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A TREATISE FOR ARCHITECTS AND ENGINEERS

LiDAR for Existing Buildings

Every dimension in a design for an existing building was either measured or assumed.

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Written for architects, structural engineers, and MEP and civil engineers.

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A registered terrestrial laser scan replaces assumed dimensions with measured ones, at an accuracy that is specified in advance and checked afterward.

01 The position

Every dimension in a design for an existing building was either measured or assumed. Record drawings supply assumed dimensions: they state what the designer intended when the building was first built. Three things separate the building from those drawings.

The first is construction tolerance. A building erected correctly was never built to its drawings. ACI 117-10 §4.1.1 permits cast-in-place concrete up to 83 ft 4 in. high to deviate from plumb by the lesser of 0.3 percent of its height or 1 in. AISC 303 §7.13.1.1 permits an individual steel column to lean 1/500 of the distance between its working points. Over a 12 ft story those limits are 11 mm and 7.3 mm.

The second is alteration. On GSA's first laser scanning pilot, at 26 Federal Plaza in New York, the scan found a wall five feet from the position shown on a design drawing some 30 years old. The project was at 35 percent construction documents when the scan caught it.

The third is movement: settlement, deflection and creep that no drawing records.

A registered terrestrial laser scan replaces assumed dimensions with measured ones, at an accuracy that is specified in advance and checked afterward. Every specific benefit in this paper follows from that one substitution. The paper covers how the instrument measures, how accuracy is specified, what each discipline gains, and where the method stops.

"LiDAR" here means tripod-mounted terrestrial laser scanning of buildings and sites.

02 How the instrument measures

A terrestrial laser scanner is a spherical-coordinate instrument. For each point it records one range and two angles, and every coordinate in the point cloud is computed from those three numbers. ASTM E3125 classes these instruments as spherical coordinate 3D imaging systems.

FARO's published specification for the Focus Premium series, the instrument I use, separates the error into its sources. FARO states all accuracy values as standard deviations.

Quantity	Published value
Ranging error (systematic)	±1 mm
Range noise, white surface (90% reflectivity)	0.1 mm at 10 m, 0.2 mm at 25 m
Range noise, dark grey surface (10%)	0.3 mm at 10 m, 0.4 mm at 25 m
Range noise, black surface (2%)	0.7 mm at 10 m, 1.2 mm at 25 m

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Quantity	Published value
Angular accuracy	19 arcseconds
3D accuracy	2 mm at 10 m, 3.5 mm at 25 m
Finest angular step	0.009°, 40,960 points per revolution
Measurement rate	Up to 2 million points per second
Laser	Class 1, 1553.5 nm

Three consequences follow from that table.

Accuracy falls with distance. Nineteen arcseconds is 0.9 mm of lateral error at 10 m and 2.3 mm at 25 m. Station spacing is an accuracy decision as much as a coverage decision.

Accuracy falls on dark surfaces. Range noise on a black surface at 25 m is twelve times the noise on a white surface at 10 m.

Sampling density is not the constraint. At the finest step the points fall 1.5 mm apart on a surface 10 m away.

Geometry adds error the specification sheet does not show. Soudarissanane and colleagues at Delft studied incidence angle, the angle between the beam and the surface normal. In a point cloud of a room they attributed 20 percent of the measurement noise to it. Returned signal weakens as incidence angle and range increase.

Edges are the second geometric effect. Tang, Akinci and Huber showed that a scanner returns inaccurate points at object edges, called mixed pixels. Those points are removed in processing, and widths and heights extracted from what remains come out smaller than the real dimension. In many of their cases the loss exceeded the tolerances in inspection manuals.

Registration is the last source. Each station produces its own cloud, and the stations are joined through shared targets or by matching overlapping surfaces. The National Park Service states the point directly: project accuracy depends on how well the scan positions register, and that depends on the operator's planning and experience. Historic England adds that survey control is essential where cloud-to-cloud registration is weak, around the outside of a building for example. Hope CGI registers to existing fixed targets, 150 mm target spheres, checkerboard targets or a combination.

Instrument performance has its own test standards. ASTM E3125-17, reapproved in 2025, tests point-to-point distance error against the manufacturer's stated maximum permissible errors. ASTM E2938-15 tests error along the ranging direction. Historic England's guidance calls for instrument certification and current calibration reports with a provider's proposal.

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03 Accuracy as a specification

"Accurate" is not a specification. Three published frameworks turn it into one.

The first is the USIBD Level of Accuracy Specification, v3.0. It defines five bands, each stated at the 95 percent confidence level, which the USIBD guide equates to two standard deviations.

Level	Tolerance at 95 percent confidence
LOA10	5 cm to 15 cm
LOA20	15 mm to 5 cm
LOA30	5 mm to 15 mm
LOA40	1 mm to 5 mm
LOA50	0 to 1 mm

The specification separates measured accuracy, the standard deviation achieved in the measurements, from represented accuracy, the standard deviation achieved once the measurements are processed into a model or drawing. It separates absolute accuracy, referred to a stated reference frame, from relative accuracy. It assigns levels element by element under CSI UniFormat. For each kind of accuracy it offers three validation choices, from no check to a check by independent measurement.

The second is the BIMForum Level of Development Specification. LOD states how far a model element is developed. It does not state how closely the element matches the building. At LOD 300 an element is represented as a "specific system, object, or assembly in terms of quantity, size, shape, location, and orientation." LOD 350 adds interfaces with other building systems. LOD 500 is a field-verified representation. A model has no single LOD; each element carries its own. An existing-conditions model therefore needs two numbers for each element: an LOD for content and an LOA for accuracy.

The third is GSA BIM Guide Series 03 (2009), GSA's guide for 3D imaging. It sets four levels by area of interest.

Level	Area of interest	Tolerance	Minimum artifact size
1	Total project area	±51 mm	152 × 152 mm
2	Subsection such as a building	±13 mm	25 × 25 mm
3	A floor level	±6 mm	13 × 13 mm
4	A room or artifact	±3 mm	13 × 13 mm

Hope CGI delivers scan data to USIBD LOA v3.0 at LOA30 unless the project calls for another level, and models the entire building in Revit at LOD 300.

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The table below sets the instrument against the tolerances a structure is built to.

Quantity	Value	Basis
Scanner 3D accuracy at 10 m, one standard deviation	2 mm	FARO specification
The same at two standard deviations	4 mm	2 × 2 mm
LOA40 band	1 to 5 mm	USIBD
LOA30 band	5 to 15 mm	USIBD
GSA Level 3 tolerance	±6 mm	GSA
AISC column plumb limit, 12 ft story	7.3 mm	3,658 mm ÷ 500
ACI 117 plumb limit, 12 ft height	11 mm	0.3% × 3,658 mm

At short range the instrument resolves deviations smaller than the tolerances the structure was built to. The model has to be held to its own standard, separately.

Bonduel and colleagues tested that directly. They scanned a 3,600 m² university building with a Leica P30, modeled it by hand in Revit 2017, and required relative LOA30: 15 mm at 95 percent. One floor element met LOA30 over 92 to 94 percent of its surface, with a 95 percent limit of 17 to 19 mm. Part of the miss was a modeling error: a sharp corner drawn where the floor has a radius. Tang and colleagues at Carnegie Mellon and NIST describe manual modeling from point clouds as time-consuming, subjective and error-prone.

Specify represented accuracy as its own line, and require a model-to-cloud deviation report as the proof.

04 What unmeasured conditions cost

The published figure for rework is 5 percent. Hwang, Thomas, Haas and Caldas analyzed 359 projects in the Construction Industry Institute database and report that the direct costs of rework alone often reach 5 percent of total construction cost. That figure covers every cause of rework. This paper cites no figure for the share caused by wrong existing-conditions data, because the research for it found no peer-reviewed study that isolates one. The percentages found in vendor marketing were published without sources and are not used here.

The record does contain a documented case and a mechanism.

The case is GSA's pilot at 26 Federal Plaza. Scanning took two and a half days. Converting the data to a 3D model took 40 person-hours. The result showed the wall described in Section 1 while the design could still change on paper. Calvin Kam, then manager of GSA's 3D-4D-BIM program, reported the result at SPAR 2006.

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The mechanism is timing. A dimensional error found in design costs a revision. The same error found after fabrication or installation costs the work. A scan moves the discovery of every visible dimensional error to the start of design.

05 For the architect

The deliverable is a Revit model of the existing building with the registered point cloud linked behind it. Revit links indexed point clouds in RCP and RCS format; other formats are converted through ReCap first. Revit places a linked cloud by shared coordinates when the cloud and the model use the same system, so the control decision made in the field carries into the model. Hope CGI delivers a Revit 2027 model with the entire building at LOD 300, in the architect's template and standards when they are provided, and the cloud in FLS, RCP, RCS or E57.

Areas come from measurement. Classification of work under the IEBC turns on area: a Level 3 alteration is one whose work area exceeds 50 percent of the building area (§604.1), and the work area is identified on the construction documents (§601.2). Both figures in that ratio come from the existing building. GSA scans for the same reason on the leasing side, where accurate space counts support billing to tenant agencies.

Level and slope are part of LOD 300. The definition requires location and orientation to be specific. Structure magazine's guidance on the specification makes the point with a roof: sloping members modeled flat are not LOD 300, however correct the plan looks. An existing floor that has settled is a sloping member.

Reliance is a contract question. AIA B101-2017 §3.1.2 entitles the architect to rely on the accuracy and completeness of services and information furnished by the Owner and the Owner's consultants. Who commissions the existing-conditions survey decides whose information it is. Settle that with the Owner, and with counsel, before the survey is ordered.

The method is non-contact. GSA cites the inspection of historic buildings without damage to their ornamentation among its reasons for scanning.

06 For the structural engineer

The scan gives the geometry of everything exposed: member locations, spans, bay spacing, bearing elevations, opening sizes, column plumb and floor profile.

Measured plumb turns a judgment into a comparison. A steel column either sits inside the 1/500 envelope it was erected to or it does not. Outside means original nonconformance or movement since. The scan does not say which. It establishes that the question exists, with a number attached.

Floors are measured as surfaces. Bosché and Guenet applied the two standard floor flatness procedures, Straightedge and F-Numbers, to scan points and obtained results that compare favorably with traditional measurement. The same data yields a deflection profile along any beam line or slab strip.

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Change is measured between two scans. A later scan registered to the same control as the first gives the movement between two dates. Historic England names long-term monitoring among the reasons to establish survey control.

Seismic evaluation has a stated data requirement. ASCE 41-17 §6.2 defines minimum, usual and comprehensive levels of data collection, and §6.2.4 applies a knowledge factor to account for uncertainty in the as-built data. Where drawings are insufficient, the standard closes the gap by condition assessment. A scan supplies the configuration part of that record for everything exposed: the layout of the gravity and lateral systems and the sizes of visible members. It supplies nothing on material properties or concealed connections, which the standard obtains by testing and exposure.

New work meets old at a tolerance mismatch. AISC 303 §6.4.1 holds the length of a member framed to other steel to ±1/16 in., 1.6 mm, for members 30 ft and shorter. The existing frame it meets was erected to 1/500 and has had decades to move. Call for LOA40, 1 to 5 mm, at the connection points and leave the rest of the building at LOA30. The USIBD specification assigns levels element by element for that purpose.

The limit is the surface. Concealed framing is not recorded, and Hope CGI shows it as assumed until it is exposed. Reinforcement, section loss behind finishes, material strength and foundations need other methods.

Hope CGI does not provide engineering services. Design, calculations and sealed drawings are the responsibility of the Arizona-registered Engineer of Record.

07 For the MEP and civil engineer

The scan records every system in view at the same accuracy as the walls: structure, duct, pipe, conduit, cable tray and equipment. Above a ceiling it records only what is opened to it. State in the scope which ceilings are lifted.

State which existing systems are modeled, and at what LOD. Structure magazine's guidance notes that above-ceiling coordination gains little when structure is at LOD 300 and MEP elements are at LOD 200, and that gravity plumbing lines must slope to qualify as LOD 300. Whatever is left unmodeled remains measurable in the point cloud.

Tie-in points carry the same logic as steel connections. Where new pipe or duct is prefabricated to meet an existing flange, call for LOA40 at that element.

On site work, the boundary belongs to another profession. Locating a property line or boundary corner is land surveying practice under A.R.S. 32-101 and is performed by an Arizona-registered land surveyor. The scan records the surfaces; it does not establish the boundary.

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08 Field time

Field time is governed by station count, and station count by the geometry of the building. Four of my own projects show the range.

Property	Area (SF)	Scan stations	SF per station
Butterfield Station ruins, Dragoon	1,200	87	14
Schieffelin Hall, Tombstone	14,540	320	45
Brophy Building, Douglas	29,000	578	50
Tombstone Chamber of Commerce	8,632	81	107

One mobilization records every visible surface, including the ones nobody thought to measure. A dimension that turns out to matter in the third month of design is taken from the cloud at the desk.

09 Limits and failure modes

- Line of sight. The scanner records what it can see. The Park Service lists elements hidden by adjacent features or vegetation, and the tops and undersides of structures, as out of reach.
- Dark and reflective surfaces. The Park Service names dark surfaces, glass, water, chrome and highly polished finishes. FARO's own figures give a black surface seven times the range noise of a white one at 10 m.
- Edges. Dimensions taken edge to edge from a cloud read small (Section 2).
- Materials and age. A scanner does not identify materials or distinguish one period of construction from another. The recorder notes those.
- Registration. A cloud is as accurate as its registration. Ask for the report.
- Modeling. A hand-built model introduces its own error, separate from the measurement (Section 3).
- Instrument class. Historic England puts tripod-based scanners at 2 to 5 mm on heritage work at 10 to 50 m and rates handheld and backpack units below that.
- Formats. Revit reads RCP and RCS. E57, defined by ASTM E2807, is the ASTM exchange format for 3D imaging data. The Park Service identifies proprietary software as an obstacle to long-term preservation of scan data.
- Professional boundaries. A scan is not a boundary survey and not a structural assessment.

A scan is evidence of visible geometry on the date of capture. It is nothing more than that, and nothing less.

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10 How to specify a scan

Item	State in the request	Basis
Intent	What the data is for: design base, structural analysis, fabrication or monitoring	USIBD: intent defines process
Extent	Spaces included; ceilings and finishes to be opened; exterior and site	Line of sight
Measured accuracy	LOA for each element group, absolute or relative, and the validation choice	USIBD LOA v3.0
Represented accuracy	LOA and LOD for each element group; a model-to-cloud deviation report	USIBD; BIMForum
Control	Targets or survey control, coordinate system and level datum	Historic England; Revit shared coordinates
Formats	RCP and RCS for Revit; E57 for exchange and archive	Autodesk; ASTM E2807
Records	Registration report and instrument calibration certificate	Park Service; Historic England
Model standards	Revit version, template and naming	Project requirement
Assumed elements	How concealed conditions are shown in the model	Project requirement

Each of the nine lines is a decision. Left out of the request, it is made by someone other than the designer.

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About this paper

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Hope CGI, LLC is a building and construction consultancy in Bisbee, Arizona: Construction Documents and LiDAR Imaging. From scan to permit set, one firm. Hope CGI captures, registers and models existing conditions in-house with its own FARO Focus Premium 70, operated by a USIBD- and FARO-certified principal and an in-house trained technician. No part of the scan or drawing production is subcontracted.

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