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GUIDELINES ON LASER SCANNING IN PLANT DESIGN



PREPARATION AND EXECUTION OF LASER SCANNING
PROJECTS FOR INDUSTRIAL PLANT DESIGN AND
DOCUMENTATION



CONTENTS

1	Introduction	4
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2	Laser Scanning Project Specifications (Technical Specifications)	5
2.1	Specification of the Project	4
2.2	Specification of Scan Areas	6
2.3	General Guidelines	6
2.4	Laser Scanning Guidelines	6
2.5	Data Format and Data Delivery	8
2.6	Nondisclosure	9

3	Execution of Laser Scanning Projects (Technical Specifications)	9
3.1	General Information	9
3.2	Description of the Project Workflow	10
3.3	Data Delivery	11
3.4	Costs	12
3.5	Important Information	12
3.6	Optional Services	12
3.7	References	13

4	Glossary	14
	Acknowledgements	20
	Editorial Notes	22

1 INTRODUCTION

In recent years, laser scanning has become established as an efficient method of data capture in the field of plant design and construction and is increasingly supplanting conventional scanning methods. As it stands, laser scanning can be expected to become the industry standard of industrial plant surveying. This technology is increasingly spreading because it is fast, cost effective and highly precise. Instead of taking discrete individual measurements, this technology practically maps the planning area entirely. Projects can generally be completed faster and better when laser scanning is used. This cuts costs considerably.

This is why laser scanning service providers are increasingly being contracted to scan plants or sections of them and thus generate digital as-built documentation with point clouds. Point clouds are used, for example, as the basis for 3D modeling, collision detection, reverse engineering and virtual reality applications. This makes it extremely important for clients and laser scanning service providers to set the basic objectives of laser scanning. Such objectives both facilitate the compilation of appropriate as-built documentation and meet clients' demand for high quality data. These guidelines identify important objectives.

The first section of these guidelines specifies the information clients have to provide to laser scanning service providers to enable them to prepare a precise and suitable quotation (Section 2). The second section examines the stipulations on technical specifications (quotation) that meet the demands in plant design and construction (Section 3). The final section presents and explains laser scanning terminology (Section 4).

Although the structures and contents presented in the second and third sections can be adopted for the compilation of technical and requirements specifications, it is expedient to modify them for individual needs.

These guidelines were compiled by the industry working group "Laserscanning und Virtual Reality im Anlagebau" ("Laser Scanning and Virtual Reality in Plant Design") and constitute a recommendation for laser scanning in plant design and construction. They are intended to furnish a sound basis for the compilation of technical specifications (requests for quotations) and requirements specifications (quotations). These guidelines are neither intended to lessen communication between clients and service providers nor to supplant service providers' guidance.

2 LASER SCANNING PROJECT SPECIFICATION (TECHNICAL SPECIFICATIONS)

This section presents the standard contents of technical specifications, which provide essential information to service providers when laser scanning is being contracted. This information enables service providers to prepare accurate and suitable quotations and additionally facilitates communication with service providers.

2.1 Specification of the Project

The service provider is given the following information on the project before the laser scanning commences:

- The name of the project
- A brief description of the project and the work planned in the scan area (retrofitting, dismantlement, construction, prefabrication, etc.)
- Names of contacts for laser scanning, site and project management as well as their contact information, e.g. phone numbers, email addresses and places of work

This information is often needed for on-site inspections, photo authorizations, work permits and safety briefings.

2.2 Specification of the Scan Area

This section roughly defines the area to be scanned:

- The company's address
- The name of the plant
- The description of the facilities
- A floor plan with identified scan areas
- A geographic description of the scan area, e.g. using coordinates from Google Maps (link to Google Maps)

2.2.1 Extent of Data Capture

This section specifies which objects in which areas are to be laser scanned.

1. A detailed site plan with the scan areas indicated by color and including
 - Information on the plant/facility, sections, and pipe racks including elevations, platforms and equipment or pipe density
 - The layout plan(s) of the scan areas
 - If possible, an aerial photo with the scan areas indicated by color
2. Photos of scan areas
 - Brief description of photos – what is pictured, what actions are planned and what requirements are imposed on scanning.
 - If necessary, with supporting identification in the photos
 - Indication of each photo's position and alignment in the site plan can be helpful
3. Specification of whether the previously specified areas are to be scanned completely or in spots (e.g. tie areas/points)
4. Specification of the objects to be scanned and the level of detail:
 - Piping including the smallest nominal pipe size to be scanned (see also Section 2.4.2)
 - Pipe racks including elevations
 - Primary and secondary steel construction
 - Adjoining buildings as volume or with interior equipment
 - Equipment (pumps, containers, heat exchangers, machines)

- Cable trays
- HVAC ducts
- Nonstandard components

5. Details, e.g. flange position, have to be provided for pipe work intended to be highly prefabricated.

2.2.3 Accessibility and Distinctive Features of the Facility

This section presents items that furnish information on the accessibility of the facility to be scanned and its special features.

1. Accessibility of the facility and the scan area
2. Information on the type of facility (is there protection against the elements?), outdoor facility or enclosed building
3. General and temporal accessibility of the scan areas
4. Details on common areas and, where applicable, work conditions (observance of legally required work breaks; possibilities to store equipment or charge batteries)
5. Distinctive features of the facility
 - Which areas are affected by vibrations?
 - Potentially explosive scan areas (classification of explosive zones)
 - Other specifics of the atmosphere (e.g. dust, temperature, humidity)
 - Can scanning be done while the plant is running?
 - What downtimes are necessary?
 - Is certain safety equipment needed and who provides it?
 - What training courses and safety briefings are necessary?

- Information on whether scaffolding is present or other constraining work such as dismantlement or construction will be performed at the time of scanning.

2.3 General Guidelines

2.3.1 Minimum Content of the Technical Specifications

The minimum content of technical specifications has to be specified in the requirements specification. This makes it easier to compare quotations and contract laser scanning services. Specifying the following points has proven effective:

- Recapitulation of the request for quotations (clarity for the contractor)
- List and itemization of the expected labor and costs
- Description of execution, if necessary with designated scan areas including scanning period and estimated number of laser scanner locations
- Names and qualifications of the scanner operators
- Documentation of equipment calibration
- Information on scanner capabilities (temperature range, maximum humidity, operability in potentially explosive atmospheres)
- Safety plan and certifications, e.g. ISO and SCC
- Quality control based on an appended quality plan
- List of services in addition to laser scanning, including prices (e.g. difficulties, additional data formats and services, etc.)
- Retention periods of data

2.3.2 Dates

The following dates have to be scheduled:

- Deadline for the submission of quotations
- Date of award of the contract

- Dates of scanning including duration, factoring in operational interruptions (construction work, scaffold building, etc.)
- Completion date of the contract

2.4 Laser Scanning Guidelines

2.4.1 Accuracy Standards

The accuracy achievable is contingent on different parameters. In general, accuracy of ≤ 5 mm (≤ 0.19 inch) can be achieved in laser scanning for plant design and construction. When necessary (custom components, fabrication of connectors, etc.), greater accuracy can also be achieved. It is advisable to consult with the laser scanning service provider about the achievable accuracy. The following points have to be stipulated:

- The accuracy or tolerances required by the client
- The service provider's estimation of achievable accuracy
- Registration accuracy.

2.4.2 Preparatory Work

Before scanning, the following stipulations to be made and communicated to the service provider:

- Piping must be stripped of insulation
- No longer needed piping and equipment must be dismantled (if possible)
- Scaffolding and aerial work platforms must be set up if necessary
- Unneeded scaffolding must be removed
- Control points must be established and the plant network must be consolidated

2.4.3 Execution of the Laser Scanning

The service provider has to be given different scan parameters since they directly affect the quality and accuracy of the complete point cloud.

1. Specify scan resolution as a function of the areas to be scanned and the size of the objects to be scanned (density of scanned points on an object must be sufficient).
2. Normally, 80% of all targets are surveyed tachymetrically.
3. Anomalies during scanning have to be documented in each scan position:
 - Unfavorable weather conditions (snow, rain, etc.)
 - Interference with measurements by dust or exhaust
 - Vibrations or jolts
4. Colorization of the point cloud:
 - Grayscale (intensity values), standard
 - Colorization using photos (panoramic images)
 - Colorization using HDR images (HDR panoramic images)
 - Unless photomapping is automatic, at least five dispersed control points should be used per scan to map panoramic photos on point clouds.
5. Information on whether the point cloud has to be divided into subareas (e.g. different platform elevations or buildings)

Note: The cameras integrated in advanced laser scanners deliver high quality results. The highest quality color photos are obtained by using an external SLR camera

2.4.4 Registration

Information on the existing facility or factory coordinate system has to be delivered to the service provider for registration.

1. Delivery of the benchmarks (measurement points) contained in the facility or factory coordinate system
2. Delivery of digital specifications of the benchmarks
3. Information on whether benchmarks need to be marked permanently, e.g. when multiple measurements are taken in the same area:
 - Specification of the type of marking, e.g. reflective tapes, ground marks or elevation marks
4. Delivery of specifications and overviews of benchmarks, including responsibilities in the event data are discrepant.

Note the following:

- Control points, which are clearly identifiable in the 3D model and the point cloud, may be used instead of benchmarks in exceptional cases. (Benchmarks should be used when they exist.)
- Registration based on five targets per position is recommended; point cloud registration is only allowed in exceptional cases and must be discussed with the client.
- Allow for differences between a point cloud (as-built) and a plant model (as-designed) and, when necessary, adjust the point cloud coordinate system.

2.4.5 Data Cleansing

The following information has to be delivered to the service provider:

1. Specification of the level of automatic data cleansing
 - Filtering of spurious points, e.g. digital artifacts, measurement noise, etc.
 - The consistency of the point cloud must be ensured.
2. Information on whether temporary objects have to be removed from the point cloud manually
 - People, vehicles, scaffolding, etc.
 - Since cleansing is a very involved process, scaffolding ought to be removed before scanning commences.
3. Information on whether scanned areas are not or may not be included in the scope of the project (adjacent facilities owned by the client or a third party) ought to be eliminated.

2.5 Data Format and Data Delivery

The laser scanning service provider has to be informed what software and what versions the client uses.

1. Specification of plant design and CAD software including the interface used later to process the point clouds
2. Specification of the viewer used to view the point cloud
3. Specification of other software (virtual reality software, analytical software, etc.)

Not only the data format but also the data storage medium should be specified. The database storage structure should also be specified. The following information should be delivered to the service provider:

1. Specification of the data to be delivered including the desired format:
 - Raw data
 - Individual registered scans
 - Registered point clouds
 - Registered point clouds processed for virtual reality
 - Individual photos and panoramic images
2. Optional delivery of data in the ASTM E7 standard
3. Records certifying the quality achieved
 - Tachymetric surveys of the benchmarks and targets
 - Registration and georeferencing
 - Specification of the underlying coordinate system

4. The medium on which data should be delivered and specification of the interfaces.
5. Specification of the file structure on the medium

2.6 Nondisclosure

Laser scans frequently capture sensitive data. A nondisclosure agreement should be signed by the respective service provider immediately before the requirements specification is sent in order to prevent the use of these data for anything but the intended purposes.

3 EXECUTION OF LASER SCANNING PROJECTS (TECHNICAL SPECIFICATIONS)

This section deals with the preparation of the technical specifications as part of a quotation and, therefore, primarily addresses laser scanning service providers. Contents, which provide sufficient information to a client requesting quotations for laser scanning, are recommended. This makes it possible to formulate the services transparently and to compile a professional and suitable quotation as the basis for the execution of laser scanning projects. The contents of the technical specifications are heavily oriented toward the requirements specification (see Section 2). Substantial parts of the requirements specification are reiterated in this section.

3.1 General Information

Both the description of the project and the description of work included in the requirements specification are presented in the technical specifications. The client and the service provider usually consult during the bidding process, e.g. by inspecting

the area concerned. Resultant agreements must be included in the quotation. Transcripts or records may be appended to the quotation.

A quotation should include the following:

1. Reiteration of the description of work and the description of the project, including additional agreements, e.g. from on-site meetings, telephone calls, etc.)
2. Description or specification of the scan areas
 - Estimated number of scan positions
 - If necessary, dimensions (width, length, height)
3. Timeframe and schedule
 - Schedule of execution (preparatory work, geodetic survey and laser scanning)
 - Date(s) when scanning can start in keeping with the awarded contract

- Daily scan times
 - Date of data delivery to the client
4. Names of contacts including contact information, e.g. telephone numbers and email addresses:
 - Project management
 - Scanning and evaluation staff
 - Qualifications and experience
 5. Safety concept
 - Safety plan and staff safety qualifications
 - Certifications
 - Scanner capabilities (temperature range, maximum humidity, use in potentially explosive atmospheres)
 - Personal protective equipment
 6. Quality assurance
 - Calibration records of instruments
 - Quality control during the project
 - Certifications
 - Information on archiving of raw data and project data
 - Information on the expected overall accuracy of the registered point cloud
 7. Information on privacy and nondisclosure

3.2 Description of the Project Workflow

This section expounds the laser scanning procedure understandably for the client. In particular, it should address the specific requirements of the project as well as quality and safety standards.

3.2.1 Preparatory Work

Preparatory work frequently has to be completed both by the service provider and in the particular plant area before scanning commences:

1. Safety briefings
2. Notification of the control center and issuance of a work permit
3. Verification of the completion of all necessary preparatory work
 - Piping should be stripped of insulation
 - Obstructions should be removed from scan areas
 - Scaffolding, aerial work platforms, etc. should be erected
 - Instruments should be calibrated and checked

3.2.2 Geodetic Survey

The geodetic survey delivers the basis for the later transformation of the point clouds into the plant coordinate system. It is the basis for high quality registration. The procedure should be detailed in the technical specifications. This section can also be combined with section 3.2.3.

1. Specification of the plant coordinate system
2. Creation of a new benchmark field or consolidation of an existing one
 - Information on the type of marking, e.g. reflective tapes, ground marks or elevation marks
 - Delivery of specifications and overviews of benchmarks
3. Specification of the measurement system employed (polar mapping or grid measurement)
4. Information on the measurement system employed

3.2.3 Laser Scanning

This section stipulates how the laser scanning will be performed:

1. Specification of scanner locations
2. Specification of the planned scan resolution
3. Specification of targets:
 - Number and distribution of targets (normally, four to five dispersed targets per location in the plant coordinate system)
 - Normally, 80% of all targets are surveyed tachymetrically
4. Information on whether photos will be taken from the scan position to colorize point clouds later
 - Use of an internal or external camera
 - Photo mapping procedure
 - Technology (photos or HDR images)
 - Unless photomapping is automatic, at least five dispersed control points should be used per scan to map panoramic images on the point cloud
5. Specification whether elevated scans are required and why
6. Documentation of anomalies during scanning
 - Unfavorable weather conditions, e.g. snow, rain, etc.
 - Vibrations or jolts
 - Disruptions, accessibility, problems, accidents, etc.
 - Presence of difficult-to-scan surfaces (e.g. shiny surfaces, glass piping, etc.)
 - Condition of piping and equipment

3.2.4 Registration

Generally, registration follows laser scanning. The following steps should be presented in the technical specifications:

- Evaluation of the tachymetric survey
- Registration based on targets (see point 3 in section 3.2.3)
- Point cloud registration only in exceptional cases in consultation with the client and with a disclosure that error propagation can cause significant losses of accuracy (especially when scan areas are larger).

3.2.5 Data Cleansing

Data cleansing includes the following information:

- Specification of the level of automatic data cleansing, ensuring the consistency of the point cloud.
- Information on whether temporary objects, e.g. people, vehicles and scaffolding, will be removed manually
- A recommendation that, since cleansing is very involved, scaffolding should be removed before scanning.

3.2.6 Data Processing

Data processing includes the following information:

- Information on whether the point cloud will be divided into subareas (limit box)
- Specification of any other data processing, e.g. unification

3.3 Data Delivery

In the quotation, the contractor should specify what data will be delivered to the client and in what form and structure. Ideally, given the large volume of scan data, data should be delivered on an external hard drive. In many cases, data formats have been specified in the requirements specification. The delivered data and formats should be stipulated in the technical specifications:

1. Definition of project execution, noting any unusual occurrences
2. Geodetic survey:
 - Overview of the newly established benchmark field (overview)
 - List of new benchmark coordinates with specification of benchmarks
 - Photo documentation of benchmarks
 - Data processing and transfer to a factory information system
3. Laser scanning
 - Floor plan with scanner locations
 - Optionally, registered scans in the stipulated data format
 - Complete point cloud in the stipulated data format
 - Viewer in the stipulated data format
4. Accuracy data (reports) verifying the accuracy achieved:
 - Benchmark field
 - Target calibration
 - Registration
 - Overall accuracy of the registered point cloud
 - Specification of areas where this accuracy was not achieved
5. Optional
Time sheets and records of incidents relevant to safety

3.4 Costs

The costs of laser scanning can be itemized in different ways. It is recommended to itemize costs in the technical specifications by scan area. The costs of the geodetic survey, laser scanning, registration and data cleansing should be included. Alternatively, costs can also be itemized as follows:

- Project preparation
- Geodetic survey
- Laser scanning
- Registration
- Data cleansing

In addition to the actual costs of the laser scan, the technical specifications should also include travel expenses, terms of payment and a period of validity. Additional costs that might be incurred should also be included:

- Costs of the use of special equipment, e.g. aerial work platforms
- Costs of the laser scanning team per day and per hour when work is interrupted because of disruptions at the company and when the scan area is expanded beyond the scope of the project
- Costs of optional services, e.g. reports for tie points (see Section 3.6.)

3.5 Important Information

The technical specifications should include information on the limitations of laser scanning. Especially clients with little or no experience working with point clouds may harbor false expectations and ideas. The limitations should always be specified in the context of the specific job rather than generally.

The following limitations of laser scanning should be mentioned:

1. A scan area is never covered 100% (The goal is to scan between 80% and 100%)
2. Errors in measurement caused by external factors
 - Noise
 - Digital artifacts
 - External conditions, e.g. vibrations, lighting conditions during color scans, etc.
 - Highly reflective surfaces
 - Absorption of laser light by black surfaces
 - Difficulties scanning particular materials, e.g. glass
3. Weather conditions, e.g. rain and snow
4. Scanning of temporary spurious points, e.g. vehicles, people, etc.

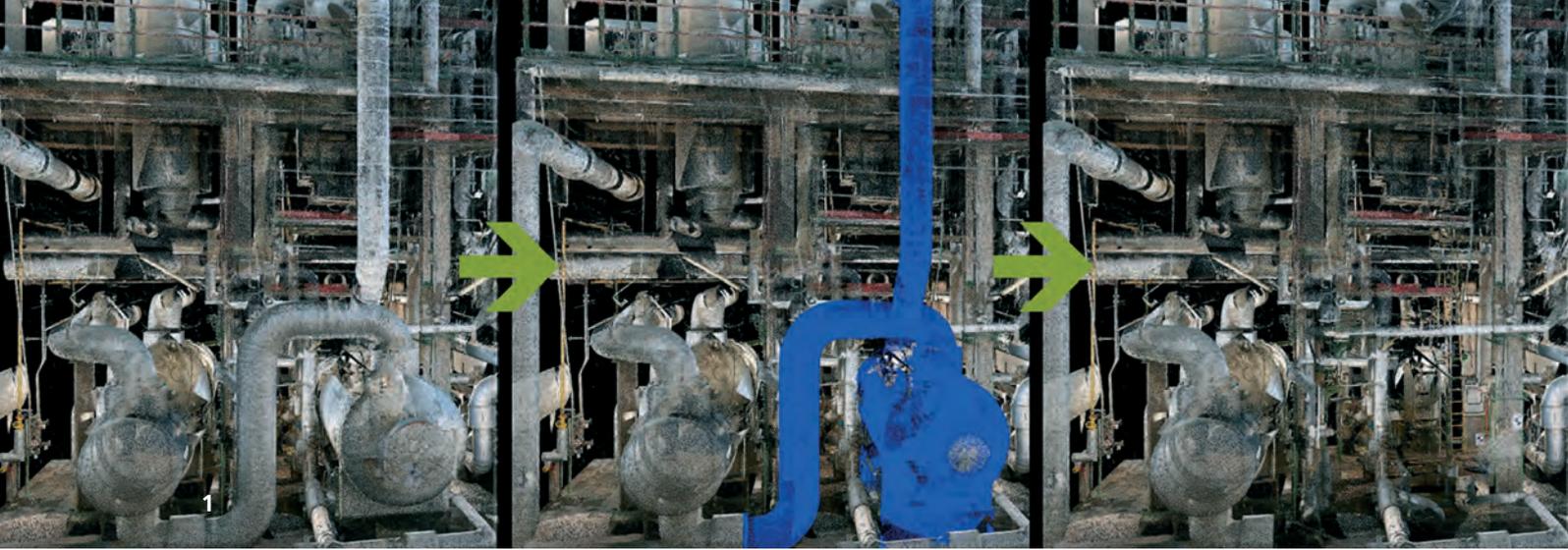
3.6 Optional Services

Depending on the extent of the client's experience, it may be helpful to offer additional services. At the same time, this raises the client's awareness of the diversity of uses of point clouds. It is advisable to specify the costs of such additional services:

- Records of tie points
- Panoramic views of scans (panoramic scan viewer)
- Creation or consolidation of the benchmark system including documentation of benchmarks overviews, specifications of the benchmarks, lists of coordinates, etc.
- Overviews with surveyed objects in buildings or facilities
- Modeling of dumb solids
- Drafting of as-built isometric drawings

3.7 References

References from comparable projects in the previous three years can be included in the technical specifications to give the client an idea of the service provider's experience.



4 GLOSSARY

This section explains the laser scanning terminology employed in these guidelines.

ASTM International

Formerly named the American Society for Testing and Materials, ASTM International is an internationally recognized market leader in the development and supply of international voluntary consensus standards, including the E57 standard for 3D imaging systems, which applies to laser scanners.

Benchmark

The conversion of scans into a local facility or plant coordinate system necessitates engineering surveying of the scanned facilities (tachymetric surveying). This requires benchmarks, which are derived from the higher-level coordinate system and have known locations and elevations. (Ill. 1)

Control points can be used instead of benchmarks for transformations, too. These are points that are present in both a 3D model and the point cloud. They also serve to bring the complete point cloud and the 3D model into congruence and, all in all, facilitate the creation of 3D models from existing planning documents.

Control point

See Benchmark.

Coordinate system

This is the coordinate system referenced by the registered point cloud (complete point cloud). Normally, it is a local reference system, e.g. a facility or plant coordinate system or a global coordinate system (global reference system).

Data cleansing

A laser scanner not only captures desired objects and their surfaces but also spurious points. Spurious points can be produced by temporary objects (vehicles, people, precipitation, materials, etc.), which are also scanned, and measurement errors (digital artifacts on edges and measurement noise, etc.) What is more, data is scanned multiple times in different areas. A laser scanner also scans surrounding areas and sections of other facilities that do not belong to the actual scan area (Ill. 1).

Such frequently unneeded data should be removed from a point cloud. This saves memory and makes work with a point cloud more efficient. Point clouds load faster and automatic collision analyses are made possible in the first place. Data cleansing includes methods for removing and correcting incorrect data (point clouds), thinning a point cloud (removal of intermediate points) and for removing measured points located on object surfaces, which are classified as irrelevant.

Data processing

Data processing entails all of the work which produces a cleansed and registered point cloud from the raw data captured by a laser scanner.

1 *Scanned equipment removed from the scan*



Digital artifact

A digital artifact is produced by multiple reflections during the digitization of a surface measurement point. It is not possible to remove such really nonexistent points fully automatically during data cleansing.

Dumb solid model

A 3D model derived from a point cloud, i.e. the as-built condition, is called a dumb solid model. It does not contain any intelligent data, e.g. temperature and pressure data or related piping. Dumb solids can be modeled with different levels of detail, beginning with the simple representation of areas as envelopes (blocks) and ranging to fully detailed models. Combinations of different levels of detail are quite common. A dumb solid model can be used, for instance, for automatic collision analysis and for presentation purposes. (Ill. 6)

E57 standard

The E57 data format is a compact, vendor-neutral format for the storage of point clouds, images and metadata. The data format is specified by ASTM and is documented in the ASTM standard E2807.

Georeferencing

Georeferencing is the transformation of a point cloud into a local (facility or plant) coordinate system or a global coordinate system.

HDR image

See Photomapping.

Laser scanning

Laser scanning is a method of scanning that uses a laser scanner to scan the surfaces of objects without contact. Millions of points are scanned automatically and, thus, entire objects are scanned precisely and in detail within a few minutes. The data generated by a laser scanner are called a point cloud. Suitable processing programs combine point clouds from individual scanner locations in one complete point cloud. 360-degree, phase-based and/or time-of-flight laser scanners are preferred for plant design and construction.

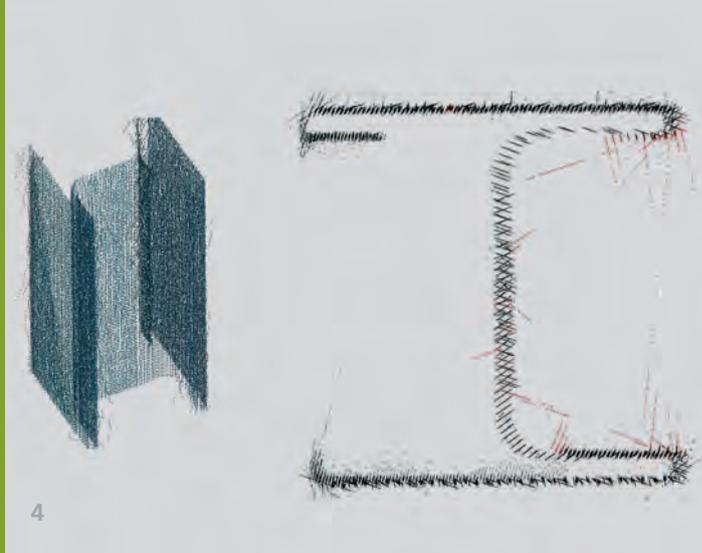
Since laser scanning is a method of optical measurement, a laser scanner can only scan points that are visible from its location. This is why any registered point cloud will also have areas that do not contain any data. Such areas are called data voids.

Laser scanning service provider

A laser scanning service provider is the company that does the laser scanning. It is responsible for data capture, cleansing and registration and, optionally, for modeling or analyses. The laser scanning service provider is additionally responsible for the compilation and delivery of the results as well as for the quality and the completeness of the results of laser scanning within the scope of the contracted service.

2 Benchmark, Photo: Robert Wetzold, pixello.de

3 Comparison of a conventional photo (left) with an HDR image (right)



Since the generation and processing of laser scan data is based on principles of geodesy, a laser scanning service provider must have technical knowledge of surveying.

Marking

Marking is the permanent application of a measuring mark for a benchmark or other survey point, e.g. a target.

Panoramic image

A panoramic image, also called a panoramic view, is a 360° view from the perspective of the laser scanner. Panoramic images can be produced in both true-color and grayscale. Grayscale images are derived from the laser scanner's raw data. True-color images are produced either directly during laser scanning with an internal or external camera or directly after scanning with a separate installation and an SLR camera. SLR cameras produce extremely high quality panoramic images.

Phase comparison

Phase comparison employs the length of an electromagnetic wave as its scale. This method is based on the assignability of a distinct phase angle to each oscillation of a harmonic wave. Continuous harmonic waves are emitted at a particular phase angle and reflected by the object in order to determine the distance between a scanner and an object. The receiver receives the reflected wave at a different phase angle, which is a function of the distance to the object and the speed of travel. A phase comparator measures the phase difference between the emitted and the reflected wave. The distinctive feature of phase-based scanners is their very short scan time.

Photomapping

In photomapping, every point of a point cloud is assigned a color value (RGB value). This requires different photographs taken directly from the scanner position. These pictures are assembled into a panoramic image by means of special software and transferred to the point cloud (mapping). A panoramic image usually consists of ordinary pictures. Generally, this suffices. Provided the lighting conditions vary, high dynamic range imaging (HDRI) can also be used. A conventional photograph and an HDR image are compared in Ill. 3.

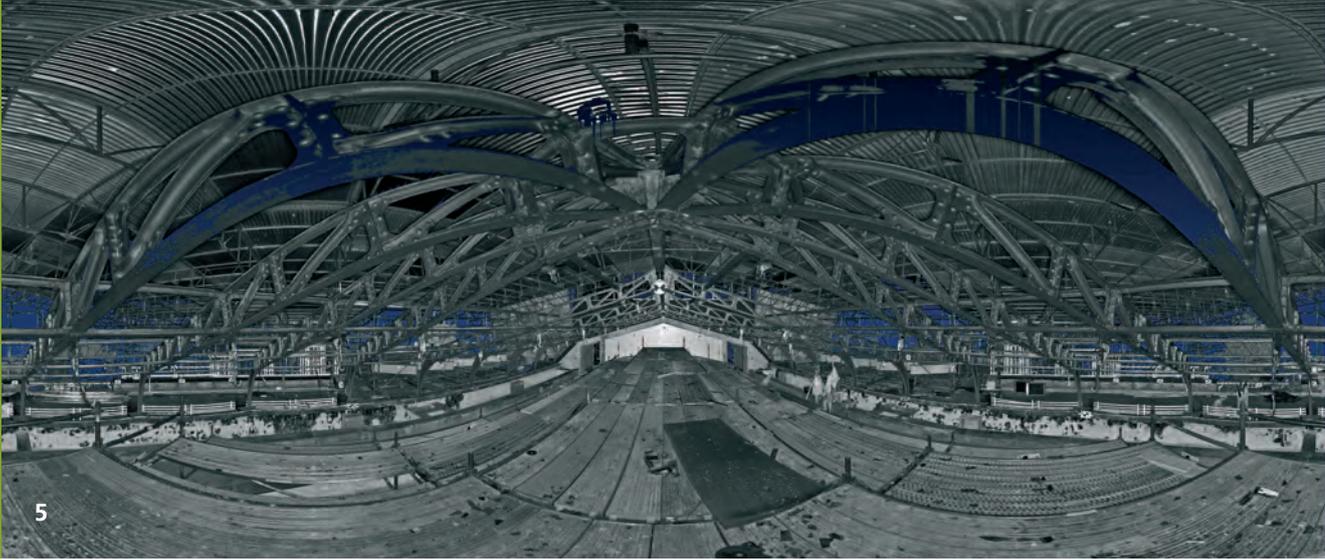
Point cloud

The points captured from one of a laser scanner's locations are generally referred to as a point cloud, scan, individual scan or 3D point cloud. The results of registration and data cleansing are also referred to as a point cloud or complete point cloud, though. A point cloud reflects the as-built condition of a plant and may, therefore, deviate from a model of an existing plant (as-designed) in some areas.

Point cloud registration

See Registration.

4 Digital artifact on an I-beam



Raw data

Raw data are digitized measured data (point clouds) captured by laser scanning, which are not registered and have not been cleansed. Tachymeter measurements and an external camera's individual digital images are referred to as raw data.

Registered point cloud

This is a point cloud that consists of several scans and has been transformed into an integrated and higher-level coordinate system. It is also called a complete point cloud. The coordinate system may be global or local (i.e. a plant).

Registration

Scanning is normally done from several locations in order to scan an object completely. This produces several point clouds (individual scans) in a localized coordinate system. The individual point clouds are combined into one large complete point cloud in one integrated coordinate system. This step is called registration. A distinction is made between point cloud registration and registration with the aid of precisely defined points (targets). Registration makes a point cloud congruent with existing 2D plans or a 3D model. Planning (as-designed) data differs from actual (as-built) data, though.

Point cloud registration entails identifying similar patterns (surface structures and objects) in the different point clouds and using these to combine the scans. Tolerances may vary greatly. Targets can be used to combine individual point clouds into a complete point cloud. The accuracy can be easily defined, verified and additionally controlled by an independent method of measurement (tachymetry).

Scan

See point cloud.

Scan resolution

Scan resolution specifies the number of points measured per unit of area. Scan resolution is frequently specified by the number of points in a laser scanner's field of view or by the distance between the measured points at a specific distance from the laser scanner. A sufficient density of measured points must be obtained on an object during laser scanning. When, for instance, a very large distance between points is selected (low scan resolution), then small objects will be scanned inadequately or not at all. When, on the other hand, the distance between points is very small (high scan resolution), then scanning will take a very long time and large quantities of data will be produced, which may cause problems during later data processing.

Piping is used as an example to explain scan resolution. The table below presents piping and the scan resolution recommended for Leica, Z+F and FARO laser scanners, which are the most common in plant design. A Leica or Z+F laser scanner set to "high" resolution may not be more than 8 m away from a DN 100 pipe (4"). This guarantees that the pipe is scanned with a sufficient number of points (23 per line) and, thus, is recognized as such.

5 *Grayscale panoramic image*



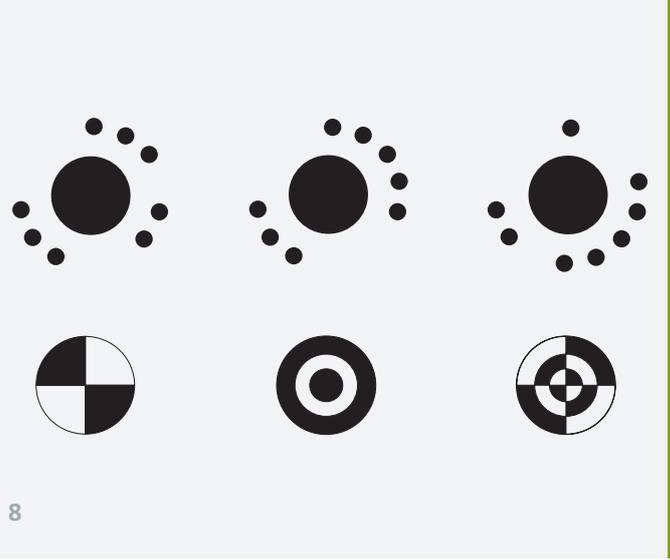
System capabilities

System capabilities indicate a system's suitability to measure an object. The cumulative influences of inaccuracies when determining a measured value are called measurement uncertainty. A system is designated suitable when the total measurement uncertainty does not exceed 10% of the measured form or shape tolerance.

Tachymetry

Tachymetry is a method of surveying that captures points quickly. It measures benchmarks or targets with very high accuracy. Tachymeters and total stations are the surveying instruments used for this. Tachymetry is used, for instance, to determine highly precise control networks, which, in turn, are the basis for registration.

Nominal pipe size (NPS)	Pipe thread taper (inch)	Outer diameter (mm)	Nominal distance between points (mm)	Maximum distance from the object (m)	Actual distance between points on the object (mm)	Number of points on the object (1 line)	Maximum distance from the object (m)	Actual distance between points on the object (mm)	Number of points on the object (1 line)
Threaded pipe EN 10255 (medium, steel)				Leica HDS 6000-7000, Z+F Imager 5003-5010 High resolution – 100% import			FARO FOCUS 3D ¼ resolution – 100% import		
8	1/4"	13.5	2	2	1.3	11	2	1.2	11
10	3/8"	17.2	2	2	1.3	14	2	1.2	14
15	1/2"	21.3	2	2	1.3	17	2	1.2	17
20	3/4"	26.9	3	2	1.3	21	2	1.2	22
25	1"	33.7	3	3	1.9	18	3	1.8	18
32	1 1/4"	42.4	3	4	2.5	17	4	2.5	17
40	1 1/2"	48.3	3	4	2.5	19	4	2.5	20
50	2"	60.3	3	5	3.2	19	5	3.1	20
65	2 1/2"	76.1	4	6	3.8	20	6	3.7	21
80	3"	88.9	5	7	4.4	20	7	4.3	21
100	4"	114.3	5	8	5.0	23	8	4.9	23
125	5"	139.7	6	9	5.7	25	9	5.5	25
150	6"	165.1	7	11	6.9	24	11	6.8	24
200		219.1	8	12	7.6	29	12	7.4	30
250		273	10	15	9.5	29	15	9.2	30
300		323.9	10	17	10.7	30	17	10.5	31
350		355.6	12	18	11.3	31	18	11.1	32
400		406.4	12	20	12.6	32	20	12.3	33
450		457	14	22	13.9	33	22	13.6	34
500		508	16	25	15.8	32	25	15.4	33
600		610	18	30	18.9	32	30	18.5	33



Targets

Targets are precisely defined points needed for registration. Targets are used to combine and transfer individual scans to a higher-level coordinate system. The shape and appearance of targets vary. Targets may, for instance, be black and white or spherical. Targets are installed in the scan area during laser scanning and are subsequently captured by tachymetry. Spheres constitute spurious objects in a point cloud. This can cause problems, especially for automatic collision analyses (III. 8).

Time of flight

Laser scanners that measure distance based on time of flight basically consist of an emitter, a receiver and a time-of-flight sensor. An extremely short pulse of light with a known speed of travel is emitted by the device's emitter, reflected at the end of the distance traveled, and received by the receiver. The round-trip-travel time, i.e. the doubled distance traveled, can be ascertained by measuring the pulse's travel time. The distinctive feature of a time-of-flight scanner is its high range.

Virtual Reality

Virtual reality is the representation and simultaneous perception of reality and its physical properties in an interactive virtual environment that is generated in real time by a computer.

7 Tachymeter, Photo: Rainer Sturm, pixelio.de

8 Black and white targets

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LASER SCANNING AND VIRTUAL REALITY IN PLANT DESIGN



The Laser Scanning and Virtual Reality in Plant Design Industry Working Group aims to use advanced 3D systems such as virtual and augmented reality cost effectively throughout the entire life cycle of industrial plants. Plant engineering companies, plant operators, hardware and software system developers and manufacturers, AR and VR system vendors, laser scanning service providers and as-built documentation service providers collaborate closely in the Industry Working Group.

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