Air Force: Point cloud data derived from digital image correlation in a process of orthophoto and DSM production;
- ESP/Navy : Generation of DTM for landing zones or beaches (wave zones and beaches analysis) – Not yet fully implemented;
- GBR (UKHO): Bathymetric (Single Beam and Multiple Beam) survey data storage and exchange, completed by terrestrial LIDAR and satellite derived bathymetry (SDB);
- SWE: Airborne and laser scanning for creation of elevation models, analysis of terrain and forest properties, analysis of occurrence and positions of various features, etc.;
- DEU/BGIC: Mobile mapping sensor acquisition as well as drone imagery for topographic information (infrastructure, vegetation, ground surface);
- DEU/ZGeoBw: Topography, buildings infrastructure information by ground acquisition (YAK truck) or airborne photo-optical sensor (drone);
- FRA/EGI: Multiple use cases with DEM creation (main use) or controlling process, environment characterization (urban combat missions and planning, obstacle detection, HLO missions), site protection issues (3D visualization of buildings, military structures and ground), or change detection (in the future);
- FRA/CNES: Point cloud intermediate products derived from spaceborne imagery (under construction);
- FRA/AI4Geo: Point cloud data for HD Maps elaboration for self-driving vehicles.

5.2.2. Source of data (acquisition)

The sources of acquisition vary from ground, sea, airborne or satellite acquisition with various types sensors (laser, optical or sonar).

The following table gives the detail of the sensors and acquisition modes used for each use case.

Table 1: Sensor and acquisition modes used for each use case

Country	Sensor	Acquisition
CZE	LIDAR ALS80 	Aerial campaign
ESP/Army	Trimble SX10 (total station) 	- Ground acquisition (man-made, total station) - Aerial campaign or drone acquisition

Country	Sensor	Acquisition
ESP/Air Force	Photogrammetric electro-optic sensor- Vexcell Ultracam Eagle 	Aerial acquisition
ESP/Navy	Laser scanners	Unmanned Aerial System (drone)
UKHO	Single and Multiple Beam Echo Sounders (SBES and MBES)	Surface vessels for acoustic data (man and unmanned) Fixed wing aircraft (LIDAR) Satellite Derived Bathymetry (SDB)
SWE		National Land survey (aerial campaigns) Occasionally completed by ground acquisition
DEU/BGIC		Mobile mapping sensor and drone imagery
DEU/ZGeoBw		- Ground acquisition by LIDAR module mounted on a YAK Truck. - Airborne photo-optical sensor (drone)
FRA/EGI	LIDAR Sensor	- Airborne acquisition - Stereographic image sensors on vehicles and deployable sensors
FRA/CNES	Matrix sensors	- Spaceborne imagery - 3Dpoints are built after stereo triangulation of matching 2D points

Country	Sensor	Acquisition
FRA/AI4Geo	Pegasus Ultimate2 (Leica),  TRK (Leica),  RS4 (Siteco),  MX9 (Trimble) 	- Ground acquisition with Mobile Mapping System
AUS	Riegl, Optech, and Trimble (among others)	- Aerial capture

5.2.3. Data modelling and, format encoding

The ASPRS LAS format and its LAZ compressed version are most often used in the use case descriptions. Point cloud data are also sometimes exchanged in ASCII/text files.

One may also note that proprietary formats linked with the management or disseminating software may be used (CPT for skyline terra explorer, CSAR for Caris HIPS and SIPS solution. PLY format is also mentioned in one use case.

In most use cases no specific data model has been defined. The model proposed by the underlying format (e.g. LAS point data format and classification) or the acquisition software is used. UKHO uses its own data model for bathymetric data description.

Coordinates of points are expressed either in WGS84 system or in global (UTM) or local projection systems.

These points are detailed use case by use case in the following table:

Table 2: Formats and data modelling for each use case

Country	Formats	Modelling
CZE	las, laz, xyz	
ESP/Army	LAS format (whatever the source)	Modelling attached to the used software: • TBC Trimble (laser scanner data) • Pix4D (drone data) • MDTOPX DIGI21 (data characteristics and Labelling)
ESP/Air Force	LAS format	
ESP/Navy	LAS/LAZ Format	laser scanners, referred to ETRS89 and WGS84
UKHO	ASCII (txt) file + Readme File LAS format GSF Format CSAR Format (CARIS based format)	Depth measurement Classification for land, seabed, wrecks, … UKHO/DBDC specific data model
SWE	LAS format occasionnaly ASCII/text files	Properties of Terrain/forest, slope, curvature, roughness Features : buildings single trees, boulders Point cloud labelling from LAS format
DEU/BGIC	- LAS format - LAS Dataset (ESRI) - LAZ	No specific data model
DEU/ZGeoBw	- LAS, LAZ formats - Conversion to CPT file format (Skyline's proprietary format)	Referenced on WGS 84
FRA/EGI	- LAS/LAZ format - PLY - Text files xyz - 3D Models (.obj, .stl) - 3D Format derived to KML/COLLADA - 3D format derived to SHAPE 3D(.shp)	- Classification of data: bare and surface ground, vegetation, buildings, water. - No specific model used. - France is working on an 3D urban French model based on DGIF - CRS is based on WGS84 Geo (EPSG : 4326)
FRA/CNES	LAZ format with Point format 2 or 8.	- UTM Georeferencing (centimetric precision) - Characteristics: radiometry (red, blue, green, NIR) coded under 8 bits per channel - Labeling: correlation criteria, confidence measurement

Country	Formats	Modelling
FRA/AI4Geo	LAS/LAZ Format	- Geo-referencing: Lambert Conformal Conic Projection (CC 9 zones), EPSG 3942 to 3950; - Labeling: Roads, markings, signs, buildings, vegetation, vehicles, furniture, pedestrians, rails.
AUS	LAS/LAZ Format	- Point cloud data generally describes ground, vegetation, building, water, bridge, and noise. Classification closely follows ASPRS Lidar 1.4 Specification. - Uses Local CRS for both horizontal and vertical datum.

5.2.4. Data disseminating

Data dissemination across the network is not very developed in most use cases. ESRI (I3S) is mentioned for some use cases, 3DTiles or Potree are sometimes a solution for visualization (potentially through network). Data can also be accessed directly through network in native format.

Table 3: Data dissemination for each use case

Country	Network dissemination
CZE	No network
ESP/Army	Under study: ESRI Webservices, I3S Format
ESP/Navy	WMS used for mapping
UKHO	Data mining
SWE	Common Windows file transfer
DEU/BGIC	Scene layers on ESRI ArcGIS Portal
DEU/ZGeoBw	Local intranet
FRA/EGI	No use of point cloud data through our network
FRA/CNES	No web service used for dissemination
FRA/AI4Geo	AWS, SFTP
AUS	Access through network folders/paths in native format.

5.2.5. Data description

Many use cases have not developed metadata elements for point cloud data description. Besides it is a key point for the exchange of data in some use cases that involves a specific data modelling and format (UKHO case). In some cases, Australia is producing metadata at a dataset level on an [ISO 19115] basis and with required metadata elements.

Table 4: Metadata for each use case

Country	Metadata elements
CZE	Date of acquisition
ESP/Army	
ESP/Air Force	
ESP/Navy	X,Y,Z and datums

Country	Metadata elements
UKHO	The data model used is UKHO/DBDC specific, but it does contain key metadata fields, For example • Horizontal datum • Vertical Datum • Collection dates • Survey standard Aligned with [MEDIN] Standard
SWE	
DEU/BGIC	No metadata is used
DEU/ZGeoBw	No use of additional metadata
FRA/EGI	Not implemented by now. Some metadata need to be carried: - Tiling of the product - Quality information (accuracy of measures, exhaustivity of classification) - CRS information (EPSG)
FRA/CNES	To be defined
FRA/AI4Geo	Information: GNSS trajectories (txt, shapefile), GCP base (txt, shapefile), zone extent; Implementation: Acquisition export is manual (each operator fills a template folder structure), post-processing (classification, segmentation) is semi-automatic; Level: Each zone is split into plots of neighborhood-scale.
AUS	Metadata information varies depending on the data provider/vendor. Where metadata exist, they are produced at dataset level, and are based on [ISO 19115] where possible. At a minimum, the following information are required: • Acquisition/capture date range • Creation date • Horizontal and vertical CRS • Data quality (accuracy, lineage)

5.2.6. Visualisation and processing tools

The software or tools used in the use cases are various and numerous, either commercial, linked with sensor material or open source. The following table gives the detail of the software used by each use case. More details for each software reference are given in Annex A.

Table 5: Visualisation and processing tools for each use case

Country	Processing	Visualization
CZE	Lastools	Erdas Imagine, ArcGIS, Fugro viewer

Country	Processing	Visualization
ESP/Army	Carta Digital (3DTiles with point clouds visualization) Off-the-shelf software: - TBC Trimble - MDTOPX DIGI21 - ArcGIS Pro - CloudCompare	
ESP/Air Force	Vexcell Ultracam Eagle software (UltraMap)	Global Mapper
ESP Navy	PIX4D, DJI TERRA, ArcGIS	
UKHO	• CARIS HiPS/SiPS to process bathymetric survey, CARIS Base Manager to database point cloud data • CARIS Base Editor to manipulate data • CARIS HPD to store digital products • QPS Qimera and FME are also used by UKHO.	
SWE	We mostly use “off the shelf” software, both commercial and free, e.g. ArcGIS, Global Mapper, Quick Terrain Modeler, CloudCompare. FugroViewer.	
DEU/BGIC	Trimble Business Center (TBC) is used to process and visualize the raw data	
DEU/ZGeoBw	- 3-D terra explorer - ArcGIS Pro - Global Mapper	
FRA/EGI	- Global Mapper (Blue Marble Solution) - ArcGIS (ESRI software solutions) - QGIS Tactical software (for units) : - Drone2Map - Pix4D - RhinoCity - MetaShape (AGISOFT)	
FRA/CNES	- Potree (to demonstrate huge Point Cloud) - CloudCompare (to analyze)	
FRA/AI4Geo	- CloudCompare, Metashape, homemade Python/C++ libraries.	
AUS	Software use is applied on best fit for required outcome and includes: - Global Mapper - Quick Terrain Modeler - Esri ArcPro - FME	

5.3. Identified standardization needs

The standardization issues shared by several use cases are mainly:

- CRS information carrying with (or within) the data
- Description of point cloud data (Metadata), especially when an unspecified format (eg. ASCII Text) is used
- Some format considerations (basic exchange formats, conversion issues to proprietary formats, information carried by the format)
- Data management regarding size and density

In the detail, the following table lists the standardization needs or issues explicitly identified in each use cases.

Table 6: Standardisation needs for each use case

Country	Standardization considerations
CZE	- Determination of the basic exchange formats
UKHO	- Variety of formats for MBES, some formats (GSF) doesn't hold all of the raw data - The encoding used for the exchange of data depends on the knowledge of the application used by the receiving/sending system (CSAR format used if CARIS is used or ASCII text files if not). - Key metadata elements to be provided with data
SWE	- LAS to zlas conversion needed for usage with ESRI ArcGIS - Hard requirement to define and include reference system/projection in the files. Today some providers deliver data without including reference system/projection in the files.
DEU/BGIC	- Point cloud size and density is an issue, where different types of software react very different. - Working properly is also a matter of the projection
DEU/ZGeoBw	- Sometimes problems with the implemented coordinate system can occur.
FRA/EGI	- CRS Information carrying - To be compatible with other systems (GIS), must be exportable to KML/COLLADA, SHAPE3D, multipatch - Metadata repartition between data and metadata files
FRA/AI4Geo	- Encourage the use of LAZ: For storage purposes and point cloud reading, it could be relevant to save point cloud in compressed mode (LAZ). - Spatial Reference System: Project all point cloud in a common EPSG (e.g. 2154, Lambert 93); - Labelling: Systematically use the ASPRS codes (LAS specification). - A single way to export point cloud: Each sensor company proposes its own tool to export point cloud. It could be relevant to achieve it using a single

Country	Standardization considerations
	software
AUS	- CRS projection tags sometimes not recognizable by all software platforms e.g. ESRI - LAZ files are not readily consumed by all software – it needs to be uncompressed before it can be exploited. - Concerns over COPC and backwards compatibility during adoption phases - Inconsistency in metadata formats eg PDF, XML, html - Different report formats and tags from different vendors makes ingest challenging Future considerations for interoperability and standardization - Requirements to consider the inter-operability of Drone Imagery and Kinematic Imagery with Point cloud data to support classification and the production of derivative products - How will sensor standards influence storage standards with possible amalgamation within a unified data model being required in the future to facilitate performance and interoperability efficiencies. - Exploration of how storage standards can impact format standards and the need for data containers to be able to support multiple formats. - A need for data to be software agnostic - What considerations need to be made to support Geopackage

5.4. Resources availability

The questionnaire asked member nations about the resources they may provide for standardization work about point cloud data.

The following table lists the level of investment proposed for this by answering nations[4].

Table 7: Resources availability by nations

Country	Presentation	Work
CZE	No	Sample data providing, document reviewing
ESP	No	We can support it through our current DGIWG P2 participation

[4] At the writing time of the document, USA hasn't answered the questionnaire

Country	Presentation	Work
GBR/UKHO	Yes	- Document writing - Document reviewing - Implementation testing - Sample data providing, hosting, serving, etc. - Others…
SWE	No	
DEU/BGIC	At a later stage	Implementation testing Sample data providing
DEU/ZGeoBw	Yes	At least some document reviewing.
FRA/EGI	Yes	Yes (level of investment being considered)
FRA/AI4Geo	No	
AUS	Not at this stage	Document reviewing

Many answering nations will provide resources for documents reviewing, providing sample data or implementation testing, GBR and France may invest more in document writing.

6. Formats and Standards overview

This clause examines some major formats or standards dedicated to point cloud data management that may be of interest for the Defence community. This is not an exhaustive examination as some known formats (e.g. "E57[5]") have not been mentioned in the Defence community's use cases stated in this document. Also, some underlying formats or standards dedicated to management of large amount of data on the cloud, such as Zarr[6], TileDB[7], Parquet[8], STAC and its point cloud extension[9], are not mentioned in this clause as they are not directly involved in point cloud data. One may find further considerations about formats in a NASA ESDIS Standards Coordination Office white paper dedicated to storage and access of point cloud data in the cloud[10].

6.1. LAS / LAZ format and derived specification

6.1.1. LAS Specification

The LAS Format is a specification that was initially developed and published by the American Society for Photogrammetry & Remote Sensing (ASPRS) in May 2003.
The latest major release 1.4 R13 was published in July 2013 and endorsed by OGC as a Community Standard (**OGC 17-030r1)** in March 2018. Since then two minor releases R14 and R15 have been published in March and July 2019 by ASPRS.

[5] ASTM E57 3D File format: https://www.astm.org/e2807-11r19e01.html
[66] Zarr: https://zarr.readthedocs.io/en/stable/index.html
[77] TileDB: https://tiledb.com/
[8] Parquet: https://parquet.apache.org/
[9] STAC: (https://stacspec.org/) Point cloud extension : https://github.com/stac-extensions/pointcloud
[10] "A Review of Options for Storage and Access of Point Cloud Data in the Cloud": https://www.earthdata.nasa.gov/s3fs-public/2022-06/ESCO-PUB-003.pdf

It is intended to contain LIDAR (or other) point cloud data records. The data will generally be put into this format from software (e.g. provided by LIDAR hardware vendors) which combines GPS, Inertial Measurement Unit (IMU), and laser pulse range data to produce X, Y, and Z point data. The intention of the data format is to provide an open format that allows different LIDAR hardware and software tools to output data in a common format.

The format defined in LAS 1.4 specification contains binary data structured as follow (see Figure 1):

1. A **public header block**, designed to describe general predefined metadata about the file and its content (including geographic extent and scale factors) and offsets to the other parts of the file.
2. Any number of **Variable Length Records (VLR)** – optional - designed to describe variable types of data including projection information, metadata, waveform packet information, and user application data. They are limited in size to 65,535 bytes.
3. The **Point Data Records** which contains the actual values for the point clouds (x,y,z positioning and their properties).
4. Any number of **Extended Variable Length Records (EVLR)** – optional - which have the same purpose as VLR except that they are not limited in size and are appended at the end of the file.

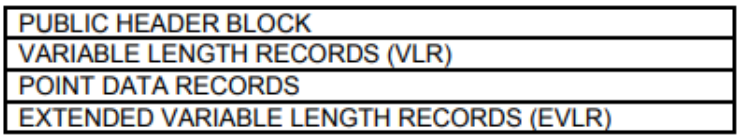

Figure 1 - LAS 1.4 Format Definition

This structure described in LAS 1.4 has been progressively enhanced in capacity since LAS 1.1 specification with the possibility to maintain a backward compatibility with 1.1 to LAS 1.3 structures within a LAS 1.4 file.

Point data description

Eleven possible point data records formats are proposed by the specification. The six first of them are maintained for backward compatibility with previous LAS releases and can be overridden by the five last (starting with “Point Data Record Format 6” as described in Figure 2) introduced in LAS 1.4.

Table 15: Point Data Record Format 6

Item	Format	Size	Required
X	long	4 bytes	*
Y	long	4 bytes	*
Z	long	4 bytes	*
Intensity	unsigned short	2 bytes	
Return Number	4 bits (bits 0 - 3)	4 bits	*
Number of Returns (given pulse)	4 bits (bits 4 - 7)	4 bits	*
Classification Flags	4 bits (bits 0 - 3)	4 bits	
Scanner Channel	2 bits (bits 4 - 5)	2 bits	*
Scan Direction Flag	1 bit (bit 6)	1 bit	*
Edge of Flight Line	1 bit (bit 7)	1 bit	*
Classification	unsigned char	1 byte	*
User Data	unsigned char	1 byte	
Scan Angle	short	2 bytes	*
Point Source ID	unsigned short	2 bytes	*
GPS Time	double	8 bytes	*

Figure 2 - Fields of Base Point Data Record Format 6 in LAS 1.4

All point data records structures share the same properties defined relative to LIDAR acquisition technology (e.g.: intensity, scan direction flag, return number and number of returns, classification,..) and offer a field to add user specific information to each point ("User Data") encoded on one byte. They differ when one wants to add information to points with three color channels (RGB), near Infrared (NIR) channel or Wave Packets as described in Table 8.

Table 8 – LAS 1.4 Point Data Records Formats Specificities

Point Data Record Format	Base fields (PDR#6)	RGB Channels	NIR Channel	Wave Packet data fields	Overridden legacy Point Data Record format[11]
PDRF 6	X				PDRF 1
PDRF 7	X	X			PDRF 3
PDRF 8	X	X	X		PDRF 3
PDRF 9	X			X	PDRF 4
PDRF 10	X	X	X	X	PDRF 5

The classification of Point clouds must adhere the classes defined by LAS 1.4 standard which allows 256 values with 19 already specified in regard to LIDAR specificities, 44 reserved values and 192 possible values that can be defined by user thanks to specific "Classification Lookup" VLRs.

[11] The Point Data Records Formats 0 and 2 don't include a GPS Time field whose presence has become mandatory in LAS 1.4.

Table 17: ASPRS Standard LIDAR Point Classes (Point Data Record Formats 6-10)

Classification Value	***Meaning***
0	Created, never classified
1	Unclassified[3]
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Reserved
9	Water
10	Rail
11	Road Surface
12	Reserved
13	Wire – Guard (Shield)
14	Wire – Conductor (Phase)
15	Transmission Tower
16	Wire-structure Connector (e.g. Insulator)
17	Bridge Deck
18	High Noise
19-63	Reserved
64-255	User definable

Figure 3 - LAS 1.4 Point Classes

Specific VLRs and EVLRs

VLRs and EVLR allows user to embed additional information to the LAS file. In LAS 1.4 some specific VLR and EVLR are already defined for:

- Coordinate Reference System Information carrying

This information can be provided through two possible methods: the first one by providing the GeoTIFF Tags (specified in OGC GeoTIFF Standard specification [OGC 19-008r4]) necessary for specifying coordinates reference systems (GeoKeyDirectoryTag, GeoDoubleParamTag and GeoAsciiParamTag), the second one by Well Known Text (WKT) definition as specified by section 7 of OGC Coordinate Transformation Service [OGC 01-009][12]. This second method has been introduced with LAS 1.4 and is not backward compatible with previous releases which rely on GeoTIFF method.
This information is required (provided either by GeoTIFF or WKT method) since release 1.4.

- Classification Lookup: for user defined point classes values
- Text Area Description: this VLR/EVLR is used for providing a textual description of the content of the LAS file
- Extra Bytes: for specifying additional information that can be added to the end of a Standard Point Record
- Superseded: Is used to negate an existing VLR/EVLR when rewriting the file.

[12] This reference is outdated and the OGC Architecture Board (OAB) recommends that future versions of LAS include reference to the latest version of the OGC Well-known text representation of coordinate reference systems (WKT CRS) standard. OGC: [OGC 12-063r5] Geographic information - Well-known text representation of coordinate reference systems, 2015.

- Waveform Packet Descriptor: These records contain information that describes the configuration of the waveform packets (mandatory when the point data record format used is carrying wave data packet fields)
- Waveform Data Packets (EVLR): Header structure followed by the waveform data packet records

LAS Domain profiles
The LAS 1.4 Specification allows the possibility of defining LAS Domain profiles in order to extend the base LAS specification by adding (but not altering or removing existing) point classes and attributes to meet the application-specific needs of a particular subset of the broad lidar community.
Such a profile has been defined for topographic-bathymetric (topo-bathy) lidar[13]. It is adding point classification values and new point attributes implemented by (EVLRs) for bathymetric points.

6.1.2. LAZ format

The LAZ format is associated with a compression library “LASzip” specially designed for compressing LAS format data in lossless mode. This library is part of the LAStools software suite developed and maintained by the “rapidlasso GmbH” company.

According to LASZip documentation, LASzip compresses bulky LAS files into compact LAZ files that are only 7-20 percent of the original size, accurately preserving every single bit. It is more efficient than regular compressor tools like bz2, gzip, and rar because it has been designed for LAS File compression and knows what the different bytes in a LAS file represent. It therefore adapts its algorithm to the specificities of each field of the Point Data Records such as intensity, classification, scan angle rank, GPS Time, RGB, NIR channels or Wave Packets. Also, LIDAR Points are compressed in completely independent chunks and each chunk can be accessed and decompressed independently.
In a LAZ file, the public header bloc and the VLRs are not compressed. A specific VLR is added to specify the composition of the compressed points and various compression options used.

The LASzip library is available in open source under LGPL license and is widely used and integrated in many software for compressed LAS point clouds management and exchange. Yet, besides the original publication by the creator of the LASzip algorithms (cf. [LASZip], there is no existing specification for the LAZ format, which makes it difficult to have alternatives implementations for readers or writers of it and to make it become a standard. This might change relatively soon, as RapidLasso announced at the 126th OGC Meeting that they are going to write a proper specification of LAZ and propose it to OGC as a Community Standard.

6.1.1. Entwine Point Tile (EPT)

Entwine Point Tile (EPT) is a storage format that defines an octree-based structure which spatially indexes point cloud data. It has been designed to deliver massive point cloud data.

An EPT dataset is composed of a set of JSON files that describe the structure of the octree nodes and a set of point cloud data files that contains the data at the end of octree nodes.

[13] Topo-Bathy Lidar LAS Domain Profile (2013): https://www.asprs.org/wp-content/uploads/2010/12/LAS_Domain_Profile_Description_Topo-Bathy_Lidar.pdf

The data files can either be LAZ files or binary files whose schema shall be described specifically.
This format is developed by Hobu Inc. company which also provides a tool suite to generate an EPT dataset from regular point cloud files or translate it to 3D Tiles streaming protocol. It is delivered in open source and has been implemented by PDAL open source library.
It has been first issued in 2017 and the last release 2.1 came out in 2019.
It is still maintained but Hobu Inc. which has now concentrated its efforts in the development of Cloud Optimized Point Cloud (COPC).

6.1.2. Cloud Optimized Point Cloud (COPC)

Cloud Optimized Point Clouds (COPC) is a specification developed by Hobu Inc. company. It is based on LAS 1.4 and its LAZ compressed form.
A COPC File is a valid LAZ 1.4 file into which the point data records have been gathered and compressed into chunks relatively to their position in space given an octree structure.
This octree structure is modelled after the EPT data model and serves as geospatial index of the chunks into the LAZ file. It is embedded in the LAZ file into a dedicated EVLR as shown in Figure 4.

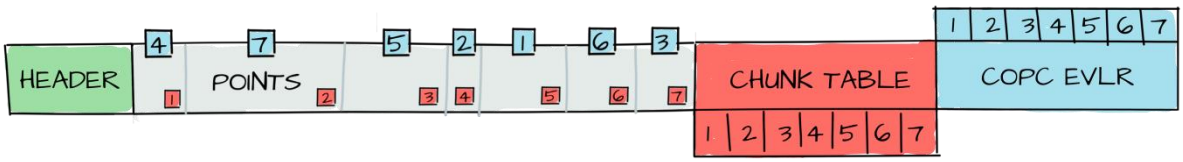

Figure 4 - COPC data organisation

COPC also defines a specific VLR header that contains general information about the octree (geographical and time extents and access to first page of the octree) that must be placed just after the public header file defined by LAS Specification.

This organisation has been designed to optimize access to data into the file by allowing readers aware of this format to read only the part of the file they need based on spatial criteria.

This specification is quite recent (release 1.0 published in 2021) and not standardized. It is open, delivered under MIT license, and has been integrated by some common open source based libraries such as PDAL or laspy and software such as QGIS and FME. This is also likely to become an OGC standard after LAZ becomes a community standard.

6.1.3. Considerations about LAS format and derived specifications

The LAS format together with its LAZ compressed form has become a widely used format to exchange LIDAR based (or other) point cloud data. It is implemented by most hardware and software tools.
Even if its structure is mostly LIDAR oriented, it offers a mechanism to expand it with some additional user specific information at file or point data level. This allows one to develop dedicated application profiles with enhanced capacities (such as COPC).

The legacy based backward compatibility maintained throughout its successive releases can be seen either as an asset for the readability of old LAS released data or as a disadvantage as it forces the maintenance of some deprecated fields or methods of encoding (e.g. CRS encoding) which may cause some confusion for software readers and interoperability issues.

It is also mostly an exchange format as its structure makes it difficult to modify only some parts of the file without having to rewrite the whole file, be it compressed or not.

The use of LAS or LAZ format has been mentioned in every use case of point cloud data reported by DGIWG answering nations. If some standardisation work occurs it should certainly deal with this format by either defining an application profile or providing some encoding rules.
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6.2. I3S

The I3S format is a container used to store large amounts of heterogeneously distributed 3D geographic data, to be consumed by mobile, web and desktop clients. A single I3S data set can be referred as a Scene Layer (I3S) or a Scene Layer Package (SLPK). Both formats are encoded using JSON and binary ArrayBuffers (ECMAscript 2015).

The first version of this standard (v.1.0 - http://www.opengis.net/doc/CS/i3s/1.0) was delivered to the OGC by ESRI, and published as an OGC community standard in September 2017 (17-014r5). The latest OGC version of this standard is v.1.3 (17-014r9), which has been published by the OGC with date 2023-01-11, and can be found here http://www.opengis.net/doc/CS/i3s/1.3 More information, documents and tools can be found at https://github.com/Esri/i3s-spec

I3S organizes information in node hierarchies. Each node contains features with geometry, textures and attributes. It is spatially indexed and has a tree structure (either Quadtree, Octree or R-Trees are supported). The CRS for the nodes is the global geographic WGS84 system (WGS84 or CGCS 2000), and heights are in meters pointing upwards towards the sky. Each node has a Minimum Bounding Volume (MBV) box, fitting features inside of it. A MBV can be described as minimum bounding sphere (MBS) or oriented bounding box (OBB) representation. Point cloud profile supports OBB representation only.

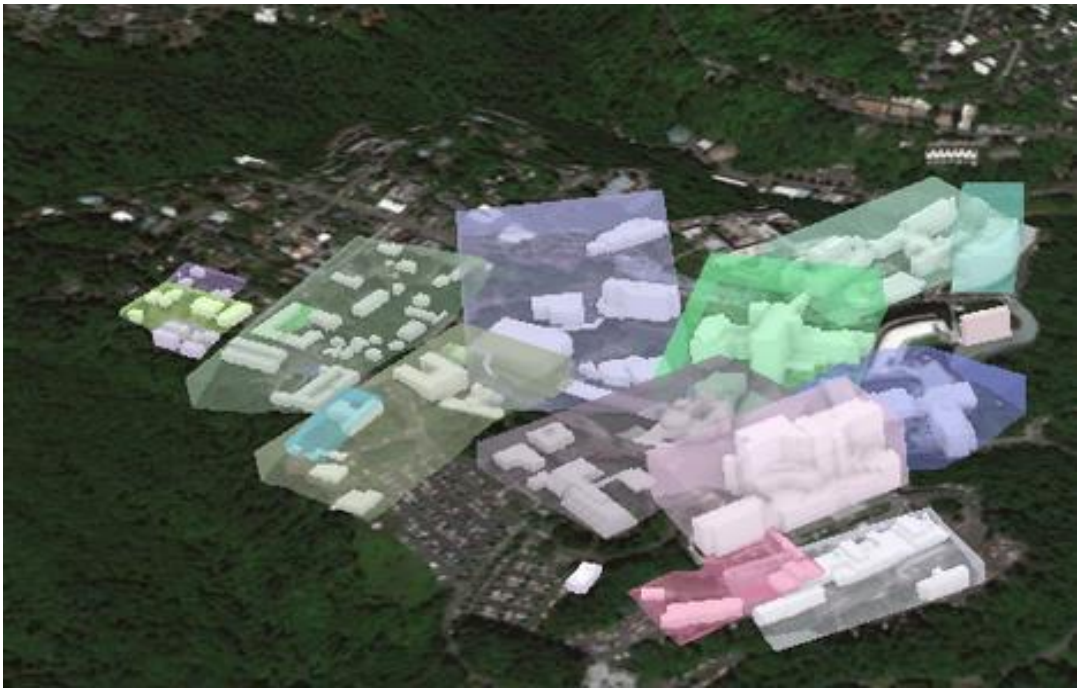

Figure 5 - 3D objects enclosed in an oriented bounding box (OBB).

It supports different Levels of Detail, allowing a feature to be described more than once in different nodes. Parent nodes contain simplified representations of their children. The features are represented using points, or vertex and textures, included as image files (jpeg, png).

I3S supports five different Layer Types: 3D Object, Integrated Mesh, Point, Point Cloud, and Building Scene Layer. This format is not specific for point clouds, but for a wide range of 3D object types (i.e. points, buildings, solid volumes, etc.).

Some references for I3S implementations and support can be found on I3S's github repository[14].

6.3.3D Tiles

3D Tiles is an open specification designed for streaming and rendering massive 3D geospatial content such as photogrammetry, 3D buildings, BIM/CAD data, instanced features, and point clouds. A Tileset is a set of tiles organized in a spatial data structure, the tree. A tileset is described by, at least, one JSON file containing tileset metadata and a tree of tiles. Each tile contains renderable content, in a binary blob, and metadata, such as the bounding volume. The format enables a Hierarchical Level Of Detail, allowing low resolution views of the objects.

3D tiles was created by Cesium, and uses the glTF file format, developed by the Khronos group (for file extensions see https://registry.khronos.org/glTF/specs/2.0/glTF-2.0.html#file-extensions-and-media-types). It has been endorsed by the OGC, and the latest version

[14] https://github.com/Esri/i3s-spec#where-can-i-use

(v.1.1) of the specification can be found here http://docs.opengeospatial.org/cs/22-025r4/22-025r4.html

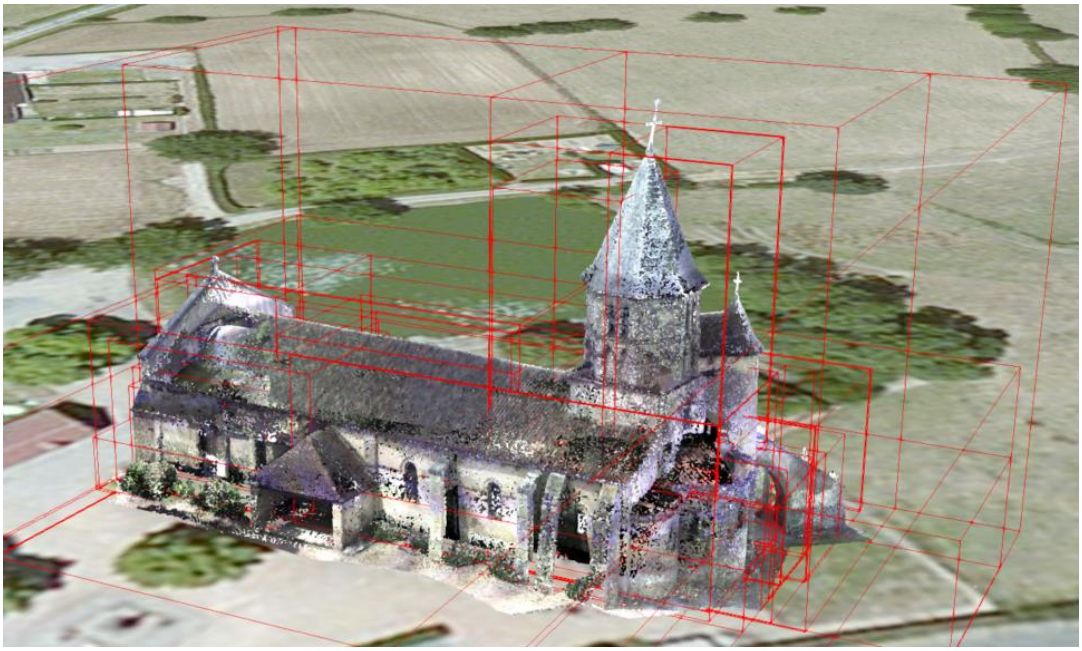

Figure 6 - Tile's division of a point cloud tileset.

The tiles in this format can host different types of bounding boxes: bounding box, bounding sphere, and bounding region. The bounding region seems to be the most appropriated one in order to deal with geographical/geospatial content, since it defines data in latitude, longitude and height coordinates. These must be noted in geographic coordinates, and WGS84 datum, as defined in EPSG 4979, but in radians, not in degrees.

This format is not specific for point clouds, but for a wide range of 3D object types (i.e. points, buildings, solid volumes, etc.).
Some references for 3DTiles resources: support, viewers, implementations, tools, generators, data providers, etc. can be found on 3DTiles's github repository[15]

6.4. ESM

6.4.1. ESM overview

The Elevation Surface Model (ESM) standards are a set of standard documents developed by the DGIWG aimed at specifying the information content required for the exchange of surface elevation data within and among DGIWG member nations.

This set consists of six documents whose scope is spreading from abstract specification to implementation specifications into standard formats (as illustrated in Figure 7):

- **[DGIWG 116-1]** which defines an abstract model based on the model of **ISO 19123** for coverage description and a metadata dictionary based on the DGIWG Metadata Foundation (DMF - DGIWG 114) model to describe elevation datasets;

[15] https://github.com/CesiumGS/3d-tiles/blob/main/RESOURCES.md

- [**DGIWG 116-2**] which defines the GML application schema and documents the process used to derive it from the ESM UML model, associated to DGIWG 116-1;
- **[DGIWG 116-3-1]** which defines the common Encoding Rules on the basis of the ESM UML model and metadata.
- **[DGIWG 116-3-2]**, **[DGIWG 116-3-3]** and **[DGIWG 116-3-4]** which respectively define the encoding rules on the basis of the DGIWG GeoTiFF Profile (DGIWG 108), the DGIWG GMLJP2 Profile (DGIWG 104) and STANAG 4545 (NSIF).

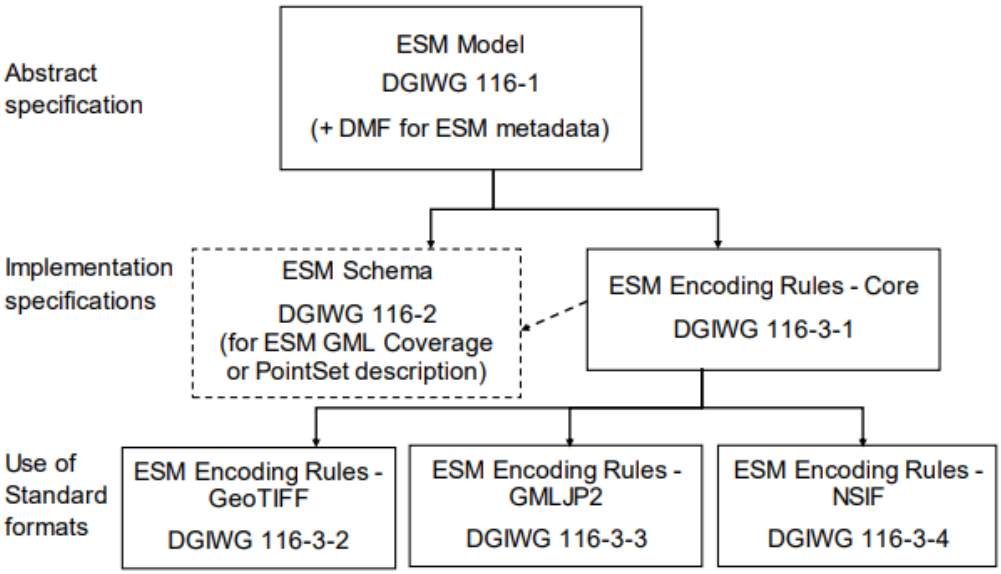

Figure 7 - Various ESM specifications

The ESM set of standards has been designed to serve as a base for the DGIWG Gridded Elevation Data (DGED – DGIWG 250) product specification.

6.4.2. ESM data content

ESM Standards are dedicated to elevation measurements which describe the position of the material surface above or below a vertical datum. They support the modelling of material surfaces such as bare earth, vegetation canopy, and bathymetric surfaces thanks to four proposed data structures that are described:

- Grids
- Triangulated Irregular Networks (TIN)
- Point coverages
- Point sets

The three first structures are designed to describe elevation as a range value associated to a position in 2D following the coverage concept. In contrast, the Point sets structure is embedding elevation into the point geometry and provides a model for describing point cloud data as a source of elevation data.
The ESM model also provides a structure to organize elevation datasets into collections, eventually by following a tiling scheme.

6.4.3. ESM metadata

The ESM also specifies the metadata elements recommended or required to describe an ESM dataset for discovery and exchange purposes. The metadata elements are based on the DMF standard [DGWIG 114] and shall be encoded in an XML file provided separately from the data files.

The metadata elements can be provided at the collection and dataset level. They are specifically addressing the following contents (in addition to the minimum metadata discovery and access elements):

- Intended use
- Surface type
- Estimated values
- Accuracy
- Void and suspect areas (only for gridded data)
- Coordinate reference systems
- Units of measure
- Processing history
- Data maintenance
- Dataset identifiers

6.4.4. Considerations about ESM and point cloud data

The model provided by ESM is consistent with point cloud data. It also has the advantage of having been designed by the DGIWG for the defence community.
However, this set of standards has been designed for elevation data description and use and some restrictions exist that, without modifications, might limit its application to point cloud data for other intended use.
Furthermore, besides GML encoding, which is not optimal for operational use, the other format encodings covered by ESM are not designed for point cloud data. It is stated in [DGIWG 116-3-1] that the GML encoding is mandatory for encoding PointSet data to be consistent with ESM.

6.5. DMF

6.5.1. DMF Overview

The DGIWG Metadata Foundation (DMF) is a standard designed by the DGIWG which provides a Defence-community metadata profile for describing:

- datasets (e.g. DGED dataset)
- non-geographic datasets (e.g. Documents and Periodicals)
- products (e.g. an output that is conformant to a Product Specification)
- series (e.g. Town Plans)
- services (e.g. Catalogue Service for the Web (CSW))
- tiles (e.g. MGCP subregions)

It is based on the ISO 19100 series of metadata standards, which include the [ISO 19115] series and the [ISO 19139] for XML encoding.

The description of the different resources enumerated above relies on the definition of **metadata elements** which are essentially defined by an identifier, a title, a description and a value domain.

DMF defines four **use case scenarios of Metadata** that will determine the choice and the number of metadata elements that are to be involved:

- **Discovery** of existing resources
- **Evaluation** of the fitness of use of discovered resources
- **Use** of and access to the resources
- **Management** of the resources

The metadata elements are grouped together into **metadata element sets** corresponding to the different aspects of the resources to be described:

- Metadata description,
- Resource identification (Data and Services),
- Coverage descriptions,
- Vector representation,
- Feature Catalogue description,
- Spatiotemporal aspects,
- Resource Management,
- Constraints
- Quality
- Distribution

Furthermore, DMF defines the following **Metadata classes** that group metadata elements regarding the use case and resource types needs:

- **DMF/Core** for the minimum set of Metadata elements to be implemented to serve a discovery usage
- **DMF/common** which extends the DMF/Core for additional description that may cover basic evaluation use cases
- **DMF/Services** which allows to describe services related to data
- **DMF/Data** for data related resources
- **DMF/Data+** extends DMF/Data for some specific cases of coverage data (e.g. quality results) description
- **DMF/Sensor** extends DMF/Data for Sensor description
- **DMF/Defence** handles specific military-oriented needs including NATOs Needs
- **DMF/Specific** extends ISO metadata standards for high level military implementation of the DMF metadata elements.

6.5.2. Considerations about DMF and point cloud data

The current metadata elements proposed by DMF have been developed while taking coverage and more specifically the ESM needs. The DMF/Sensor Metadata class allows the description of a wide variety of sensor types that are used to collect Point cloud data such as LiDAR instruments. This standard should already fit most of point cloud data description in an elevation representation use case and it might need to be extended for further use cases involving for instance thematic classification.

Because DMF is the standard designed to implement metadata for the Defence community client of DGIWG, the development of metadata to describe point cloud data for the Defence Community shall be addressed by DMF, either by a profiling of existing metadata elements or by an extension of them if a need should occur.

6.6. HDF5

6.6.1. HDF5 overview

Hierarchical Data Format version 5, HDF5, organizes heterogeneous data and metadata in a hierarchical structure which resembles a file system. HDF5 is an open-source format. There are several tools and libraries available for using HDF5. HDF5 has been in use since 2002. The predecessor, HDF4, had many limitations, like a 2GB size limit, which HDF5 solves.

HDF5 has two important units:

- **Group**: like a folder/directory in a file system

- **Dataset**: like a file in the file system

By using groups, one can organize the datasets in many different ways. Like a group for each sensor type, each site or each type of data.

Datasets can contain any different types of data, including metadata. One can use many instances of metadata to describe the separate datasets that are within the particular HDF5 file. That makes the HDF5 file self-describing.

6.6.2. Consideration about HDF5

It is a hierarchical system, similar to file systems. However, all data is read using the tools and libraries intended for HDF5. The datasets are not like GeoTIFF files or [ISO 19115] metadata files. This is not a problem, but a piece of information, since the file format is compared to a file system.

6.6.3. NetCDF

NetCDF (Network Common Data Form) uses HDF5 as one of the storage options for scientific data, including geographical data, which could be vector, raster or tables. If one opts for HDF5, NetCDF might be worth considering. It is handled by GDAL.

6.7. XYZ

6.7.1. XYZ overview

XYZ files are text files where the columns are delimited by some separator character. One row represents a point in a point cloud. The first three columns contain the coordinates, including elevation.

In addition, there can be any number of columns for any attribute one wants to capture.

6.7.2. Consideration about XYZ

XYZ is a legacy format for point cloud description along with other similar formats relying on an ASCII encoding. It is mentioned as being used in some use cases of Defence community related by this document.
The exploitation of such formats relies on the description of the column contents, which is not standardised. This makes them barely interoperable.

6.8. PLY

6.8.1. PLY overview

Polygon File Format, PLY, is a format which describes an object as a list of flat polygons. The polygons can have properties like color, transparency, textures and error estimations. The PLY format exists both as an ASCII format and a binary format. The PLY format was developed in the mid-90s.

6.8.2. Consideration about PLY and point clouds

PLY stores polygons. All properties are bound to polygons. It doesn’t seem like a good fit for point clouds.

7. Standardization work items proposal

This clause proposes potential standardisation work items to point cloud data and has been developed in response to the standardisation needs of the defence community. They rely on the DGIWG existing standard portfolio. They might be complementary or replace each other given what is preferred or feasible by DGIWG.

7.1. Rules or Application profile for standardized formats or specifications carrying point cloud data

7.1.1. LAS format

This proposed work item aims at defining a profile of the LAS specification which would contain additional requirements and/or recommendations when using the LAS format to exchange point cloud data for the Defence community usage.

The choice of LAS format is motivated by the fact that it is used in most of the use cases mentioned in clause 5. It is also a format that has been adopted as a community standard by OGC and therefore it represents a stable foundation for recommendations and requirements to be built for the defence community.

As stated in clause 6.1.3, the legacy based backward compatibility maintained between the successive releases of LAS may introduce some confusion for data encoding. Indeed, the same information can be encoded in two different ways while being still conformant with the latest LAS specification. Therefore, such a profile would help to resolve such ambiguities when used in a defence community framework.

The following non exhaustive list proposes items that could form the requirements or recommendations made by the profile:

- the conformance to a minimum LAS release (e.g. 1.4);
- a limitation of valid CRSs to be used for collection. This is a common practice in DGIWG profiles;
- a recommended (or required) way of encoding the CRS in the LAS file taking into account matters such as epoch, geoid model or a vertical datum separation from ellipsoid;
- some recommendations for the usage of VLR and EVLR (when in LAS 1.4) to store specific additional information. For instance, some metadata elements;
- recommendations or requirements for which Point Data Record Format to use given the kind of points to be described;
- some recommendations on the usage of ASPRS thematic classification of points and the potential definition of specific defence classes.

Additionally, as LAS is often used in a compressed LAZ form. Some considerations or recommendations could be provided on the compression options to be used for generating the LAZ file. Furthermore, recommendations could also be made to organize the data following the COPC specification when using LAZ in distributed environment in serverless mode. Those two items should be considered in function of the maturity of such formats in terms of standardization.

7.1.2. Indexed 3D Scene Layer I3S or 3D Tiles usage for point cloud

As I3S and 3DTiles are two concurrent specifications covering the same functionalities with similar approaches for 3D data streaming, the work item proposed by this clause can be used either for I3S or 3D Tiles.

A standardisation work item dealing with point cloud streaming with those two specifications would consist in giving rules or recommendations on how to organize the points in the tiles hierarchy they propose.

For I3S, such recommendations could deal with:
- a selection of coordinate reference systems either in 2D, compound or in 3D to be used;
- the partitioning schemes to be used (regular or density dependent);
- the preferred methods to generate the intermediate levels of Detail

For 3DTiles, the recommendations would deal in the same way with:
- a selection of coordinate reference system for tilesets to be used (even if it is often based on a WGS84 earth-centered, earth fixed reference frame);
- a preferred method of refinement (replacement or addition) between parent tiles;
- some guidance for defining the bounding volumes of tiles (box, sphere or region) or using an implicit tiling scheme which has been introduced by release 1.1 of 3DTiles. This is to define a regular subdivision of the tileset and enables accelerated spatial queries based on tiles indexing.

7.1.3. ESM extension with point cloud

This proposed work item aims at extending the DGIWG ESM standards family to better support point cloud data for elevation description.

As stated in 6.4.4, The ESM model is consistent with point cloud data by defining ESM Point Sets which carry elevation values directly with the point geometry by contrast with the coverage approach based on legacy [ISO 19123:2005] where the elevation value is carried out by the range associated to a position in 2D. Since [ISO 19123-1:2023] point cloud data are also considered as coverage thanks to the concept of Multi-Point Coverage.

Furthermore, [DGIWG 116-3-1] Elevation Surface Model (ESM) Encoding rules - Part 1: Core states that the encoding of Point Sets shall be made in GML, which forbids the use of other well-known formats for point Cloud such as LAS to encode elevation values.

Therefore, this work item would make the ESM evolve in order to be consistent with the new release of ISO 19123, allow the use of alternative encodings for point Cloud elevation data and propose a specific new part to define rules for LAS encoding. The documents that could be potentially impacted in their content are:
- [DGIWG 116-1] for the model upgrade;
- [DGIWG 116-2] as a consequence of the model upgrade;
- [DGIWG 116-3-1] to prepare for a specific encoding document rules;
- a new [DGIWG 116-3-5] ESM LAS encoding rules for point cloud elevation data. This latest document would benefit in relying on a DGIWG LAS Profile such as proposed in 7.1.1 LAS format

7.1.4. DMF Profile for Point cloud dataset and series description

As stated in 6.4.4, Due to the DMF/Data+ and DMF/Sensors metadata classes, DMF has many existing metadata elements to accurately describe point cloud data coverage and the sensors they originated from. A work item for point cloud data standardization would imply a review of those elements and lead to some specific recommendations of their use in the case of point cloud datasets.

The need for metadata expressed in the use cases and questionnaire answers is rather to have the elements necessary to read and decode the point cloud files when they are delivered in unstandardized or not enough documented formats. In the case of DMF, this might imply an extension of the Resource Distribution Format element (RSDFMT) and the underlying Format description on which it relies by the addition of supplementary information on how it is used for the point cloud encoding.

7.2. Product specification for point cloud data exchange in the defence community

This work item proposal aims at defining a product specification profile for the exchange of point cloud data with similar purposes as for DGED, DOP or DRP.

It could be a dedicated point cloud product specification in addition to these three existing IGD product specification profile which would rely on:

- format recommendations and encoding rules as defined in 7.1.1 for the LAS format
- metadata elements requirements and recommendations based on a DMF extension as proposed in 7.1.4
- recommendations for data streaming using either I3S or 3DTiles a proposed in 7.1.2

If the aim of such a product is mainly elevation data, it could also consist of an extension of the DGED specification including the previous elements with the addition of the ESM extension proposed in 7.1.3.

7.3. Work item proposals and standardisation needs

The following table shows how the standardisation needs expressed in 5.3 should be addressed by each of the work items proposed in the previous clauses.

Table 9 - Work item proposals and standardisation needs

Standardisation need **Work item proposal**	**CRS information carrying with (or within) the data**	**Description of point cloud data (Metadata), especially when an unspecified format (eg. ASCII Text) is used**	**Some format considerations (basic exchange formats, conversion issues to proprietary formats, information carried by the format)**	**Data management regarding size and density**
LAS format application profile	Yes	Yes (for information shipped into LAS data)	Yes with the LAS format profile	Yes with recommendations of VLR and EVLR usages such as in LAZ and COPC

Standardisation need **Work item proposal**	**CRS information carrying with (or within) the data**	**Description of point cloud data (Metadata), especially when an unspecified format (eg. ASCII Text) is used**	**Some format considerations (basic exchange formats, conversion issues to proprietary formats, information carried by the format)**	**Data management regarding size and density**
I3S implementing rules for point cloud	Yes	Not applicable - Metadata shall be carried outside the I3S stream	Yes (with conversion from standard data to I3S)	Yes
3DTiles implementing rules for point cloud	Partially applicable (The choice for CRS is limited in 3DTiles)	Not applicable - Metadata shall be carried outside the I3S stream	Yes (with conversion from standard data to I3S)	Yes
ESM extension with Point cloud	Yes	yes (because of metadata in DMF)	implicitly covering	Yes with LAS profile capabilities + ESM collection management
DMF Profile for Point cloud dataset and series description	Yes as CRS are described in the metadata	implicitly covered	Yes with the description of the resource distribution format.	Yes with the existence of metadata elements describing those aspects.
Product specification for point cloud data exchange in the defence community	Yes	Yes	Yes	Yes

Annex A - Tools reference

The following table lists the references of the tools mentioned in the use cases.

Table 10 - Tools references

Tool	Editor	Flyer abstract	Ref.
Lastools	rapidlasso GmbH	LAStools are the fastest and most memory efficient solution for batch-scripted multi-core LIDAR processing and can turn billions of LIDAR points into useful products at blazing speeds and with low memory requirements.	https://rapidlasso.com/lastools/
TBC Trimble	Trimble Geospatial	Trimble Business Center's field to finish survey CAD software helps surveyors deliver high-accuracy GNSS data, create CAD deliverables, and leverage full data traceability throughout a project's lifecycle.	https://geospatial.trimble.com/products-and-solutions/trimble-business-center
MDTOPX DIGI21	Digi21	Digital Terrain Models Processing Software. It has analysis of LIDAR and Laser-Scan, generation of Digital Surface Models, generating of ortho-mosaics, road design, etc.	https://www.digi21.net/
Pix4D	Pix4D	A unique photogrammetry software suite for mobile and drone mapping	https://www.pix4d.com/
ERDAS IMAGINE	Hexagon	ERDAS IMAGINE provides true value, consolidating remote sensing, photogrammetry, LIDAR analysis, basic vector analysis, and radar processing into a single product.	https://www.hexagongeospatial.com/products/power-portfolio/erdas-imagine

Tool	Editor	Flyer abstract	Ref.
ArcGIS	ESRI	ArcGIS offers unique capabilities and flexible licensing for applying location-based analytics to your business practices. Gain greater insights using contextual tools to visualize and analyze your data. Collaborate and share via maps, apps, dashboards and reports.	https://www.esri.com/en-us/arcgis/about-arcgis/overview
Fugro Viewer	Fugro	FugroViewer is a robust, easy-to-use freeware designed to help users make the most of their geospatial data. We have developed it for use with various types of raster- and vector-based geospatial datasets, including data from photogrammetric, LIDAR, and IFSAR sources.	https://www.fugro.com/about-fugro/our-expertise/technology/fugroviewer
Cloud Compare	Open Source	CloudCompare is a 3D point cloud (and triangular mesh) processing software.	http://www.cloudcompare.org/
Global Mapper	Blue Marble Geographics	Global Mapper® is a cutting-edge GIS software that provides both novice and experienced geospatial professionals with a comprehensive array of spatial data processing tools, with access to an unparalleled variety of data formats.	https://www.bluemarblegeo.com/global-mapper/
UltraMap	Vexcel Imaging	Photogrammetry post-processing software. UltraMap is the all-in-one photogrammetric processing software for rapid generation of point clouds, DSMs, DTMs, ortho imagery and 3D textured TINS from UltraCam aerial imagery.	https://www.vexcel-imaging.com/ultramap/

Tool	Editor	Flyer abstract	Ref.
DJI Terra	DJI	Photograph, analyze and visualize your surroundings with DJI Terra, user-friendly mapping software designed to help professionals turn real-world scenarios into digital data.	https://www.dji.com/en/dji-terra
CARIS Software - HIPS and SIPS - Base Editoir - HPD	Teledyne	The HIPS and SIPS™ suite of products offers essential capabilities and professional grade tools for hydrographic data processing. Supporting over 40 industry standard data formats, HIPS and SIPS can easily integrate into any workflow. It enables you to simultaneously process multibeam, backscatter, side scan sonar, single beam and LIDAR data. It incorporates the latest in 3D visualization technology for the purpose of hydrography, oceanography and marine science.	https://www.teledynecaris.com/en/products/hips-and-sips/
Qimera	QPS	Qimera is a multibeam data processing and analysis software.	https://qps.nl/qimera/
Quick Terrain Modeler	Applied Imagery	Quick Terrain Modeler is a 3D point cloud and terrain visualization software package. Designed for use with LIDAR, but flexible enough to accommodate any 3D data source, Quick Terrain Modeler provides an easy to use software experience that allows users to work with significantly more data, render larger models, analyze data faster, and export a wider variety of products than any other tool.	https://appliedimagery.com/

Tool	Editor	Flyer abstract	Ref.
Terra Explorer	Skyline	A cutting-edge 3D GIS desktop viewer and creator that provides powerful tools and a high resolution 3D environment in which to view, query, analyze and present geospatial data.	https://www.skylinesoft.com/terraexplorer-for-desktop/
QGIS	OSGeo	QGIS is a professional GIS application that is built on top of and proud to be itself Free and Open Source Software (FOSS).	https://www.qgis.org/en/site/index.html
Drone2Map	ESRI	ArcGIS Drone2Map is the desktop app for your geographic information system (GIS) drone mapping needs. As part of the ArcGIS system, Drone2Map provides easy access to a range of tools and capabilities for accurate mapping and geospatial analysis. As a 2D and 3D photogrammetry app, Drone2Map lets you create the outputs you need—including orthomosaics, 3D point clouds, and textured meshes—and then easily share them with your ArcGIS organization.	https://www.esri.com/en-us/arcgis/products/arcgis-drone2map/overview
Rhino City	RhinoTerrain	Featuring a unique building modeler and extensive automatic texturing capabilities, **RhinoCity™** is the ideal tool to produce high quality, textured 3D data that can be used directly in **CityGML** format.	https://www.rhinoterrain.com/en/rhinocity.html

Tool	Editor	Flyer abstract	Ref.
MetaShape	AGISOFT	Agisoft Metashape is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales.	https://www.agisoft.com/
PoTree	TUWien	Potree is a free open-source WebGL based point cloud renderer for large point clouds, developed at the Institute of Computer Graphics and Algorithms, TU Wien.	https://potree.github.io/
PDAL	Hobu Inc.	PDAL(Point Data Abstraction Library) is a C++ library for translating and manipulating point cloud data. In addition to the library code, PDAL provides a suite of command-line applications that users can conveniently use to process, filter, translate, and query point cloud data.	https://pdal.io/en/2.6.0/
pgPointcloud	Natural Resources Canada	pgPointCLoud is an open source PostgreSQL extension for storing point cloud data and use it with PostGIS.	https://pgpointcloud.github.io/pointcloud/
PFMABE	Naval Oceanographic Office	The Pure File Magic Area Based Editor (PFMABE) is a hydro, bathy and topo data editing suite that ingests most major sonar and lidar data types and allows for quick and easy analysis, cleaning and quality control.	https://pfmabe.software/hydrographic-editing-software/

Tool	Editor	Flyer abstract	Ref.
FME	Safe Software	FME is a data processing tool that was originally designed to handle geographic information but has proven to be extremely effective in handling all types of data with an unparalleled interface and usability at a cost that is unmatched by general purpose ETLs.	https://fme.safe.com/