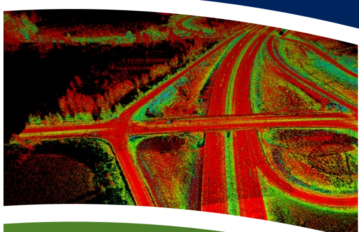
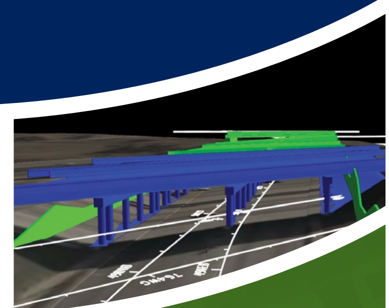
Guide for

Using 3D Engineered Models for Construction Engineering and Inspection

Winter 2017





3D Engineered Models:

Schedule, Cost, and Post-Construction

*An **Every Day Counts** Innovation*

U.S. Department of Transportation

Federal Highway Administration

Contents

This guide highlights key considerations for deploying three-dimensional (3D) engineered models for construction inspection. These include generating workflows for activities before, during, and after construction through partnering agreements; updating or creating new specifications and workflows for inspection work; and providing the necessary training and tools for construction staff to be successful.[1]

1 This document is based on guidance provided in the following sources:

Maier, F., Mallela, J., Torres, H., Ruiz, J. Mauricio, and Chang, G., 2015. *Automation in Highway Construction Part II. Final Report*. Federal Highway Administration, McLean, VA.

Federal Highway Administration (FHWA), 2015. *EDC-3 3D Engineered Models: Schedule, Cost and Post-Construction Workshops and Peer Exchange Training Materials*. Washington, DC.

Maier, F., Chummers, L., Pulikanti, S., Struthers, J., Dr. Mallela, J. and Morgan, R., 2016. Utilizing 3D Digital Design Data in Highway Construction: *A Case Study*. *Draft Final Report*. Federal Highway Administration, McLean, VA.

Using 3D Engineered Models for Construction Engineering and Inspection

Introduction

In recent years, state transportation agencies (STAs) have made investments in creating 3D engineered models in design, but few STAs are realizing the benefits of using these models in construction engineering and inspection. Agencies that use the models and related survey technology report time savings, safety improvements, increased confidence and transparency in measurements, increased confidence in verifying stakeless construction, and an ability to keep pace with accelerated construction methods such as automated machine guidance (AMG).[2] For example, on the Parksville Bypass in New York, inspectors noted time savings in a range of tasks, shown in Figure 1.

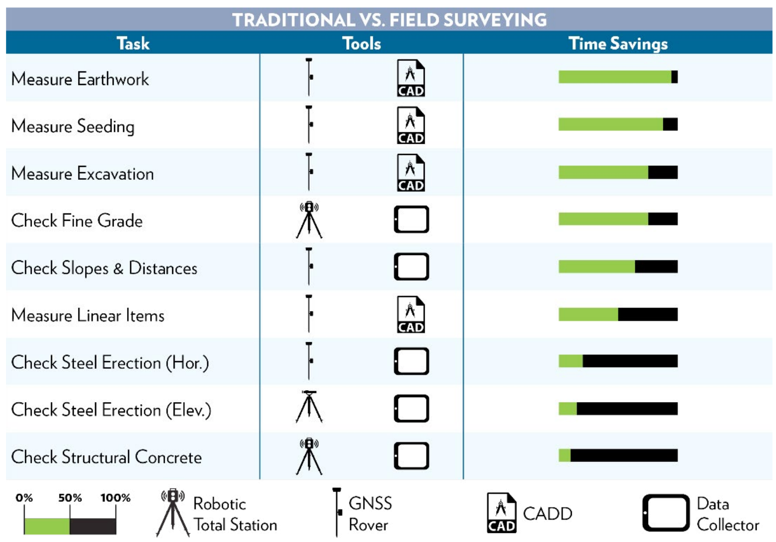


Figure 1: Time savings using 3D models in construction engineering and inspection on the Parksville Bypass.

Recent advances in construction technology create an opportunity to significantly increase safety, accelerate project delivery, and reduce the number of change orders and claims. The technologies include AMG, mobile devices, and modern surveying equipment such as robotic total stations (RTS), LiDAR[3], and small unmanned aerial systems.

A critical success factor for AMG is simultaneously using survey technology for real-time quality control (QC) feedback. The survey technology also enables collecting more and better data efficiently in a safer manner. Many construction inspectors continue to use traditional tools that are inefficient and may put workers in unsafe situations to measure quantities or verify results. As AMG

2 Dean, Brett. *Parksville Bypass CADD/Survey Tasks Performed*. New York State Department of Transportation. Albany, NY: s.n., 2014. p. 3

3 Light Detection and Ranging.

adoption among contractors accelerates, the technology divide between contractors and inspectors is deepening, putting many resident engineers in a difficult position. While the inspection team often lacks the capability to use 3D data, there are missed opportunities for preemptively catching issues; verifying construction in real time; and collecting a rich, 3D record of construction that supports daily diary entries and measurements for payment. Moreover, inspectors are challenged to keep pace with AMG construction without modern tools that use 3D data. Consequently, many STAs are finding ways to use the same surveying equipment as contractors use to identify locations on the job site to perform quality assurance (QA) functions and to measure pay quantities.

Challenges for inspectors in using 3D engineered models in construction inspection tasks include:

- a lack of equipment and software to use the 3D models in the office and in the field
- a lack of familiarity with or confidence manipulating 3D models
- a need for a reliable set of 3D data that accurately reflects design intent and field conditions
- an unfamiliarity with field survey methods and tools
- the need to learn how the 3D data and surveying equipment relate to the contract plans, specifications, and field conditions

Thus, resident engineers and inspectors need a practical means of overcoming these challenges to realize the mutually beneficial goals of faster, safer construction that is more accurately and more transparently measured and accepted.

Collaboration through Construction Partnering

Construction partnering in the past was a dispute resolution tool used to minimize claims. However, the concept has evolved into a scalable collaboration process between contractors and STAs. The objectives of partnering are to reduce claims and associated costs; provide a framework for improved quality; reduce or eliminate conflicts, waste, litigation, and budget overruns; and ensure timely project completion. Using 3D technologies and innovative workflows for construction and inspection can help meet all of these goals.

STAs and contractors can partner in using the 3D data to perform pre-construction reviews. Risks of quantity differences and constructability challenges (including mass balance issues that affect haul distances) can be minimized and mitigated through joint decision-making for field fits or adjustments to optimize pavement material quantities. Through transparent teamwork with a single 3D engineered model, the STA and contractor can avoid the need to exchange data, overcome the disparity in 3D modeling capability, and agree on a set of common 3D data reflecting the design intent to use for AMG and verification.

Using 3D models and field survey equipment successfully requires that all potential sources of measurement error are controlled by using the same control network, survey setup, 3D data, and instrument type to inspect the work as was used when it was constructed. This requires close collaboration with the contractor, which naturally lends itself to construction partnering to streamline the process.

Key elements to consider in controlling sources of measurement error:

- Survey plan, including the control network, source of real-time kinematic (RTK) correction for global navigational satellite systems (GNSS) for all positioning applications, and survey method to manage grid scale factor distortion
- Maintenance plan for site passive control
- Unique identification and management of the 3D Model of Record to be used for construction (including version control), inspection, and quantity calculations
- Positioning methods for AMG construction, stake-out, and inspection
- Methodologies for contractor QC and inspector QA observations
- Timing and notification requirements to verify and measure completed work
- If applicable, the contractor's furnishing of hardware, software, and training for inspectors
- Protocols for calibration and daily validation of field technologies

Contract Language for 3D Engineered Models

Construction specifications and special provisions should provide language that clarifies the contractual aspects associated with using 3D models in construction, such as:

- Sources of 3D data, its authorized uses, and its hierarchy for controlling work
- Managing changes that do not affect the design intent, including version control
- Management of errors and omissions in the contract documents
- Uses of 3D models in the contractor's quality control
- Contract requirements regarding accuracies, tolerances, and means for measuring and paying quantities for different activities, including any adjustments to existing pay items
- Issue resolution process and documentation protocols

Several existing sections of the standard specifications can be modified to accommodate these considerations, most of which are located under the Controlling Work section.

Risk Mitigation through Survey Verification

Survey control is the fundamental connection between a 3D model and field conditions. It is used to create the 3D coordinates prior to design and then to place the 3D design onto the earth. Survey data verification should be a key component in the contractor's overall quality plan. The contractor's control and localization plan should be developed by a qualified individual based on the STA's survey manuals and specifications. The California, Oregon, and Utah Departments of Transportation have incorporated modern surveying technologies into their survey manuals or specifications, which can serve as references.

3D Engineered Model of Record Used for Construction

The Model of Record is a set of 3D data files that represent different components of the roadway design intent, as shown in Table 1. The design intent may be communicated in a variety of ways, including plans with cross-sections at regular stations and in 3D models of varying detail. Design functions can tolerate significantly more approximation in the models than can construction functions.

Table 1: Example of 3D design data files, schema, and uses.[4]

Example of 3D Design Data	Open Data Formats	Example of Data Use
Geospatial metadata	PDF report	Defining the datum and reference frame for the 3D coordinate system, as well as the units
Primary and secondary control	LandXML, CSV	Verifying horizontal and vertical positioning
Alignments and profiles	LandXML	Verifying horizontal layout and grades, measuring areas and lengths, locating features
Surfaces	LandXML	Verifying material depths, computing volume quantities, creating as-built records
2D or 3D line strings	DXF	Verifying horizontal layout and grades and structure elevations, creating as-built records
3D solids or meshes	DXF	Computing volumetric quantities
Subsurface utilities	LandXML, IFC, DXF	Verifying location and elevations, calculating quantities, creating as-built records
Bridges and structures	IFC, DXF	Verifying location and elevations, calculating quantities, creating as-built records
Non-graphical information	XML schemas for spreadsheets and text documents	Calculating quantities, reviewing reference material

Usually, design models need to be densified to provide the detail needed to ensure consistent grade control with AMG systems. Figure 2 compares the typical amount of detail and approximation in a design model to the typically increased amount of detail and reduced amount of approximation in a construction model. The design intent is based on an assumption of field conditions reflected in the survey data. Once the survey has been verified, there may be a need or an opportunity to revise the 3D model to make the design intent match actual field conditions.

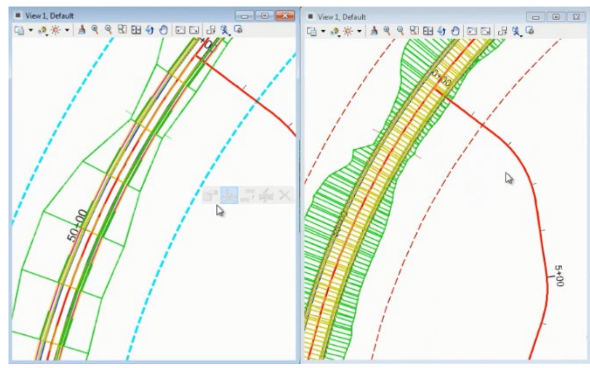


Figure 2: Typical 3D model detail for design (left), versus construction (right). Image courtesy of Bentley Systems.

Managing Changes to the 3D Engineered Model

Transparent communication and collaboration between the engineer and the contractor are two success factors in using digital data for construction automation. This can be fostered with a pre-construction meeting to discuss how a Model of Record will be established to support both AMG and inspection. AMG construction is usually faster, so real-time feedback is important to provide rigorous QA without delaying the contractor. These mutual benefits are ripe for a construction partnering initiative.

In the absence of construction partnering, agreement on a Model of Record could be facilitated through the Plans and Working Drawings process. This would involve data exchange to review the contractor's 3D model in a different proprietary format—a cumbersome, manual process that is vulnerable to data corruption. The alternative is for the STA to provide a Model of Record from the design process, but this would not capture the contractor's staging, discrepancies between survey data and field conditions would need to be incorporated, and the data would need to be exchanged to be compatible with the inspector's field survey equipment. The contractor would need to duplicate this work to have data for AMG, and differences in the 3D models, such as data density, would accumulate and would need to be isolated from construction errors. A single Model of Record saves time and increases transparency and confidence for both the engineer and contractor.

4 Adapted from Maier et al., 2016. *Utilizing 3D Digital Design Data in Highway Construction: A Case Study. Draft Final Report.*

Relating 3D Engineered Models to Construction Engineering and QA

3D models provide an opportunity to improve inspection processes and make them more efficient by offering a new way to conduct core inspection tasks, such as verifying tolerances and measuring payment quantities. A work flow is shown in Figure 3.

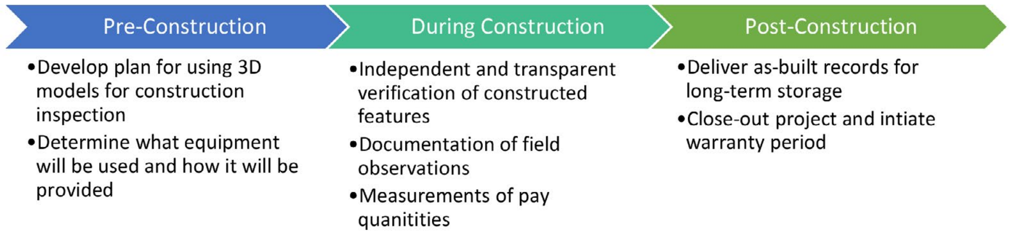


Figure 3: Use of 3D engineered models for construction engineering and quality assurance.

Pre-construction

The resident engineer needs to plan how the inspectors will use 3D models and the available survey equipment and network, prioritizing inspection tasks using a risk-based approach. This may require advanced notice of some construction activities in order to have the appropriate construction inspectors or surveyors on the job site with the right tools or skill set to inspect specific work. The contractor's work plan will influence the engineer's inspection plans because there is an opportunity cost associated with establishing the survey network needed to support AMG and 3D inspection activities.

The desired outcome in this project stage is to develop the framework for setting the Model of Record; assess the impacts of differences between survey data and field conditions; manage the digital data; define the tools and methods for inspection work; identify a source of support for CADD or survey issues during construction; establish the process for measuring and calculating quantities for payment; and determine the needs and formats for 3D as-built records.

During construction

Technology enables an objective and transparent construction inspection process through digital documentation and rapid decision-making throughout the project delivery lifecycle. The workflow for construction inspection using 3D data is illustrated in Figure 4.

Observations should only be stored if they are a meaningful as-built record, document an issue that needs to be resolved, or are part of a pay quantity measurement.

Figure 4: Construction Workflow when Using 3D Data for Inspection Data Collection

Additionally, observations and measurements taken should be repeatable within the instrument tolerance, and inspectors should take advantage of the available automation processes. For example, using field codes enables the inspector to automate drawing production and as-built documentation, as well as taking measurements for payment quantities. There are many ways to view the data collected, including visual field representations and spreadsheets.

An important consideration for the inspector is how the field conditions relate to the standard drawings and the specification. Inspectors need guidance or judgment to determine what 3D data is required for documenting construction in accordance with the specifications, versus measuring quantities.

Documentation of proper construction may require elevations, cross-slopes, etc., but length, width, and depth measurements may be needed to calculate volume based on a regular area. Figure 5 illustrates how 3D data and survey equipment can be used to inspect a pipe installation. It shows the relationship between a utility installation standard drawing and the 3D data needed to verify proper placement and calculate quantities. It also depicts how the inspector could observe many locations to verify that the pipe was installed correctly, using the appropriate horizontal and vertical offsets for the bedding, trench, and cover.

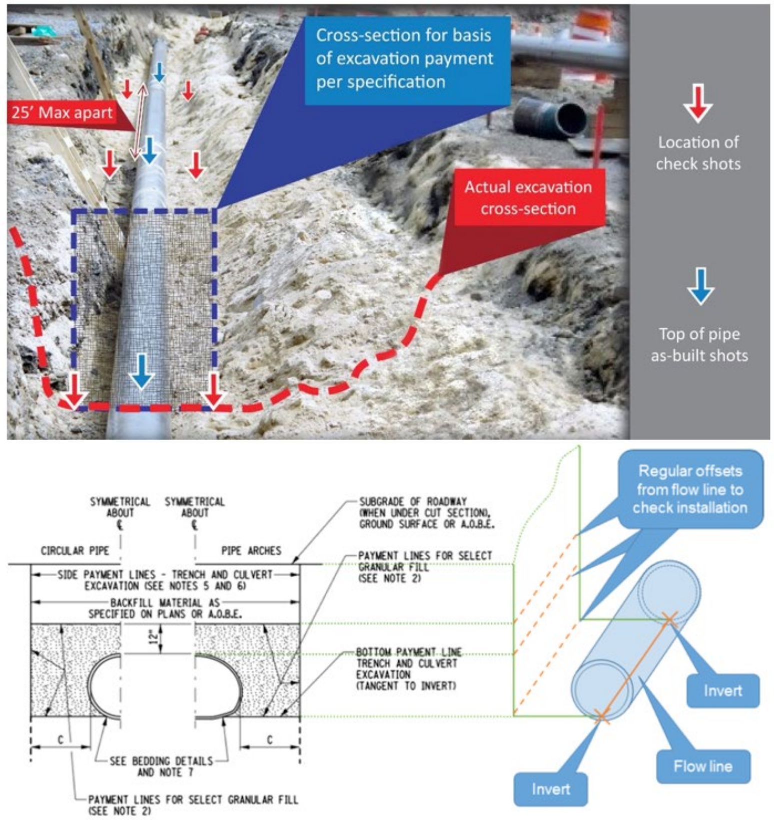


Figure 5: Illustration showing how 3D data relates to standard field conditions (top) and standard drawings (bottom).

Post-construction

The as-built conditions of the project should be reflected in the final 3D model delivered for acceptance following certification protocols for accuracy and completeness, providing reliable and trusted data for long-term documentation and asset management records.

Developing Workforce Core Skills

The 3D models and field survey tools are largely new tools and methods for inspection. Consequently, there is a need to develop core skills to use them with confidence. Understanding the data and tools is the first step. Learning to select and use tools that provide repeatable measurements and how to manage the data recorded in the field are other important skills.

Developing a training program in the core knowledge areas is a key success factor for implementing 3D engineered models for construction inspection. Delivery methods should include a variety of options to meet the needs of a diverse workforce, including traditional instructor-led, train-the-trainer, short how-to documents and video (e.g., YouTube).

The core skills described in Table 2 need to be developed within the inspection team. Which specific team member holds each skill is less important than having someone skilled in the required competency available when needed. Some of these core skills are used on a daily basis for routine tasks, while others are used only at the beginning and end of the project or occasionally to troubleshoot problems.

Usually, the level of competency needed on a daily basis is lower than the level of competency needed when establishing the Model of Record, survey network, and protocols for inspection. For simplicity, the main three competencies are defined as:

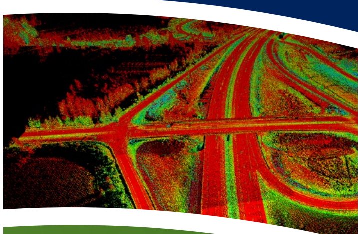
- **Expert:** Able to troubleshoot, often a licensed professional
- **Practitioner:** Trained to execute task following guidance documents
- **Aware:** Knows that this skill or knowledge may be needed, and when to call for help

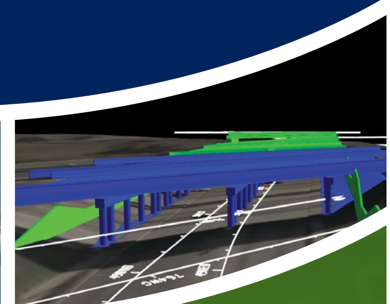
Table 2: Core knowledge areas for developing workforce competency.

Core Knowledge Area	Guidance/ Policy Document	Initial Setup Task	Routine Task	Support Resource
Mapping Fundamentals Coordinate systems, transformation and project-scale factors, site localization	Survey Manual	Practitioner	Aware	Survey Staff
Data Management Version control, data validation, collaboration tools	CADD Manual	Practitioner	Aware	IT and/or CADD Staff
Field Survey Data Collection Collection of topographic data, proper use of feature codes and attribution, quantity calculations, automation of as-built drawing creation	Survey Manual	Practitioner	Practitioner	Survey Staff
Survey Tool Selection Understanding of equipment tolerances, ability to choose tools for different activities	Construction Manual, Specifications	Practitioner	Practitioner	Survey Staff
Hardware Skills Using survey equipment and data collector correctly	Survey Manual, Equipment Manual, Training Materials	Expert	Practitioner	Survey Staff
Software Skills – Data Collector Using data collector to collect data and compute measure-ments	Training Materials, Construction Manual	Expert	Practitioner	Survey Staff
Software Skills – CADD Using CADD software to review or update data correctly	CADD Manual, Training Materials	Expert	Practitioner	CADD Staff

Conclusion

The technology advancements that are creating new, safer, more accurate and faster means and methods for highway construction are available to bring similar benefits to QA inspection workflows. The benefits of repeatable, digital, and transparent data-driven measurements alone make this an important component of e-Construction practices. The synergistic benefits of fast, transparent, repeatable measurements and a digital record of construction progress make this an area ripe for construction partnering. The contractor and engineer can partner to create a 3D Model of Record that enables both parties to adapt the 3D model to a more accurate reflection of the original ground, identifying and resolving constructability issues and opportunities for material balance to mutual benefit. The process of establishing a Model of Record with construction partnering offers the engineer and the contractor mutual benefits in avoiding the data exchange burden and places them with an equal facility for manipulating 3D data. Finally, the agency needs to be prepared to make the right tools available for inspectors to perform their daily tasks, along with proper training on the new processes, equipment, and software used for QA work.





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For additional information about this EDC Initiative, please contact:

Christopher Schneider
Construction Management Engineer
Office of Infrastructure (HIAP-30) — FHWA
Phone: (202) 493-0551
Email: christopher.schneider@dot.gov

R. David Unkefer, P.E.
Construction & Project Management Engineer
FHWA Resource Center - Atlanta
Phone: (404) 562-3669
Email: david.unkefer@dot.gov

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