REALITY CAPTURE / SCAN-TO-MODEL / ASSET INTEGRITY

From Point Cloud to Engineering-Ready 3D Models

A detailed practical workflow for industrial facilities, offshore assets and brownfield engineering.



Photographic illustration of industrial survey capture. AI-generated; not an HPG project photograph.

The engineering value lies beyond the scan

Laser scanning can record millions of surface observations in a short time. Converting those observations into a dependable model requires a planned survey, controlled registration, disciplined reconstruction and verification against the intended engineering use.

This paper follows the complete process: what happens in the field, how the data is prepared, how pipes and steelwork become model objects, and how the resulting information can support inspection, modifications and integrity decisions.

For asset owners, engineering managers and technical teams.
Includes seven explanatory diagrams, two photographic illustrations, a worked example, acceptance checks and a handover framework.

READER GUIDE

What the process delivers

Executive overview

A point cloud is a spatial record of observed surfaces, not a finished engineering model. It can answer questions about visible positions and dimensions, but it does not automatically identify equipment, establish connectivity or supply material properties. Modelling adds interpretation; assurance establishes how confidently the result can be used.

The distinction matters on operating assets. A pipe may be hidden by insulation, a beam may be partly obscured by services, and an apparently continuous component may include a connection that the scan cannot reveal. These gaps should remain visible in the information record rather than disappear behind a polished rendering.

How to read this paper

Section	Pages	What it explains
Define and capture	3-6	Requirements, control, scanner setup and field execution
Register and prepare	7-9	Alignment, verification, cleaning and data organisation
Develop the model	10-13	Representation, segmentation, reconstruction and attributes
Verify and use	14-17	Model assurance, example, delivery and digital twin integration
Reference guide	18	Terms, primary sources and publication notes

Three questions should govern every stage

What decision will this support? The answer sets the scope, required geometry, verification effort and information requirements.
What evidence supports it? The answer distinguishes measurements, verified records and assumptions.
Who maintains it? The answer determines whether the information remains useful after the next modification.

Core principle: detail, accuracy and completeness are different. A highly detailed object may be poorly located; a correctly located object may have incomplete attributes. Specify and verify each requirement separately.

01 / DEFINE THE REQUIREMENT

Begin with the intended use

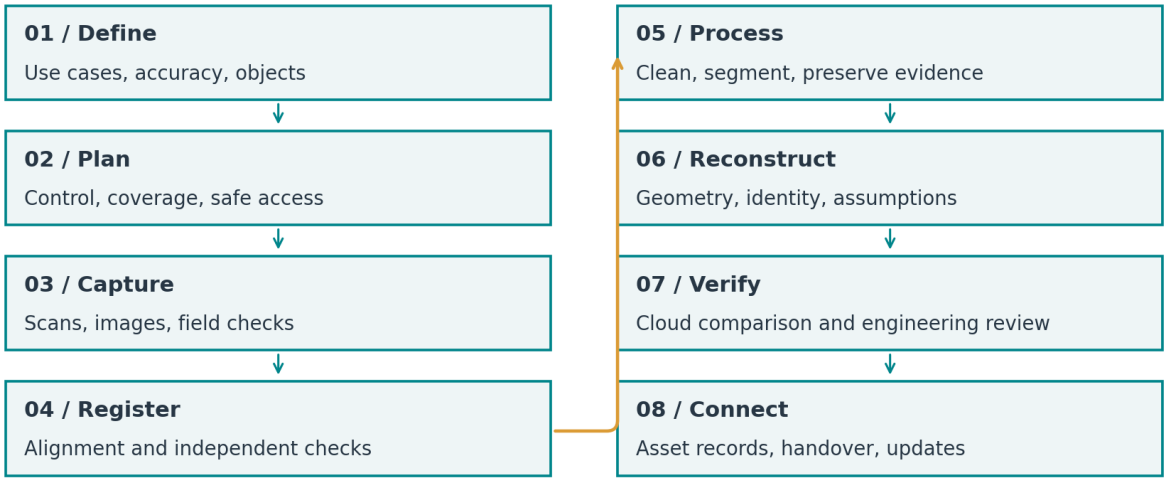


Figure 1. End-to-end delivery sequence. Assurance and evidence control apply throughout; this is a proposed practical workflow.

1. Define the decision and model boundary

Identify whether the model is for navigation, inspection planning, modification design, clearance checks, quantities or assessment preparation. List the areas and systems included, the components that require detailed reconstruction, and exclusions such as hidden services or submerged members. Agree who will approve the final outputs.

2. Specify geometric and information requirements

For each object class, define the geometry to capture and attributes to deliver. A structural member may need a section designation, endpoints and orientation; a pipe may need a centreline, outside diameter and line identifier. An inspection model may prioritise stable component IDs and links to findings over detailed bolts.

3. Define acceptance before capture

Set dimensional tolerances by component and use, the required surface coverage, independent verification and treatment of assumptions. Describe the reference against which each tolerance is checked. A cloud-to-model tolerance is not a guarantee of absolute survey accuracy. An execution plan helps separate accuracy and model-development requirements. [1]

Output: approved survey and modelling brief, object list, accuracy requirements, acceptance plan, responsibility matrix and deliverable schedule. Avoid specifying a generic level of detail as the only quality requirement.

02 / PLAN COVERAGE AND CONTROL

Design the survey before site work

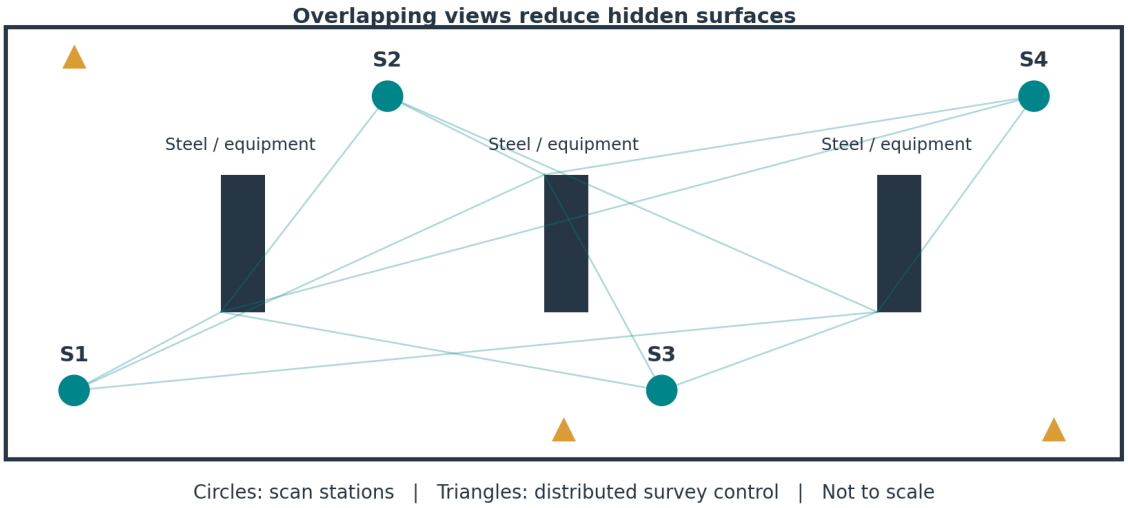


Figure 2. Schematic station layout. Multiple viewpoints reduce occlusions; distributed control supports spatial alignment. Not a prescribed layout or overlap percentage.

1. Review access and the existing information

Obtain layouts, drawings, asset tags and previous surveys. Identify congested areas, elevations, safe routes and operating restrictions. Treat drawings as planning inputs until checked; discrepancies with the physical asset may be the reason for commissioning the survey.

2. Establish control and coordinate conventions

Agree the plant grid or project coordinate frame, units, origin, axis directions and vertical reference. Establish stable, surveyed control suitable for the site. Distribute it through the survey area and retain additional check points that are not used in the alignment. Record how any local model coordinates transform into the plant frame. Survey coordinates can align a registered cloud with existing CAD data. [2]

3. Plan connected, overlapping scan positions

Choose positions that see shared stable features in several directions, while adding views behind equipment and around structural members. Long chains with few cross-links can allow alignment errors to accumulate. Plan connections between decks or rooms and return checks where practical. No single overlap percentage guarantees a reliable network.

Output: station plan, control/check-point register, coordinate specification, access plan and coverage priorities. Log areas that cannot be safely captured and agree how they will be represented.

03 / SELECT AND CONFIGURE CAPTURE

Understand what the scanner measures



Photographic illustration of a scanner near steelwork and piping. AI-generated; not a survey record or a product specification.

1. Select a method suited to the work

Static terrestrial laser scanning offers controlled station-based capture of industrial geometry. Mobile or handheld systems can improve coverage efficiency, but their trajectory and alignment must be validated for the required use. Photogrammetry can complement images and geometry where suitable views, scale and control are available. Underwater surfaces require an appropriate separate survey method.

2. Understand the observations

A terrestrial scanner typically measures a range and two angles, then calculates XYZ coordinates in its local frame. Time-of-flight and phase-based ranging are common approaches. Intensity describes the returned signal; camera colour can be mapped onto points. Colour helps interpretation but does not establish the identity or condition of a component.

3. Set resolution for the smallest relevant feature

Point spacing increases with distance for a fixed angular sampling interval. As a simple illustration, spacing is approximately range multiplied by angular increment in radians: a 0.001-radian increment gives about 10 mm spacing at 10 m and 30 mm at 30 m. This describes sampling, not accuracy. Capture fine or critical details from suitable closer positions.

Output: selected capture method, checked instrument, appropriate resolution/settings and a field verification procedure. Site suitability, hazardous-area restrictions and safe access determine how capture is executed.

04 / CAPTURE THE ASSET

Execute a repeatable field sequence

1. Set up and identify each station

Place the tripod on stable support, check instrument status and secure the work area. Assign a unique station ID that links the scan to its location, time, operator, instrument and settings. Avoid movement or vibration during acquisition. Follow the instrument procedure for levelling and checks rather than assuming the image proves correct setup.

2. Capture the geometry and supporting images

Acquire the scan using the planned resolution and range settings. Record colour imagery where it helps identify equipment and tags. Observe common targets or shared geometry from successive stations. Supplement obscured labels, connections or unusual details with close photographs and field notes; a panoramic image may not resolve a small tag.

3. Review while the team is still on site

Check that adjacent scans can be connected and that critical surfaces are visible. Inspect likely problem areas, including reflective metal, dark surfaces, grating, edges, insulation and moving equipment. Add viewpoints or targeted observations before demobilisation where a gap would affect the intended use.

4. Preserve context and raw data

Retain raw scan files, target observations, control measurements and original photographs. Back up data and maintain a scan log. Record the capture date for each area: a model assembled from several campaigns may represent different physical states. Do not silently merge a removed component and its replacement into one apparent current arrangement.

Common field limitations

Issue	Practical response
Occlusion behind equipment	Additional views; document gaps that remain
Movement or vibration	Stable setup and suitable capture window; review affected scans
Reflective / dark surfaces	Review return quality; vary view and supplement evidence
Hidden or insulated components	Record observed exterior and qualify underlying geometry

Output: raw observations, field scan log, photographs, control data and coverage exceptions. Demobilise only after the agreed critical coverage checks are complete.

05 / REGISTER INDIVIDUAL SCANS

Align observations into one framework

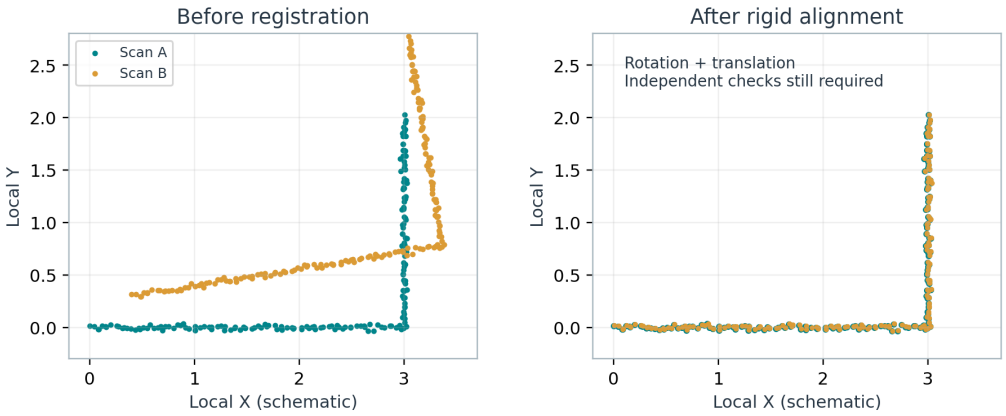


Figure 3. Synthetic 2D demonstration of registration. A rigid transformation aligns views of the same features; real registration operates in three dimensions.

1. Import and preserve the station structure

Load raw scans and confirm units, station identifiers and available target or image data. Keep an unaltered copy. Each station initially has its own coordinate frame; matching views does not yet establish the plant coordinate reference.

2. Establish a credible initial alignment

Target-based registration matches common target centres. Cloud-based registration uses shared surfaces or features. A hybrid method can use targets to establish orientation and surface matching to refine it. Repetitive pipe racks or large featureless planes can provide misleading correspondences, so inspect the geometry being used.

3. Refine and review the registration network

A rigid transform can be written as **p = Rq + t**, where R rotates a point q and t translates it into the reference frame. Iterative Closest Point methods refine alignment by repeatedly associating points and reducing mismatch; they need suitable starting alignment and correspondence control. A converged fit can still be physically wrong. [3]

Connect scan groups into a coherent network and inspect joins, cross-links and return connections. Check for doubled edges, separated surfaces and implausible target associations. Then align the accepted network to the surveyed reference rather than moving individual components to fit drawings.

Output: registered scan network and documented transformations. Review suspect matches before accepting summary statistics or exporting a merged cloud.

06 / VERIFY THE POINT CLOUD

Prove alignment before modelling

1. Separate the quality measures

Measure	What it tells you	What it does not prove
Instrument performance	Behaviour of the measuring device under stated conditions	Accuracy of the whole registered project
Registration residual	Agreement between matching observations	Correct plant coordinates or complete coverage
Independent check error	Agreement with unused reference observations	Quality everywhere beyond those checks
Point spacing / density	Sampling of visible surfaces	Identity, accuracy or hidden geometry

2. Review local and global behaviour

Examine residuals for individual targets and scan links, not only the project average. Check whether poor links cluster in one area or whether drift develops across the network. Inspect cloud sections through columns, walls and pipe runs for split or doubled surfaces. Registration reports can expose overlap and geometric balance, but independent evidence remains necessary. [4]

3. Check against independent observations

Compare unused surveyed check points, reference lengths and critical dimensions with the registered cloud. State the reference accuracy, the observed differences and acceptance rule. Record failures and corrective action. Do not use points in the adjustment and then present the same points as independent validation.

4. Release with explicit limitations

Confirm the coordinate frame, control integrity, coverage and capture dates. Where accuracy varies, describe the affected area and permitted use. A small residual in a local pipe rack does not prove that every deck is accurately positioned in the asset grid.

Gate: approve the spatial evidence before object reconstruction. The issue package should include registration checks, independent validation, coverage exceptions and the coordinate transformation. Modelling cannot repair an unrecognised survey error.

07 / CLEAN AND ORGANISE

Prepare data without losing evidence

1. Remove transient or unreliable observations

Isolate people, temporary objects, obvious reflections and points that do not belong to the intended asset state. Distinguish a temporary obstruction from an actual installed component. Preserve raw data and document the criteria for removal so another reviewer can understand the cleaned result.

2. Apply filtering conservatively

Statistical outlier removal examines how far points lie from their neighbours and flags unusual observations. It can help reduce isolated noise, but real small features and sparse edges can also appear unusual. Review the effect on brackets, thin plates and small-bore piping rather than applying one aggressive setting everywhere. [5]

3. Reduce size for a stated purpose

Downsampling can create a lightweight working cloud by retaining representative points within spatial cells. Choose the cell size against the features to be modelled and retain the higher-resolution evidence. A viewer derivative and a source cloud for detailed reconstruction need not use the same density. Smoothing can conceal deformation or local changes, so preserve the unsmoothed observations.

4. Segment and index by area

Organise decks, modules, rooms or systems as manageable regions. Keep common coordinates when splitting files. Apply clear naming, revision and capture-date conventions. Preserve station information where it helps trace gaps or investigate unexpected geometry.

5. Verify the export

E57 is a standard exchange format for 3D imaging data. [6] Native formats may retain software-specific project structure. Whatever the format, test the export in the receiving tool: verify units, extents, orientation, expected points and any images or station metadata needed for the next stage. Do not assume all optional information transfers.

Output: an accepted master cloud, documented processing history and purpose-specific working subsets. Keep the master and viewer derivatives distinguishable; avoid treating a heavily simplified cloud as the complete measurement record.

08 / CHOOSE THE REPRESENTATION

A cloud, a mesh and a model are different



Figure 4. Three representations of the same synthetic pipe-and-support arrangement. The illustration demonstrates the distinction; it is not real scan data.

Representation	Contains	Suitable uses / limits
Point cloud	Discrete XYZ observations, optionally colour and intensity	Spatial reference and measurements; no inherent object identity
Surface mesh	Vertices and connected faces approximating a surface	Visualisation and surface comparison; semantics need separate work
Object-based CAD / BIM	Recognised geometry with IDs, types and attributes	Engineering coordination and asset information; assumptions need review
Analysis model	Idealised geometry, connectivity, properties and loads	Calculation after engineering preparation and validation

1. Select by the intended decision

Use the cloud where the observations themselves are the required evidence. Use a mesh when a continuous surface is useful, for example to describe irregular shape. Use engineering objects where teams need identifiable beams, pipes or equipment that can be edited, queried or linked to records.

2. Control reconstruction of missing surfaces

Meshing joins nearby samples; sparse regions and occlusions can produce artificial bridges or holes. Hole filling estimates geometry that was not observed. Similarly, completing a fitted cylinder around its unseen side is reconstruction. Keep these operations traceable and avoid presenting completed surfaces as fully captured.

Decision: build the representation that supports the job. An industrial model often combines simplified equipment envelopes, detailed critical interfaces and linked point-cloud evidence rather than maximum detail everywhere.

09 / SEGMENT AND FIT GEOMETRY

Turn observations into candidate shapes

1. Isolate a manageable component or region

Clip the cloud around the item being reconstructed. Separate adjacent objects and remove obvious non-component points from the working selection. Use sections and multiple views; a point selected in one view may belong to a different object behind it. Preserve a route back to the full cloud for context.

2. Identify the geometric primitive

Planes can represent deck surfaces, plates or equipment faces. Cylinders can approximate straight pipe runs, tubular braces or vessel shells. Lines and profile sections help reconstruct structural members. Surface normals, where computed, describe local orientation and can help distinguish regions. Their reliability depends on neighbourhood choice and noise.

3. Use robust fitting as an aid

Sample-consensus methods such as RANSAC test candidate shapes and identify observations consistent with a selected distance threshold. Plane and cylinder segmentation are documented examples in Point Cloud Library. [7,8] The threshold should reflect data quality and the component, rather than being chosen merely to maximise the number of accepted points.

4. Test the result against engineering evidence

Review the support for the fit: visible surface extent, curvature, local noise and interference from other objects. A narrow visible arc may fit several plausible cylinders. Check the proposed diameter or section against reliable drawings, specifications or targeted measurements. A mathematically plausible shape does not identify its engineering function.

5. Author controlled objects

Convert approved candidates into objects with clear origins, orientation and boundaries. Use a suitable catalogue profile where confirmed; preserve measured deviation where it matters. Do not snap every member or pipe to a convenient grid if the asset actually departs from it. Record whether geometry is measured, idealised or inferred.

Output: reviewed geometric candidates and authored components, with fitting assumptions and evidence status. Automatic extraction accelerates repetitive tasks; engineering judgement resolves ambiguity.

10 / RECONSTRUCT INDUSTRIAL COMPONENTS

Pipes, steelwork and equipment

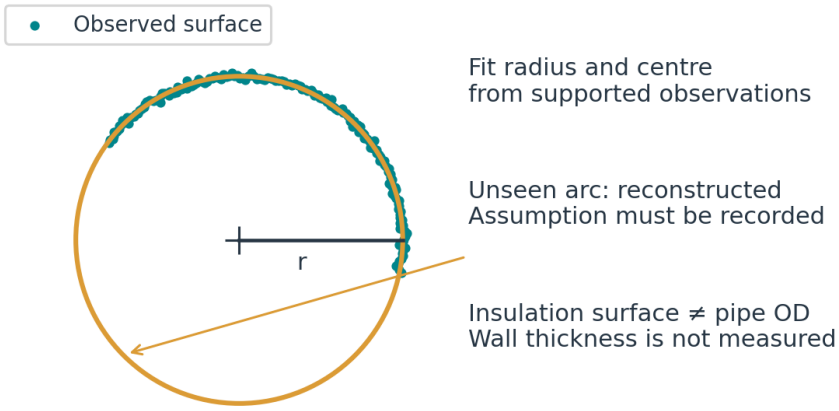


Figure 5. Synthetic pipe cross-section. Fitting a circular surface estimates a centre and radius; the unseen arc is reconstructed and the exterior may be insulation.

Piping: from exterior surface to centreline

For a visible straight run, isolate the surface, fit the cylinder and check its axis and diameter. Build a pipe object with the confirmed centreline and dimensions, then reconstruct bends and fittings using observed interfaces and verified records. For insulated piping, distinguish the measured insulation envelope from the underlying pipe. Do not infer schedule or wall thickness from the exterior radius alone.

Steelwork: section, position and orientation

Use transverse sections through a member to identify its shape and orientation. Confirm the section designation from sufficient visible faces or reliable documentation. Reconstruct endpoints and connections from the evidence; avoid assuming end fixity or continuity because objects appear to touch. Check how nominal profiles differ from actual visible geometry, especially where damage or distortion may affect a decision.

Equipment: choose useful detail

A vessel or pump may initially be represented by its envelope, nozzles and key interfaces. Add the detail required for access, clearance or modification work. Verify nozzle orientation and flange faces where these govern fit-up. Keep inaccessible internal geometry document-derived, with its source stated.

Practical rule: capture and model the details that control the decision. Bolts, welds and hidden interfaces should not be added as apparent facts simply to make the model look complete.

11 / ADD IDENTITY AND INFORMATION

Make the model traceable and searchable

1. Establish stable identifiers

Assign a persistent model ID and reconcile it with the asset register. An equipment tag may already exist; structural components may require an agreed hierarchy such as asset, module, deck, member and connection. Keep display names separate from stable identifiers so renaming does not break links to inspection or maintenance records.

2. Attach attributes from verified sources

Add type, location, dimensions and engineering attributes that the scope requires. Link materials and design properties to records rather than treating them as scan results. A model can carry a material grade without the scan having established that grade; users need to see the source and verification status.

Field	Example	Evidence / control
Stable object ID	A-D02-BM-014	Agreed structural identification scheme
Geometry source	Scan campaign SC-01	Station/subset reference and capture date
Section designation	Catalogue profile, where verified	Drawing or field evidence; source retained
Evidence status	Observed / record-derived / inferred	Applied to relevant fields, not only whole object
Integrity link	Inspection finding IF-026	Record ID, date, status and responsible owner

3. Resolve conflicts rather than overwrite them

If a drawing shows one section and the cloud suggests another, log a discrepancy and seek clarification. Keep both the original source and the accepted resolution. Avoid copying missing attributes from neighbouring objects unless the assumption is explicit and authorised within the project rules.

4. Manage status and revision

Record who created and reviewed the component, its model revision, applicable asset state and unresolved issues. Link documents through maintained references rather than embedding untracked copies wherever possible. Set field-level evidence status when geometry is observed but other attributes remain uncertain.

Output: an object register connecting geometry, evidence, records and review status. This turns a visual model into useful asset information.

12 / VERIFY THE COMPLETED MODEL

Check geometry, coverage and fitness for use

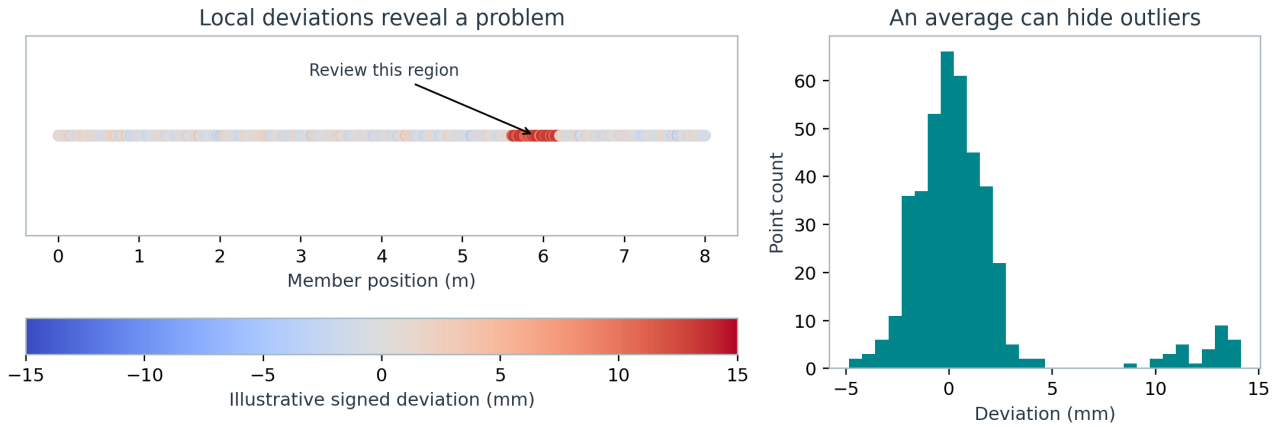


Figure 6. Synthetic deviation example. A short region with a larger offset can be concealed by an acceptable-looking overall average. The values are illustrative, not acceptance thresholds.

1. Compare model surfaces with the accepted cloud

Use overlays, sections and distance comparisons to inspect the reconstructed geometry. Cloud-to-mesh tools measure point distances to a model surface and can support colour maps and statistics. [9] State the distance convention, comparison direction and regions being tested. A cloud-to-model check only tests sampled visible evidence; it cannot establish that hidden geometry or every required object is complete.

2. Investigate patterns and outliers

Check whether deviations come from modelling error, registration error, insulation, nominal-profile idealisation, local deformation or an actual change in the asset. Avoid moving a model to hide a survey problem. Verify critical interfaces directly, including tie-ins, flange planes and clearance bottlenecks.

3. Review completeness and information

Check required objects against the scope register. Identify missing components, duplicates, disconnected runs and inconsistent names. Reconcile links and attributes with authoritative sources. Apply agreed checks by object class and intended use; a large vessel envelope and a fabrication interface require different acceptance logic.

Acceptance: issue exceptions alongside results. If a location remains unverified, restrict its use explicitly. A convincing rendering, a low mean deviation or a completed checklist alone is insufficient evidence of engineering suitability.

WORKED EXAMPLE / ILLUSTRATIVE

A pipe rack modification from start to finish

Scenario: a new pipe run is proposed through an existing process module. The team needs to confirm the route, establish tie-in geometry and identify supports for engineering review. This is an illustrative example, not an HPG project case study.

1. Define the critical information

The brief identifies the proposed route, existing piping, equipment envelopes, access routes and potential support steelwork. It distinguishes layout review from fabrication verification and specifies tighter checks at tie-ins. Existing drawings and line lists are collected, with unresolved revisions flagged.

2. Capture and establish the spatial baseline

The survey team plans stations on both sides of the rack and at suitable elevations to reduce shadowing. Control is surveyed and unused check points retained. Additional observations are taken at tie-ins and support interfaces. Insulated runs are recorded as external envelopes unless the underlying geometry is separately verified.

3. Register, verify and reconstruct

Scans are aligned, checked for local mismatches and placed in the agreed plant grid. Independent observations confirm critical positions. The modeller builds the visible pipe runs and steelwork, identifies components using the records and logs uncertain section sizes or hidden connections.

4. Review the proposed modification

The design team checks route conflicts and access clearances, then verifies dimensions that govern fit-up. The structural engineer prepares a separate calculation model for support loads and checks capacity, material properties and condition using appropriate evidence. The scan does not supply those conclusions.

5. Accept and update

The owner receives the model, survey evidence, critical dimension checks and unresolved-item register. After installation, the revised physical arrangement is surveyed or otherwise verified as required, then incorporated into the governed model. The record distinguishes the pre-modification and installed states.

Illustrative acceptance lesson: if a cloud-to-model check meets an agreed tolerance over visible steelwork, that does not automatically demonstrate the positional accuracy or fit-up suitability of an obscured tie-in. Its independent verification remains a separate requirement.

13 / DELIVER AND MAINTAIN

Handover should preserve the evidence chain

1. Agree the package, not just the model file

Deliverable	Minimum purpose / content
Raw and accepted point clouds	Original observations; accepted registration and coordinate metadata
Survey and registration report	Control method, check results, alignment review, exceptions
Native engineering model	Editable objects, hierarchy, attributes and reference alignment
Exchange / viewer derivatives	Agreed interoperability and navigation outputs; export tests
Object and evidence register	Stable IDs, source links, evidence status and capture dates
Verification and issue register	Acceptance checks, assumptions, limitations and unresolved items
Change procedure	Owner, revision process, access, review and update triggers

2. Test interoperability

IFC provides a vendor-neutral framework for identity, geometry, attributes and relationships. [10] Select an exchange schema and deliverable rules supported by the project tools. Test a representative export/import early, then check the final files for coordinates, units, hierarchy, properties and object IDs. A successful import does not prove complete information transfer.

3. Distinguish the engineering and viewer outputs

Lightweight viewers support navigation and coordination. They may simplify geometry or carry fewer attributes than the native model. Label their revision and intended use, retain the accepted master and provide a clear route to supporting survey evidence.

4. Govern changes after handover

Define which modifications, inspections or discoveries trigger an update. Record the physical change date, source evidence and review status. Preserve revision history and avoid mixing proposed work with the current installed state. Assign ownership for both model geometry and linked information.

Output: a usable, auditable package with an owner and update process. An unmanaged model becomes less dependable as the physical asset changes, even if its original survey was excellent.

14 / EXTEND TOWARDS A DIGITAL TWIN

Connect geometry to integrity decisions

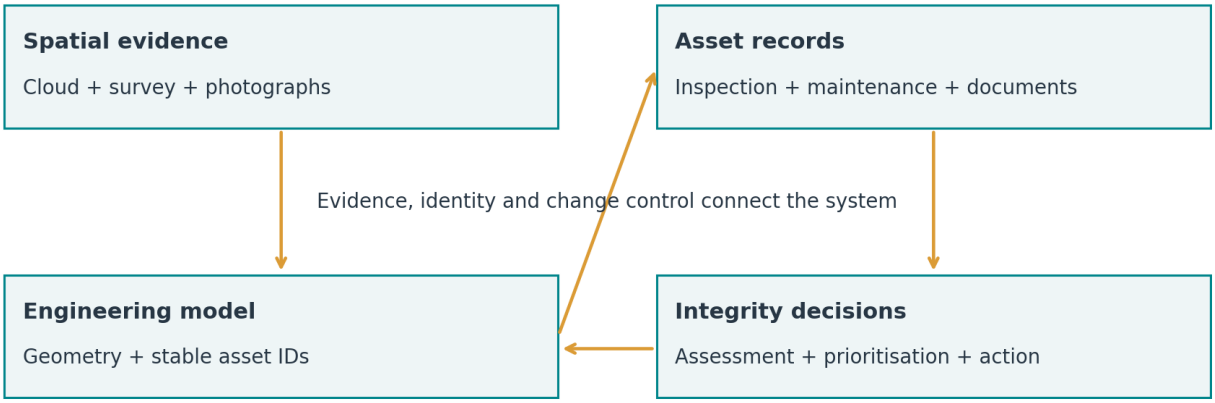


Figure 7. A practical information architecture. Stable identifiers link spatial evidence, model objects, asset records and engineering action; update controls keep the relationship meaningful.

1. Treat the 3D model as a spatial foundation

A model locates and represents components. To support a digital twin use case, connect it to the asset state and information needed for decisions. Examples include inspection findings, maintenance history, operating constraints and engineering assessments. Where time-series data adds value, define what is measured, how it is mapped and how quality is checked.

2. Link findings to the right component

An inspection finding should identify the component, location, observation date and evidence. The model can help reviewers see its context and reach the relevant assessment. Integrity decisions still depend on appropriate engineering methods, inspection quality and approved criteria; colour-coding a finding does not complete that assessment.

3. Convert insight into controlled action

Connect significant findings to recommendations, priorities, work orders and close-out evidence. Record who approves the decision and verifies completion. Avoid an impressive dashboard with no reliable component IDs or process for resolving stale information.

Scanning establishes visible geometry. It does not, by itself, establish wall thickness, material grade, hidden corrosion, fatigue damage, remaining life or structural adequacy. Add these through appropriate inspection, records and engineering assessment, with their confidence and limitations retained.

REFERENCE GUIDE

Terms, sources and publication notes

Term	Meaning in this paper
Registration	Aligning scan coordinate frames using matching observations
Survey control	Reference observations used to place data in an agreed frame
Independent check	Reference not used in the adjustment being tested
Occlusion	A surface hidden from a particular capture viewpoint
Segmentation	Separating a cloud into regions or candidate components
Geometric fitting	Estimating a shape from selected observations
Evidence status	Whether a field is observed, record-derived or inferred

Primary sources and further reading

[1] Autodesk University. Developing an Execution Plan for Scan to BIM. Open source.

[2] Autodesk ReCap Help. Adding Survey Points to Scan Projects. Open source.

[3] Point Cloud Library. How to use Iterative Closest Point. Open source.

[4] Autodesk ReCap Help. Registration Quality Report. Open source.

[5] CloudCompare. SOR filter. Open source.

[6] ASTM. E2807: Standard Specification for 3D Imaging Data Exchange. Open source.

[7] Point Cloud Library. Plane model segmentation. Open source.

[8] Point Cloud Library. Cylinder model segmentation. Open source.

[9] CloudCompare. Cloud-to-Mesh Distance. Open source.

[10] buildingSMART Technical. Industry Foundation Classes (IFC). Open source.

Publication notes

Published by HPG Engineering Limited, October 2026. Sources accessed 13 October 2026. Diagrams are original explanatory schematics or synthetic demonstrations, not measured asset data. Both photographic illustrations are AI-generated and depict no actual client project. This paper provides a technical framework; the project execution plan establishes applicable survey and acceptance requirements.

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