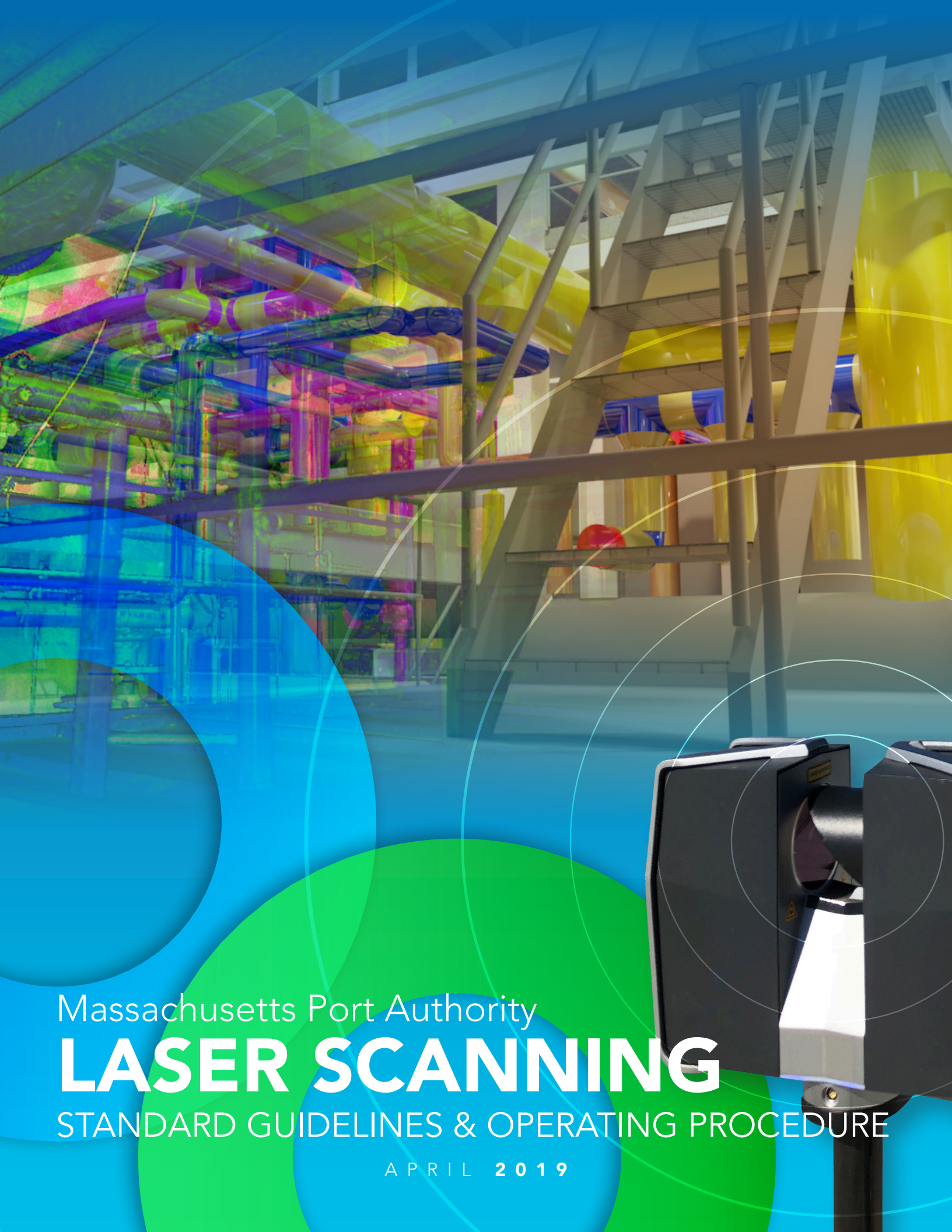


Massachusetts Port Authority

LASER SCANNING

STANDARD GUIDELINES & OPERATING PROCEDURE

APRIL **2019**

Table of Contents

List of Acronyms

ACT	Acoustic Ceiling Tiles
ASTM FF/FL	American Society for Testing and Materials Floor Flatness/Floor Levelness
BIM	Building Information Model
BIMxP	BIM Execution Plan
CD	Construction Documents/Drawings
CM	Construction Manager
CPM	Critical Path Method
DTIG	Design Technologies Integration Group
LiDAR	Light Detection and Ranging
LOA	Level of Accuracy
MEP	Mechanical Electrical and Plumbing
MPA	Massachusetts Port Authority
PPE	Personal Protective Equipment
QA/QC	Quality Assurance/Quality Control
SIDA	Security Identification Display Area
SLAM	Simultaneous Localization and Mapping
SOP	Standard Operating Procedure
TLS	Terrestrial Laser Scanning
TVP	Temporary Visitor Pass
USIBD	U.S. Institute of Building Documentation

This document was developed for MPA Capital Programs Department Digital Technologies Group (DTIG) with collaboration from MPA Survey, Bond Brothers Inc., Feldman and AECOM

PURPOSE AND SCOPE

The purpose of this guideline is to provide support on the scoping and implementation of existing condition surveys, Asbuilt conditions and record capture with a focus on terrestrial laser scanning technologies.

This process includes establishing a Standard Operating Procedure (SOP) for implementation of 3D surveys and the provisioning of deliverables to Massachusetts Port Authority (MPA) from its consultants and contractors. To enable the fullest utilization and maintain long-term usability of the captured data, it is essential that the data is both reliable in its internal survey control and have the potential for flexible future uses. Due to an array of available collection devices, various softwares, output file formats, and intended uses of the data, it is of primary importance that contractors and consultants provide MPA with deliverables that adhere to the specifications and guidelines herein.

Figure1: Laser scanning of airfield

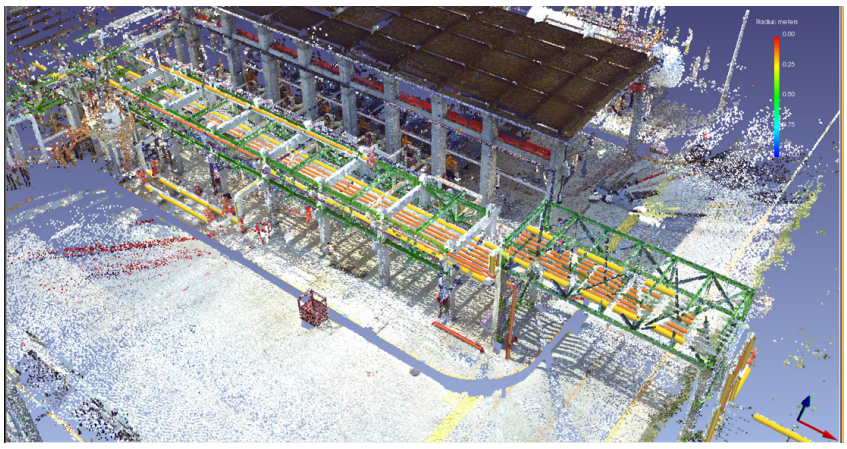


Figure 2: Point Cloud and BIM Integration

Figure 3: Model generated from point cloud

POINT CLOUD OVERVIEW

Generating point cloud data via laser scanning is a means to capture a precise and an accurate representation of existing facility conditions.

Due to increased accuracy and reduced turn time this technology has vastly replaced traditional data collection methods. In addition, when scoped and executed properly, the captured data can be used in conjunction with design and construction efforts to reduce the potential for project risk through increased coordination and a shared awareness of the existing conditions.

While there are multiple methods for delivering point cloud data points, each method has strengths and limitations. Awareness of the tradeoff between 'fit for purpose' and future limitations is crucial when determining the correct collection device that will maximize the usage of the resulting point cloud data.

Laser scanning activities add value through the reduction of project cost and the development of data that can be used for project validation, future development and planning efforts, and adding current condition information to survey activities.

While there are many scanning hardware options, this document focuses on mandated terrestrial laser scanning (TLS) a groundbased, active imaging method that rapidly acquires accurate, dense 3D point clouds of object surfaces by laser range finding.

The image below highlights the variety of laser scanners that are used for specific scanning applications, based on desired accuracy and data collection speeds.

Common point cloud data capture technologies include ▼

Static/Terrestrial Scanning

- 1mm Accuracy
- 900K+ points per second
- Color or B&W
- HDR Images
- Long Range (350M+)
- Valuation and Reuse
- Multi-Sensor

Handheld Scanning

- 1mm Accuracy
- LED light for low light
- Real time visualization of point cloud
- Access to tight spaces
- Integration with static systems

Photographic Scanning Systems

- Lower Accuracy
- Structured light (infrared) 3D sensor
- 20 seconds capture per scan/sweep
- Automatic 3D Data Registration
- Dependent on lighting

Vehicle Scanning

- 2cm accuracy
- Rapid collection (40 -50 mph)
- Useful for airfield pavement, minimizing disruptions to airfield operations

Mobile Scanning

- 2cm Accuracy (greater w/ control)
- 100K to 250K SF per day
- Geo-located maps and models
- Spherical Imagery
- 360 web interface for imagery
- Little to no shadowing
- Cannot access all spaces

UAS Drone Scanning

- 5cm accuracy
- 1cm accuracy (laser)
- Fast Aerial Point Cloud
- Remote operations in hazardous
- RTK Geo-located
- 2D& 3D mesh
- Digital terrain & mesh models
- Restricted use

RESOLUTION, ACCURACY AND MINIMUM FEATURE OF INTEREST

The different technologies available for point cloud data capture and delivery provide potential for alternate or variable future uses.

For instance a lower-resolution rapid approach may provide value for general scoping and positioning but this may be insufficient for defining boundaries, trade coordination, vertical discontinuances, and deformation analysis. Projects will have varying requirements that call for a higher level of accuracy and detail in a defined area. Currently construction grade scanning is required at MPA and provides the most benefit in terms of overall use throughout the project life-cycle and for development planning.

A multiphase scanning approach may be more appropriate due to project time lines, area coverage, and budget constraints and therefore using lower resolution planning phase collection methods may suffice. These scans can be enhanced at a later date with a highaccuracy survey, should a need arise.

Short example of resolution differences and the potential impact on use ▼

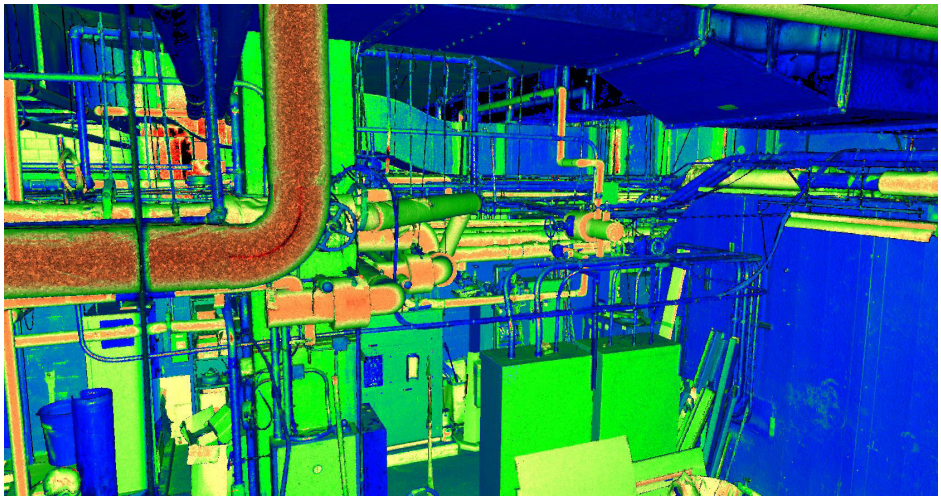


Figure 4: MEP scanned at construction grade, ¼ inch positional accuracy

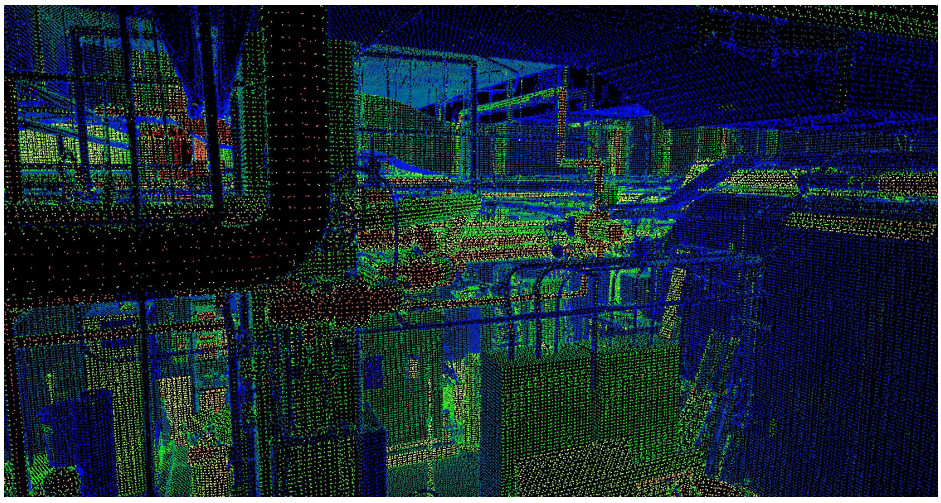


Figure 5: MEP scanned at lower resolution, 1 inch+ positional accuracy

The images above show point cloud data for various scanning applications. Without guidance as to the required detail, or minimum features of interest, the data sets provide vastly differing returns. When scoping and communicating requirements to a service provider it is key to be clear on minimum feature of interest for project areas while keeping in mind additional usages and potential future use for the data. Construction grade scanning is the default option at MPA.

PROJECT PHASING

As mentioned previously, the correct scan technology will be determined through an initial analysis of the data intent, as well as the project time lines, area of coverage, and budget constraints.

While lower-resolution data collection may be an option, MPA requires terrestrial scanning for all project work to maximize the return on investment by collecting highly accurate point cloud data at the onset of each project. The following sections outline the phased approach for project scanning.

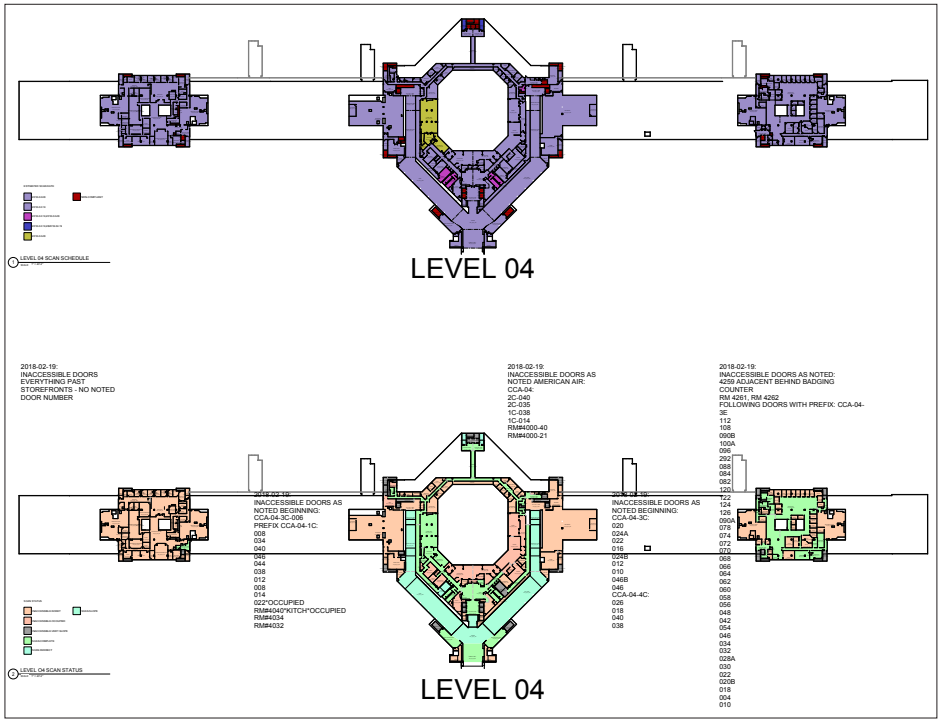


Figure 6: Scheduling scan activity and accurate record keeping of progress is vital when capturing large areas

Pre-Design Phase

Early adoption of laser scanning in the project design process allows for the development of a usable Building Information Model (BIM) with greatly increased accuracy. BIMs form the foundation for the design consultant to pre-coordinate the project scope of work and this process can help mitigate the potential for construction coordination risk.

Scanning allows for the maximum return on initial investment through long-term utilization of collected data across the project team. Another potential benefit is the reduction in redesign and project vision due to potential existing condition interferences.

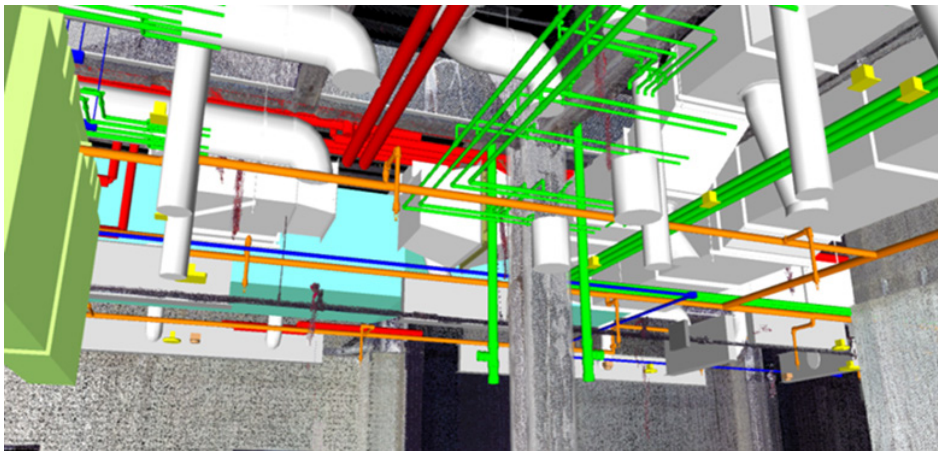


Figure 7: Point Cloud Scan overlaid with BIM for MEP Coordination

Design Phase

Schematic or Development laser scanning of existing conditions during the design phase provides the ability to both coordinate site conditions with archived as-built documentation, and to identify any initial issues with early model development. Conducting and resolving conflicts via a spatial coordination analysis between the existing conditions point cloud files and the design model, prior to construction is required and thus reducing potentially costly changes post submission of 100% construction documents/drawings (CDs). Implementation at this time will cause additional work for the design team but reduce the risk of rework during construction. This must always be considered on a project

basis as the benefits out way the upfront expense.

Construction Quality Assurance / Quality Control and As-built Survey

During construction, ClearEdge3D Verity can be used to validate laser scanned and constructed elements against construction documents within the software application.

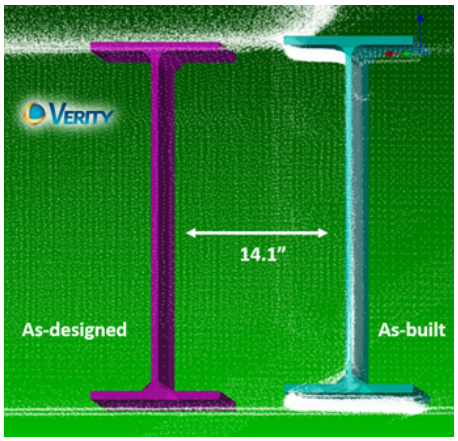


Figure 8: Construction verification against BIM

Point cloud capture and analysis must be performed at key project milestones that correlate to project deliverables. Milestones will vary by specific project type and should be established and validated prior to project kickoff.

Required are the following:

- Prior to slab pour for subsurface utilities and or rebar placement
- Post slab pour for slab deformation and ASTM FF/FL requirements.
- Structures to be scanned post slab installation for beam deflection
- In-wall utilities prior to wall finishes
- Above ceiling utilities post grid and framing, prior to Acoustic Ceiling Tiles (ACT) and gypsum
- Prior to trench infill for site utilities
- Finished conditions as-built

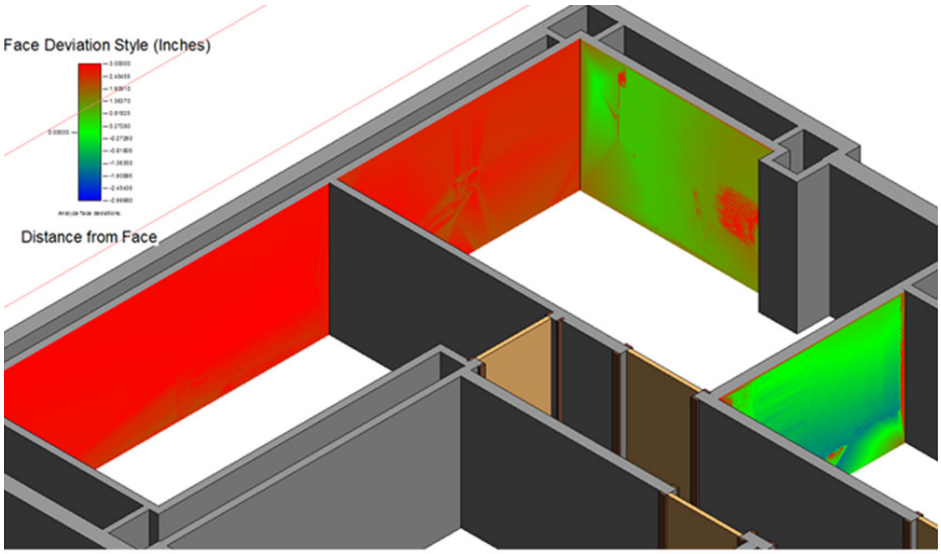


Figure 9: Scan data analysis to identify Wall Face Deviation

Figure 10: Point Cloud As-Built Verification against BIM

Close coordination will be required between project Construction Manager (CM) or General Contractor (GC) and survey provider and managed by MPA. This ensures appropriate establishing of survey control and timing to capture all required phases. Laser scanning activities shall be included in the CMs/ GCs Critical Path Method (CPM) schedule as areas could be scanned at more than one interval (wall utilities, ceiling utilities, final finish). Meta data documentation and multiphase exports are helpful for future use.

Project scanning that occurs during the construction phase must always be of construction grade; ¼ inch accuracy and tied to survey control.

PROJECT CLOSE OUT/FINAL AS-BUILT SURVEY

Post construction as-built or 'button up' documentation provides MPA and future stakeholders with a valuable design resource for future development.

The final as-built existing conditions prior to occupancy should be in addition to construction phase scanning of final MEP/utility installation. The resulting point cloud deliverable should form part of the handover package, supporting QA/QC of the record model upon project close out. This process should be highly coordinated with the CM/GCs and incorporated within the BIMxP.

Figure 11: Panoramic High Resolution Image from Scanner provides an immersive experience of the facility for developing an as-built or turnover of a project deliverable

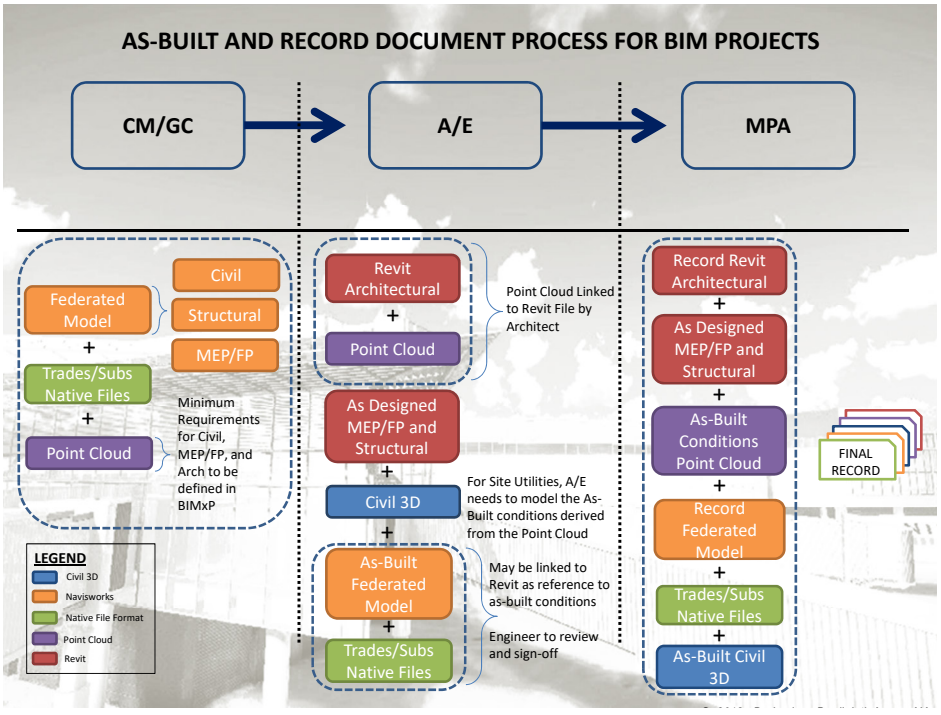
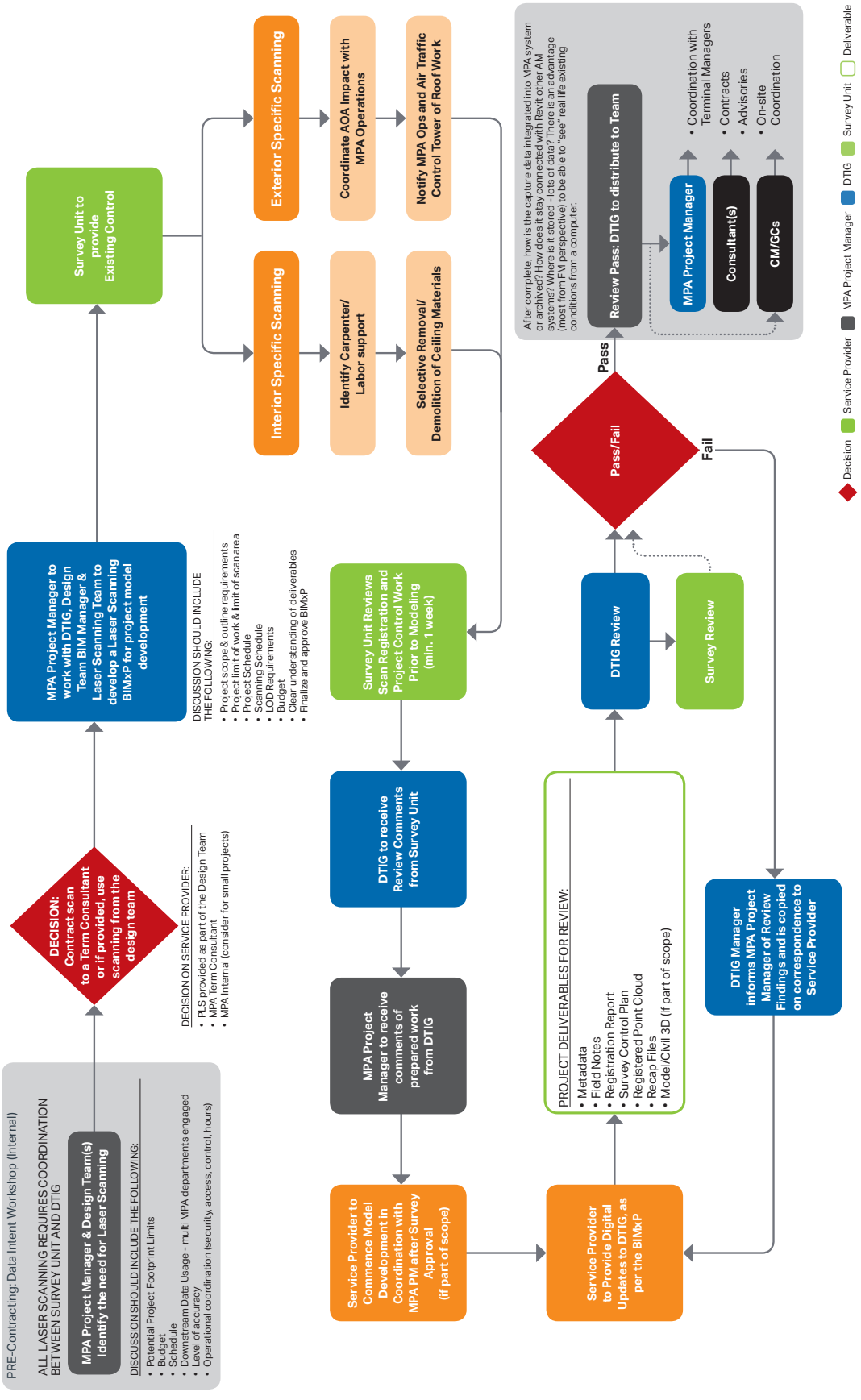


Figure 12: Scan Deliverable Workflow (image taken from AS-BUILT AND RECORD DOCUMENT PROCESS FOR BIM PROJECTS, January 2018)

PROCESS FLOW CHART



IMPLEMENTATION

The following process will be initiated by MPA Managers if their project requires the use of laser scanning.

Please note that all coordination with Terminal Managers, project stakeholders, contract discussions, advisories, and onsite coordination should be conducted by the Project Manger or Project Manager's Consultant.

Implementation (Scoping Procedures)

Point cloud documentation is required by MPA at specific project milestones. The use of laser scanning should be considered during the development of budget, scheduling, project requirements, and included within Designer and Construction Manager RFPs. During construction, the Project Manager shall work with the Construction Management (CM) CM/GC firms to ensure point cloud capture is implemented at the required key milestones outlined above. The BIMxP shall be developed cohesively by the DTIG PM, the MPA Project Manager, primary design consultants and CM/GCs

1. MPA Project Managers shall identify Capital Projects in which point cloud delivery will be required during the projects design/build lifecycle. Team discussion must occur with Design Technologies Integration Group (DTIG) and Survey Unit to determine survey needs including potential project footprint, viability of any previous capture in project area, budget, Level of Development, Building Information Model (BIM) requirements, deliverables, and schedule.
2. The decision should be made by the project team to use a term Consultant, project Consultant, or in-house scanning. MPA Project Managers should establish if the scope area has already been captured and the potential to reuse existing data.
3. The MPA Project Manager will work with DTIG and the Design Team (when applicable) to develop a BIM Execution Plan (BIMxP) to set the scanning/point cloud delivery scope of work and drive specifications with maximum potential for future use.
4. Scanning provider should be briefed on, and understand the BIMxP (once defined) or the minimum features of interest and key trade coordination conditions impacted by point cloud resolution and accuracies.
5. DTIG and Survey Unit advise on applicability of specific laser scanning approaches. SLAM technologies, mobile LiDAR, terrestrial scanning have differing end accuracies and resolutions. 'Fit for purpose' evaluation will impact potential end usage of scanning deliverables:

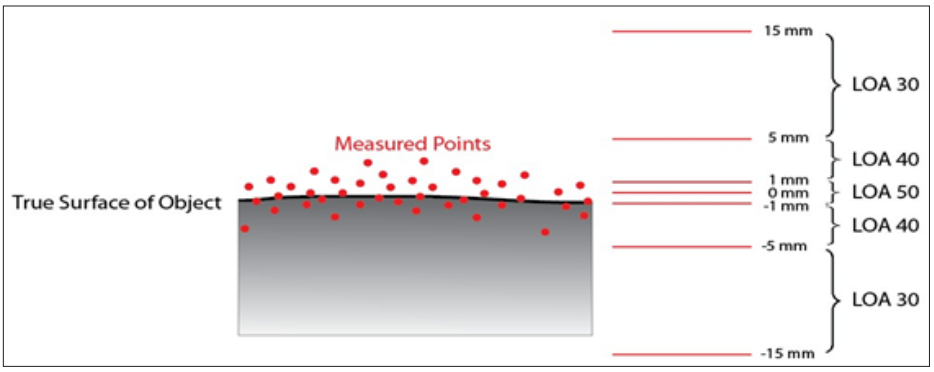


Figure 13: USIBD Level of Accuracy (LOA)

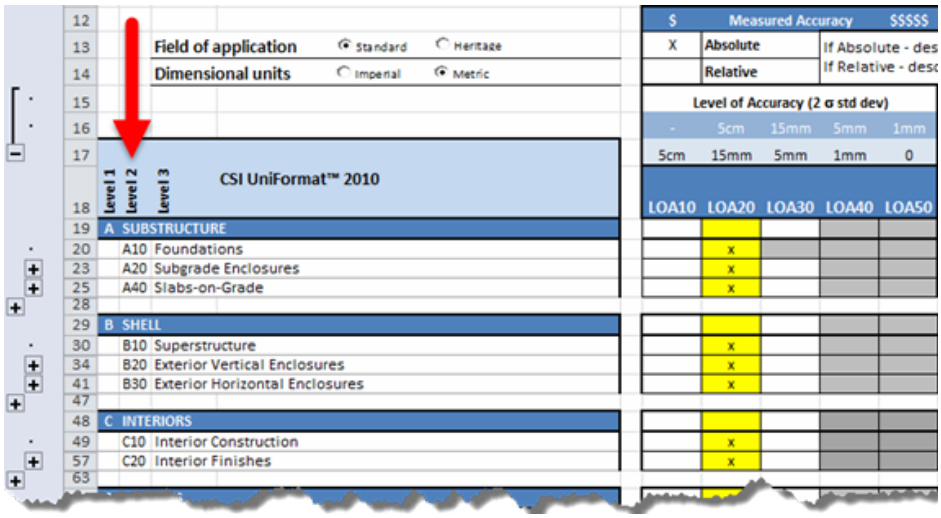


Figure 14: LOA per UniFormat

i. SLAM based scanning – interior feasibility and space planning. Rapid collection but low resolution and accuracy (multiple inches)

ii. Mobile scanning – rapid large area infrastructure/road way mapping (sub inch)

iii. Terrestrial laser scanning – high detail engineering grade scanning (1/4 inch), slower collection (preferred option).

i. For terrestrial scanning, the use of USIBD LOA specification is required.

6. All scans should be colorized in typical lighting conditions. Only in low-light conditions may color be omitted and when first communicated with MPA Project Manager where color will not be captured. Color capture can double field time and be sensitive to light levels.

Implementation (Survey Control Requirements)

1. All laser scanning survey to be performed under review of a Massachusetts registered Professional Land Surveyor.
2. MPA Survey Unit shall provide the service provider with existing horizontal control and vertical benchmarks relative to the project. Any scanning must tie directly to MPA survey control.
3. Scanning provider to perform additional adjusted closed traverse to enhance local area control through or around project area as necessary, to ensure acceptable scanning target constraints and QA. For building interiors, floor tile intersections shall be utilized as control points when finished surfaces are present. No permanent interior monumentation should be installed without prior MPA consent.
4. Any additional control used shall be submitted to MPA Survey Unit for review and record.
5. All control to be provided in accordance to current MPA Survey SoP (NAD 83/NAVD88) and additionally a project specific local coordinate system as defined by DTIG, Survey Unit, and Design Team.

Figure 15: B&W Point Cloud

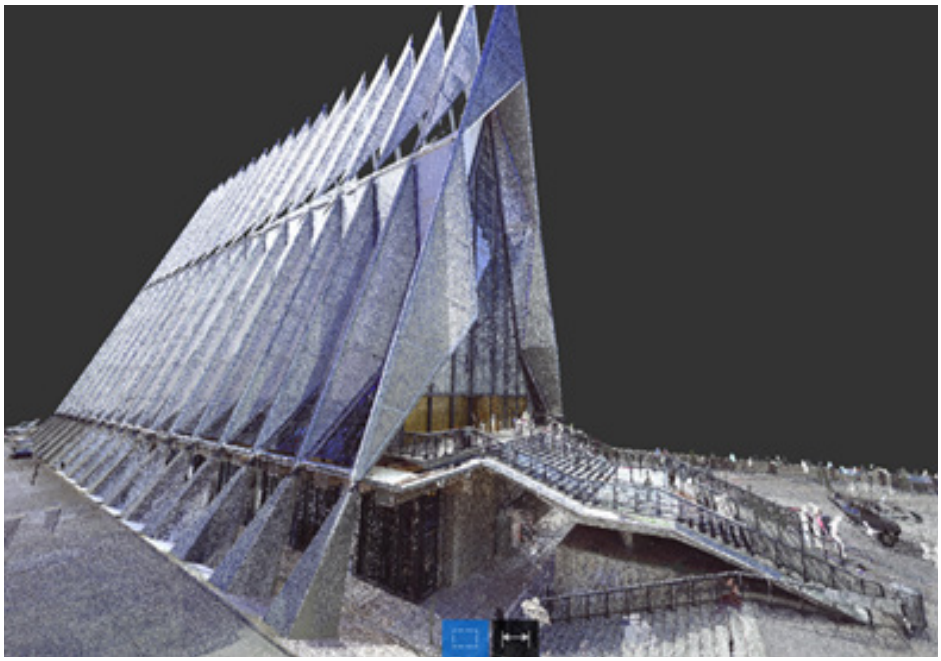


Figure 16: Colorized Point Cloud

Implementation (Preplanning)

1. Confirmation on requirements for survey personnel SIDA badging or TVP dependent on project location (airside/public landside). Due to the lead-time involved in the badging process, any SIDA requirement should be

communicated at the earliest opportunity.

2. MPA Project Managers should ensure that proper coordination and advisories are in place prior to the beginning of laser scanning and data capture. The MPA Project Manager or appointed Resident Engineer is responsible for coordination with Terminal Managers, MPA Operations, Aviation Security, and any impacted Tenants
3. Service provider to submit work plan for review by the MPA Project Manager. Work plans should use Massport's standard template and include all safety and key personnel contacts. The work plan should be maintained and updated through the projects duration allowing for required notification timelines.
4. Tenants and terminal managers should be informed that temporary scan targets will be around project scope areas while survey is taking place and should not be touched.

Implementation (Field Procedures)

1. Scanning data capture is performed through a series overlapping scans and interconnected areas spread across the scope area and related to site control. As scanning is line-of-sight only, collection is to finished surface only and cannot connect around corners or see through solid surfaces. Consideration should be given to scan coverage for allowing connection back to site control as well as those required to cover scope area.
2. Additional scanning targets (checkerboard or sphere) may be used to ensure best relation between scan locations. Overlapping scan data between connected locations can be used to provide additional constraints. These temporary targets shall be removed by the scan group within one week of completing the scan.
3. Any instances of fully targetless scanning, such as for above ceiling integration, can only be used when following communication with the project team, DTIG, and the Survey Unit, and when lower accuracies are acceptable in comparison to required coverage.
4. No permanent monumentation of interior control should be set by consultant without prior authorization. Tile intersections and similar reference features must be utilized and documented as the basis for fixed target control points.
5. Differential levelling to be performed to validate primary control and QA stacked floor levels and provide spot grade checks.

Figure 17: Temporary scanning target placed along slurry wall for concrete tolerance laser scan

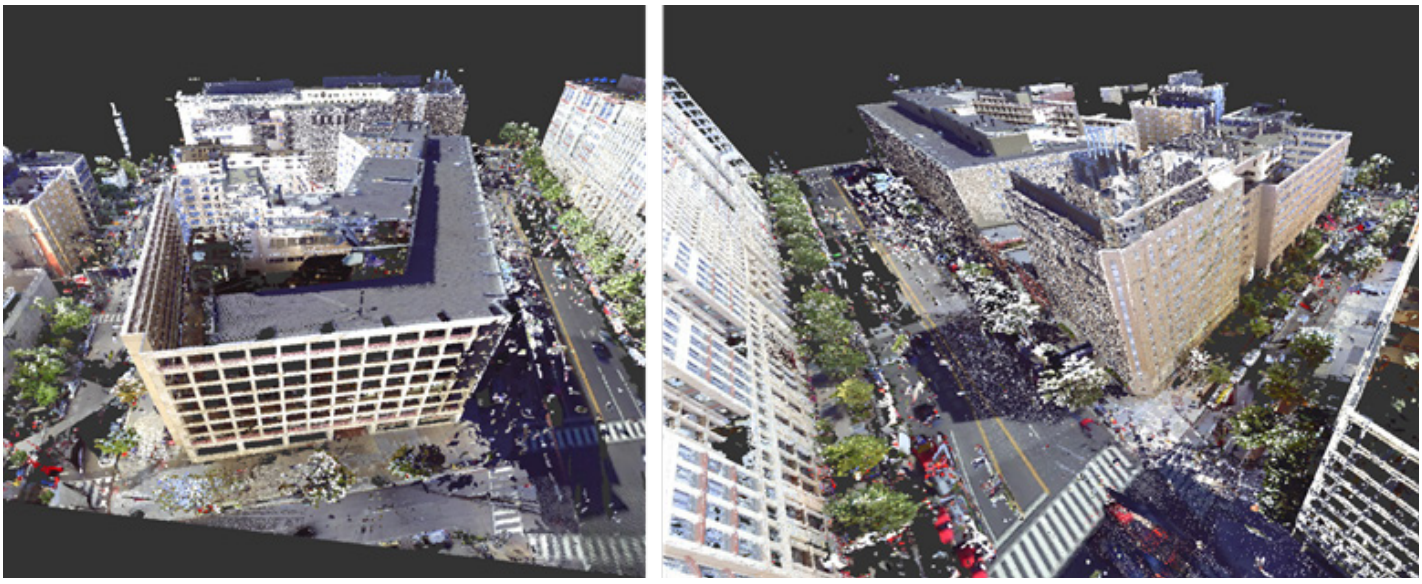


Figure 18: This model is comprised of forty six (46) exterior scans that have been combined into a single model

6. All field staff must be properly outfitted with standard personal protective equipment (PPE) in accordance with on-site health and safety requirements. In nonconstruction areas crews should be clearly identifiable to the public via high visibility clothing. Inside terminals, protective barriers should be utilized to separate scanning equipment from the public.
7. Point cloud registration reports to be provided to MPA Survey Unit for review. If multiple phases of scanning are taking place, then final registration reports should be provided at data delivery.

Implementation (Site/Horizontal Specific)

1. Coordination of field crews in and around active apron areas and gates may require additional personnel for safety. Consideration should be given as to night work if preferable.
2. Any exterior roof work must ensure additional notification to MPA Operations and Air Traffic Control Tower every time exterior roof areas are occupied.
3. Active taxi areas should be captured remotely whenever possible. If occupation is required to achieve required resolution this must be done in conjunction with a Properly badged and equipped MPA escort.

Implementation (Interior/Vertical Specific)

1. MPA Project Manager should work with Service provider to identify additional support required to accurately capture the scope area. Union carpenters are often required to remove and replace ceilings. Additional cleaning may be required post survey where tiles have been removed.
2. Work performed during public high traffic times should use mobile barriers to create a safety zone if an area is to be occupied for an extended time. Cones can always be used along with staff remaining in attendance when scanning is moving at a rapid rate.
3. Interior scanning is likely to require the removal of ceiling materials (ACT, Slat, etc). Additional setups should be performed when scanning above ceiling to ensure accurate relation to ground level control and overlapping scans. All ceiling materials should be replaced in their original locations at the end of each shift unless in prior agreement with MPA and relevant stakeholders.
4. When scanning above ceiling ensure that the scan head clears remaining ceiling materials as fully as possible to provide best coverage. Where clearance allows scanning should be performed at multiple heights above ceiling in dense areas.
5. It is recommended that scans be conducted during the evening when travel times are light, and minimal passenger traffic.

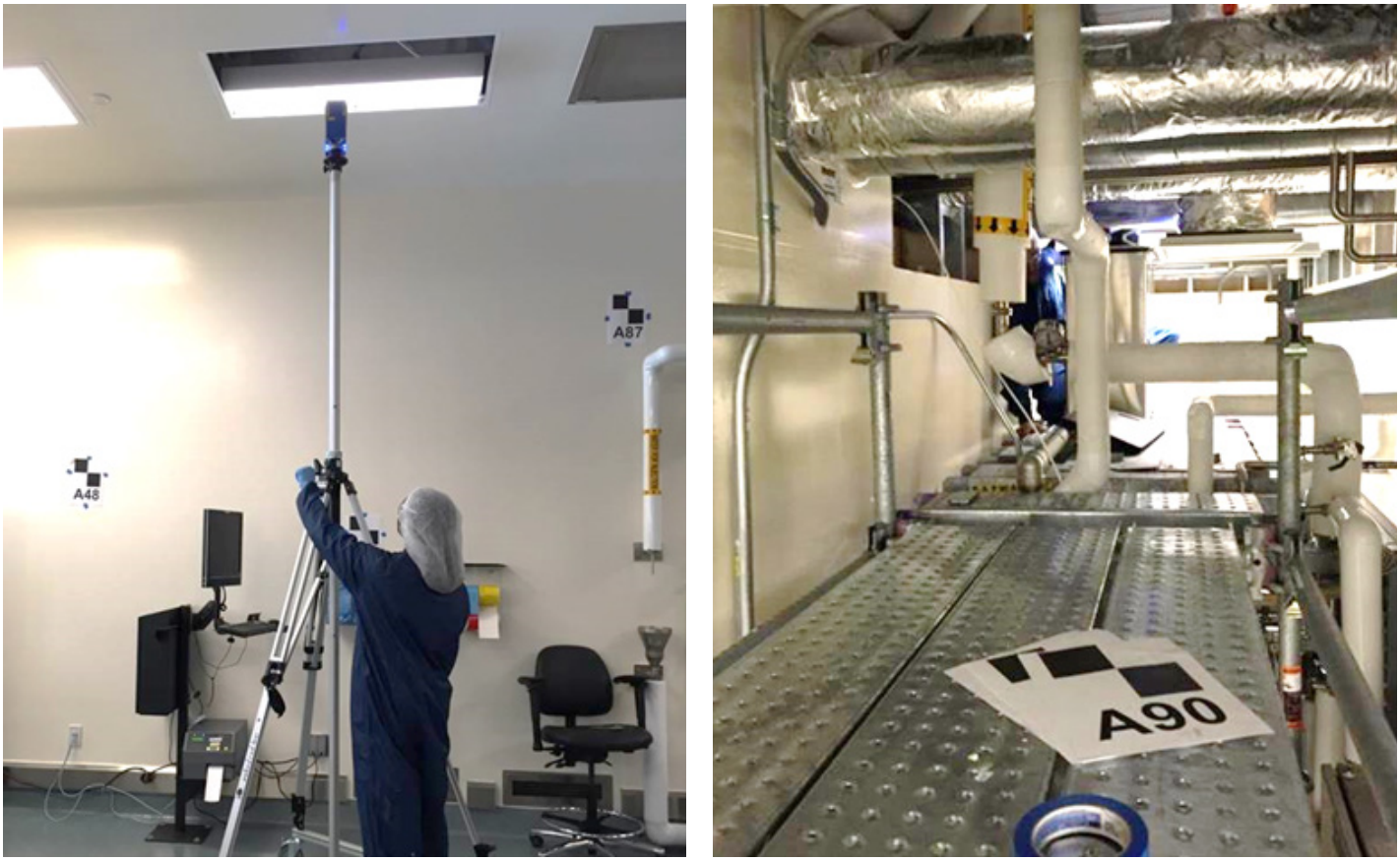


Figure 19: Laser scanning of above ceiling space accomplished with telescoping tripods. Targets distributed around above ceiling MEP

SUBMISSION & REVIEW

1. Following data capture, scanning data should be processed and registered using the relevant proprietary software for the service provider's equipment.
2. Registration for construction grade terrestrial laser scanning should have a global accuracy of ¼ inch across survey area.
3. Any reflective false positives or 'through and through' glass and mirrored data should be removed
4. During data registration, consultant is responsible for removing any persons and/ or legible privacy information from the scan data (public, end users, license plates, TSA/Airline information) prior to creation of point cloud files.
5. Point cloud to be provided in two coordinate systems:
   a. Current Massport Survey SOP (NAD83(2011) NAVD88 U.S. Survey Feet)
   b. Local coordinate system/ Campus system
      iii. MPA Campus area control is based on a direct coordinate value reduction of current NAD83 control values. The Northing and Easting value reductions for specific areas can be found int the table below. Vertical Datum to remain consistent with NAVD88 benchmark control. Logan Campus coordinate system provision allows DTIG to relate all deliverables provided by subcontractors directly without spatial limitations cause by current software platforms with large coordinate systems. Refer to local coordinate SoP for process and FAQ.
      iv. Logan campus coordinate values for exiting control to be provided to consultant prior to scanning. Data should be provided in both local campus and current MPA Port Survey SOP coordinate versions
      v. Consultants and design team members will need to utilize scope boxes within Revit to allow for squaring up of modeling views when using the Campus coordinate system.
6. Data deliverables should include:
   a. Metadata documentation (PDF/Word)
   b. Scans/photos of field notes (PDF/JPG)
   c. Registration report (PDF/Excel/ Word)
   d. Survey Control plan (PDF/CAD) including benchmarks
   e. Registered point cloud with full point information (FLS, PTX, PTG, ZFS, E86 or similar) suitable for automated modeling.
   f. Registered point cloud in nonvendor specific format (ascii text or las) with XYZI (plus RGB if applicable).
   g. Register point cloud in Autodesk RCS/RCP format
7. Consultant will be responsible for coordination of point clouds to existing project datasets.
8. A project specific laser scanning checklist (Appendix A) will be filled out during this process and will be required as part of final submission.

CAMPUS AREA	NORTHING REDUCTION	EASTING REDUCTION
Hanscom	2,990,000	700,000
Boston	2,945,000	770,000
Worcester	2,915,000	540,000
Logan Express – Braintree	2,900,000	780,000
Logan Express – Framingham	2,930,000	680,000
Logan Express – Peabody	3,020,000	790,000
Logan Express – Woburn	3,000,000	750,000

Figure 20: MPA northing and easting reduction values

9. Meta data report should include:
   a. equipment used
   b. software used
   c. overall (global) survey accuracy
   d. registration quality
   e. area coverage map showing unedited data capture and scope area
   f. date/time
   g. project phase
   h. MPA project number
10. Final Delivery to be on physical external storage (USB/HDD). Mid-point deliverables can be via digital download in agreement with project team. Final delivery should adhere to the following Folder structure::

PROJECT NUMBER\RCS-RCP
\FULL CLOUD
\DECIMATED CLOUD
\PHOTOS
\RAW DATA
\METADATA

Files names should adhere to following syntax: PROJECT-AREA-LEVEL-PHASE-DATE

11. Survey Unit to review submissions for achieved accuracy and QA.
12. DTIG will update Laser Scanning map with project boundaries.

Appendix A - Scanning BIM Execution Plan

Phases		Model Development from Point Clouds Existing Conditions Pre-construction		
		R/P	Notes	LOD
A				
	Foundations			
	Standard Foundations	**P**	Comments	**300**
	Special Foundations	**CM**		
	Subgrade Enclosures			
	Walls for Subgrade Enclosures	**CG**		
	Slabs-on-Grade			
	Slabs			
B				
	Superstructure			
	Floor Construction			
	Roof Construction			
	Structural Framing			
	Structural Columns			
	Exterior Vertical Enclosures			
	Exterior Walls			
	Exterior Windows			
	Exterior Doors			
	Exterior Louvers			
C				
	Interior Construction			
	Interior Partitions			
	Interior Windows			
	Interior Doors			
	Interior Grilles			
	Raised Floor Construction			
	Suspended Ceiling Construction			
	Interior Finishes			
	Wall Finishes			
	Flooring			
	Stair Finishes			
	Ceiling Finishes			
	Interior Finish Schedules			

D				
Conveying				
	Vertical Conveying Systems			
	Horizontal Conveying Systems			
	Material Handling			
Plumbing				
	Domestic Water Distribution			
	Sanitary Drainage			
	Building Support Plumbing			
	General Service Compressed Air			
	Process Support Plumbing			
HVAC				
	Facility Fuel Systems			
	Heating Systems			
	Cooling Systems			
	Facility HVAC Distribution System			
	Ventilation			
	Special Purpose HVAC Systems			
Fire Protection				
	Fire Suppression			
	Fire Protection Specialties			
Electrical				
	Facility Power Generation			
	Electrical Service and Distribution			
	General Purpose Elec. Power			
	Lighting			
	Misc. Electrical Systems			
Communications				
	Data Communications			
	Voice Communications			
	Audio-Video Communication			
	Distributed Communications and Monitoring			
	Communications Components			
Elect Safety and Security				
	Access Control and Intrusion Detection			
	Electronic Surveillance			
	Detection and Alarm			
	Electronic Monitoring and Control			
	Electronic Safety and Security Supplementary Components			
Integrated Automation				
	Integrated Automation Facility Controls			

E				
Equipment				
	Vehicle and Pedestrian Equipment			
	Commercial Equipment			
	Institutional Equipment			
Furnishings				
	Fixed Furnishings			
	Movable Furnishings			
F				
Special Construction				
	Special Function Construction			
	Special Facility Components			
	Athletic and Recreational Special Construction			
	Special Instrumentation			
G				
Site Improvements				
	Roadways			
	Parking Lots			
	Pedestrian Plazas and Walkways			
	Airfields			
	Athletic, Recreational, and Playfield Areas			
	Site Development			
	Landscaping			
Liquid and Gas Site Utilities				
	Water Utilities			
	Sanitary Sewerage Utilities			
	Storm Drainage Utilities			
	Site Energy Distribution			
	Site Fuel Distribution			
	Liquid and Gas Site Utilities Supplementary Components			
Electrical Site Improvements				
	Site Electric Distribution Systems			
	Site Lighting			
Site Communications				
	Site Communications Systems			
Miscellaneous Site Const				
	Tunnels			

MASSACHUSETTS PORT AUTHORITY
CAPITAL PROGRAMS AND ENVIRONMENTAL AFFAIRS

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