U.S. Department of Transportation
Federal Highway Administration

Guide for Digital As-Builts Using Integrated Digital Workflows

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TABLE OF CONTENTS

FOREWORD

As-built drawings have long served as a critical construction documentation that captures how a project was actually built, noting deviations from the original plans and any changes made during construction. Traditionally the transportation agencies have used two-dimensional (2D) paper sheets, image scans, and document-based PDFs for as-builts. Technological advancements have led to the use of 3D as-built drawings.

These 3D models represent a significant leap forward, offering more than just visual representations. As data-rich repositories containing detailed project and asset information, they serve as a key link between project design, survey, and construction data, connecting them to ongoing operations and asset management. Many transportation agencies have made significant strides in digital delivery to create a comprehensive digital ecosystem for the lifecycle management of highway infrastructure, and digital as-builts (DABs) is one among them.

Implementing DABs requires a systematic approach that addresses key requirements related to processes, people, tools and technologies, and data, which, when met, enable agencies to formulate effective workflows for DAB implementation. State Departments of Transportation (DOTs) employ a range of practices that significantly vary based on their specific project delivery and asset management needs and capabilities. Despite the diversity, these practices can be broadly categorized into two main workflows: the Simplified Lifecycle Digital Workflow and the Integrated Digital Workflow. Both workflows aim to develop DABs, but they differ in their complexity and integration of design and data collection processes.

The Simplified Digital Workflow is a straightforward approach that separates the design process from the data collection process, which is undertaken using data templates during the construction phase. The Simplified Digital Workflow stands in contrast to the Integrated Digital Workflow, a more comprehensive approach that intertwines the design process and data collection, making asset data a core component of the digital design model. This guide presents a detailed discussion of the steps involved in the Integrated Digital Workflow with illustrative examples drawn from various State DOTs.

INTRODUCTION

As-built drawings are an essential part of construction project documentation. They capture changes made during construction, deviations from as-designed plans, and provide asset-specific information for use in the operations and maintenance (O&M) phase of roadway facilities. Traditionally, as-built drawings were presented as two-dimensional (2D) paper-based markups, later transitioning to paperless image-based scans and document-based Portable Document Formats (PDFs). While the paperless formats made the files more accessible, they were static representations of the as-built conditions.

With technological advancements, digital as-builts (DABs) have emerged as a better alternative than traditional practices. Throughout the project lifecycle, the DAB serves as a central repository of asset information, continuously evolving as new data are collected, organized, and managed. Starting from the design phase, the DAB is enriched with as-built information during construction and then becomes a valuable resource for operations, maintenance, and asset management. With this information, DABs can provide a comprehensive representation of the physical built infrastructure using data-rich three-dimensional (3D) models. DABs also serve as a key information management link throughout the project lifecycle, from design and construction to operations, maintenance, and asset management.

DIGITAL AS-BUILTS WORKFLOW IMPLEMENTATION

DABs offer significant advantages over traditional as-builts in providing additional levels of detail for construction documentation:

- Encoding intelligence related to assets, such as material types, quality, and quantities in addition to spatial information.
- Updating continuously to reflect changes during construction and maintenance, ensuring that the records remain relevant and accurately represents current conditions.
- Facilitating seamless data exchange with various information systems used in construction and asset-specific management systems.
- Enabling automated extraction of data elements using location-specific, asset-specific, and attribute-specific criteria.

While these advantages present a compelling case for the adoption of DABs, they also serve as clear objectives that guide the implementation and use of DABs in a highway project lifecycle.

DABs require improvements to business processes that formalize standard procedures to achieve these goals. Implementing DABs involves a systematic approach that includes the following considerations:

- Establishing a Strategic and Technical Working Group(s)—Involves setting up a dedicated team to:

    - Establish a strategic working group to develop the roadmap, formulate strategies, and allocate resources and oversee the implementation.

- Form technical subcommittees and working groups (e.g., digital delivery, geographic information systems [GIS], utilities, asset management) to address specific aspects of the implementation process, including data collection, data governance, and business process improvements.
- Implement continuous improvement efforts to refine and optimize DAB processes.

- Undertaking Process Improvements—Entails formalizing standardized procedures and integrating them to project lifecycle workflows to accommodate DAB implementation, including:

  - Develop digital design models for construction with or without asset-specific intelligence.
  - Create standardized templates and forms for capturing and reporting asset data consistently.
  - Share detailed digital models with contractors and field inspectors to facilitate data capture and validation.
  - Establish procedures for field inspection and verification of as-built data.
  - Coordinate during construction to incorporate field revisions and updates into the DABs.
  - Implement a review process for asset data by asset stewards to ensure quality and compliance with standards.
  - Define procedures for handling errors, inconsistencies, and missing data in the DABs.
  - Link electronic data, such as quantities and bid items, to construction documentation, and use them in contract administration.

- Determining data and technology requirements—Entails identifying and implementing robust data governance measures and technological tools to:

  - Define data requirements for collecting roadway geometry and design, contract administration data, and asset-specific life-cycle data.
  - Establish data standards and formats to provide consistency and interoperability.
  - Develop data validation processes to maintain data quality and integrity.
  - Establish data governance policies to protect data security, privacy, and access control.
  - Identify and implement digital tools to support DAB processes, such as field inspection.
  - Use software solutions for creating, managing, and visualizing DABs.
  - Provide Implement extract, transform, load (ETL) capabilities to facilitate data exchange with other information systems.
  - Continuously evaluate and update technology solutions to keep pace with industry advancements.

- Engaging Stakeholders—Entails fostering active participation of people in the process to:

  - Understand the needs, concerns, and expectations of internal stakeholders through requirements gathering and consultation sessions.

- Coordinate with external stakeholders, including contractors and design consultants, before and during construction.
- Establish policies on roles and responsibilities for all relevant stakeholders.
- Develop and deliver training programs, such as computer-aided design (CAD) and GIS training.
- Establish clear communication channels for stakeholder feedback.
- Encourage a culture of collaboration and continuous learning.

By addressing these key requirements that cover stakeholder engagement, process improvements, data needs, and technological capabilities, State DOTs can formulate a comprehensive approach to DAB implementation that culminates in effective workflows. State DOTs can consider adopting one or both primary methodologies: the Integrated Lifecycle Digital Workflow (addressed here) and the Simplified Digital Workflow.

The Simplified Digital Workflow is a straightforward approach that separates the design process from the data collection process, which is undertaken using data templates during the construction phase. The Simplified Digital Workflow stands in contrast to the Integrated Digital Workflow, a more comprehensive approach that intertwines the design process and data collection, making asset data a core component of the digital design model.

Both workflows aim to develop DABs and facilitate the transfer of as-built data to the O&M phase, but they differ in their complexity and integration of design and data collection processes. The Simplified Digital Workflow offers a balance of ease of implementation and functionality. It requires minimal disruption to existing workflows and systems, allowing agencies to pilot and scale up gradually. Staff can leverage their current design processes and tools, minimizing training needs. However, this simplified approach relies on manual data entry using templates, which can be time-consuming and error-prone. Additionally, this approach is significantly limited in its ability to automate processes or leverage advanced digital tools.

While the Integrated Digital Workflow is more complex and resource-intensive to implement compared to the Simplified Digital Workflow, this approach offers significant advantages in terms of data consistency, automation, and efficiency for more complex projects. This workflow enables greater automation and efficiency in data management because of its ability to leverage object-based data modeling, the integration of design and asset data collection, and the automated tracking and extraction of quantities. These features collectively contribute to a more streamlined and effective data management process.

In a nutshell, selecting the appropriate workflow depends on an agency's specific needs, project complexity, available resources, and organizational readiness. This guide presents a detailed discussion of the steps involved in the Integrated Digital Workflow with illustrative examples drawn from various State DOTs.

INTEGRATED DIGITAL WORKFLOW TO DEVELOP DIGITAL AS-BUILTS

The Integrated Digital Workflow adopts a comprehensive, more automated, and object-based data modeling approach to achieve the core objectives of DABs. Essentially, the integrated workflow intertwines the design process and data collection, and makes asset data a core component of the digital data-centric design model. This approach is suited for moderately complex to highly complex projects with a large number of assets and assets with higher complexity.

In this workflow, after identifying the information requirements, the data attributes are encoded into design models. During the preliminary design phase, asset data from the proposed project area are extracted from enterprise systems and supplemented with survey information. In the design phase, this additional intelligence enriches the design model to facilitate field data collection. The agency continues with the normal design process to produce digital models as legal contract documents (MALD) or for informational purposes.

In the construction phase, construction inspectors access the information encoded in the design model via digital inspection tools. This process enables them to add newer asset attributes, record any deviations observed in the field, and automate the extraction of material quantities by bid items for contract administration. Upon verification of the field inspection findings, the design model is updated with this new information to create as-built models for the project closeout.

During the handover, the asset data encoded in the final as-built model, including their locations, are transferred to the respective information systems or an enterprise data warehouse typically using ETL techniques. In the O&M phase, the asset information is updated periodically and kept dynamic throughout the facility's lifecycle.

Figure 1 illustrates a schematic flow diagram for the integrated workflow. Each of the steps involved in this workflow, along with their pertinent process, people, data, and technology considerations, is discussed in the next section.

Workflow

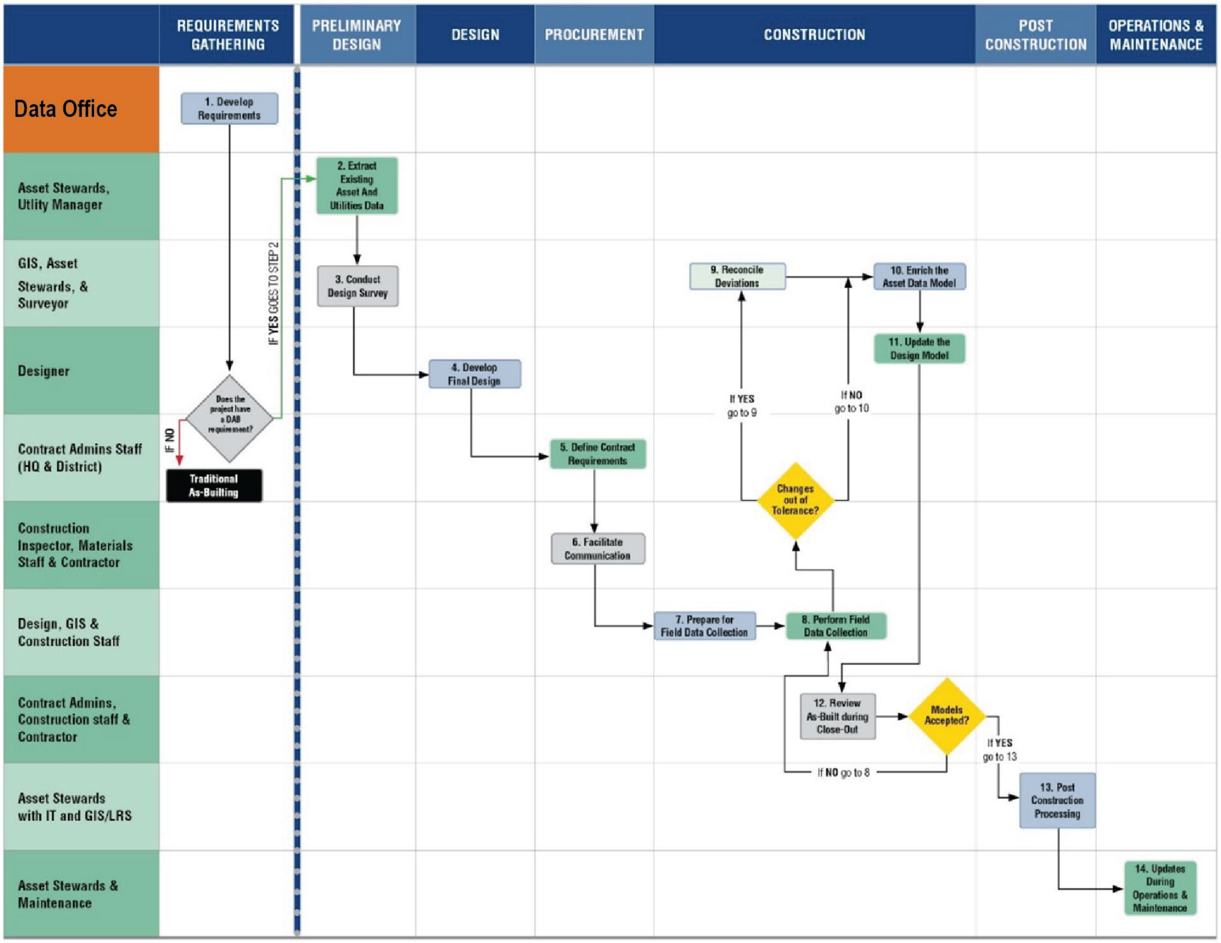

Figure 1. Integrated Workflow for Digital As-Builts.

Steps

1. Develop Requirements

   Objective

   This step is to establish a clear understanding of the information needed throughout a highway facility's lifecycle. The outcome of this step is to develop the specifications for producing as-builts to fulfill diverse information requirements. In addition to redlining construction-related changes and deviations, many types of information, including asset attributes, and contract administration data, are collected. These information types may be grouped into four categories:

   - Asset Information Requirements—describing the information required to know how to operate a facility and maintain its assets. This information typically includes asset attributes, such as material quality records, and geometry locations.

- Project Information Requirements—describing the information related to project delivery (e.g., quantities of various bid items for payment processing).
- Organizational Information Requirements—describing the high-level information of the asset lifecycle, such as for environmental requirements, inventory data collection, asset lifecycle and maintenance planning, project scoping, and regulatory needs.
- Exchange Information Requirements— describing the information that needs to be exchanged and delivered by the project team (e.g., redlining).

These requirements adhere to the information standards outlined in ISO 19650. Note that this step is common is both simplified and integrated digital workflows.

Phase/Process

This step is undertaken prior to initiating any project and operates at the enterprise level. The process begins with a review of the agency's strategic plan and roadmap. Typically guided by one or more strategic and technical committees, the agency evaluates its current maturity internally and establishes milestone goals to achieve the desired maturity level. The maturity assessment helps the agency assess its current capabilities related to the process, information, infrastructure, and personnel, which will aid in identifying near-term initiatives.

The agency then identifies current processes, maps out existing workflows and data flows, and develops a long list of potential use cases that align with the agency's goals. Adopting an incremental approach, most agencies develop a prioritized list of use cases for which data requirements are developed. The maturity assessment results help inform the prioritization of use cases by allowing the agency to focus on those cases that align most closely with milestone goals.

For each prioritized use case, data requirements are gathered through cross-functional consultation with subject matter experts (SMEs) from multiple departments, including design, materials, construction, maintenance, operations, asset management, GIS, and planning. The requirements solicitation entails investigating the follows:

- The business users of the data.
- How these data will be used.
- Party responsible for collecting the data.
- Timing for data collection.
- Process for verifying the data.
- The formats, accuracy, and completeness requirements for the data.

Finally, the requirements are formalized in a policy, practice, and specifications document, and communicated to pertinent stakeholders. The agency regularly reviews, updates, and adapts the requirements, as needed, based on changing delivery scopes or stakeholder needs.

People Involved/Roles

The agency's data office leads this step, and it involves a range of internal stakeholders, including designers, digital delivery leads, construction project engineers, materials engineers, contract administration personnel, asset stewards, maintenance personnel, surveyors and GIS specialists, software stewards in design and construction, utilities coordinators, strategic asset management staff, and policy and planning staff.

Data/Technology Used

Only standard technological resources, such as a productivity software suite, are required; however, prior knowledge of industry standards and existing information systems may be useful.

Illustrative Example—Pennsylvania DOT

PennDOT has devised a strategic plan to fulfill the objectives of Digital Delivery Directive 2025. This plan is being executed in three distinct phases over five years: Strategic Planning, Development, and Deployment. PennDOT engaged in an extensive stakeholder engagement program (Figure 2) to gather the necessary information to evaluate the current state of project delivery and identify priorities for digital delivery.

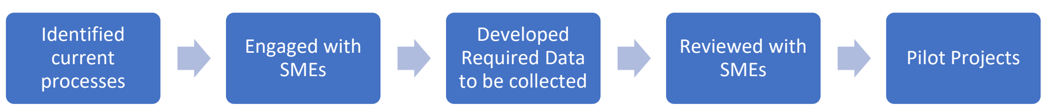

Figure 2. PennDOT's Requirements Gathering Process.

PennDOT's roadmap includes quick start tasks, implementation planning, and use case development. PennDOT develops use cases incrementally and systematically as part of its strategic plan for the Digital Delivery Directive 2025.

The PennDOT Digital Delivery Execution Plan, a digital data management plan, presents a streamlined approach for developing and delivering discipline-specific design models for various use cases. The process of data exchange throughout the project lifecycle is elucidated in the plan, along with guidance on the development of the model element breakdown (MEB) structure and the definition of the level of development (LOD) and information. The agency plans to develop digital delivery interim guidelines that will include defining data requirements using a MEB table, LOD, level of accuracy (LOA) and level of information (LOI) attributes, and a quality management plan.

2. Extract Asset Data

Objective

This step involves extracting existing asset data, which includes both above-surface and subsurface assets, from enterprise information systems for a specified project area. The purpose is to identify the assets located within the footprint(s) of the proposed project at an early stage and use the extracted information for design purposes.

Phase/Process

This step begins with the initiation of a project as soon as the agency identifies that the project requires DABs. During the preliminary design phase, asset stewards and utility managers collaborate with GIS specialists to gather existing data on aboveground and/or underground utilities within the proposed project's footprint(s) from enterprise systems, such as GIS or Linear Referencing Systems (LRS). Using ETL techniques, specifically the Feature Manipulation Engine (FME), asset information is extracted from these enterprise systems. This information is then transformed and loaded into CAD models to facilitate developing digital design models (in Step 4). The extracted data may include various attributes of the assets, including their quantities, types, conditions, and associated repair costs.

People Involved/Roles

Asset stewards, utility managers, and GIS specialists collaborate during this step. Asset stewards, who are responsible for the overall management of the assets, provide valuable information about the assets located within the project area. Similarly, utility managers provide information on the location of subsurface assets. These staff work with the GIS specialists to extract, transform, and load the asset information from enterprise systems into CAD models using ETL techniques.

Technology Used

This step primarily involves enterprise-level data warehouse, GIS systems, and asset-specific information systems, including subsurface assets.

Illustrative Example—Colorado DOT

CDOT adopts a lifecycle approach to managing subsurface utilities on highway projects. During the initial stages, CDOT incorporates survey data collection for both surface and subsurface utilities to create as-built documentation. The agency employs a variety of data collection techniques, ranging from traditional survey methods to modern approaches such as the use of uncrewed aerial systems (UAS) or mobile applications.

For subsurface utilities, CDOT adheres rigorously to the requirements outlined by ASCE/CI 38-02 standards. These standards provide guidelines for conducting subsurface utility engineering (SUE) surveys to accurately locate and map underground utilities. They also provide a system for classifying the quality of data associated with existing subsurface utilities.

Throughout this process, CDOT ensures a consistent and precise data collection process. Critical attributes, such as the type, size, condition, and material of subsurface utilities, are captured. The collected data are then published to the GIS database to inform decisionmaking throughout the project's lifecycle.

This process begins at the 10 percent design phase and continues through permitting, relocation, and field-verified DABs. The base utility data, classified in accordance with the ASCE standards, serve as a reference or part of a specification for the entire project lifecycle to aid engineers, project managers, utility owners, and contractors in their respective roles.

3. Conduct Additional Surveys

Objective

The agency conducts additional surveys to provide accurate measurements and locations of features to support design and construction inspection. These design-grade surveys are conducted to gather high-quality and precise data on topography, right-of-way utilities, and asset information, all of which serve to advance the final design. The survey information collected is then used to further enrich the digital design model, building on the data extracted in the previous step.

Phase/Process

The surveys are carried out in the preliminary design phase of a project.

People Involved/Roles

This step is conducted with the help of asset stewards, surveyors, and GIS staff.

Technology Used

This step primarily involves geospatial technologies such as Light Detection and Ranging (LiDAR), UAS, and global navigational satellite systems/global positioning systems (GNSS/GPS), among others.

4. Develop Design Files

Objective

This step entails creating detailed design models to communicate the project's design requirements. These models are then used to create the data models and data structures that are necessary to meet the enterprise information requirements for the project. The CAD models are encoded with asset attributions and pay items that align with these information requirements. The result is a data-rich 3D model that supports field inspection. This model subsequently evolves into a DAB model, providing valuable support for future asset management.

Phase/Process

This step occurs during the design phase. The agency follows the standard design process using digital design models to produce design deliverables. The agency also follows standard procedures for submitting a project package of plans, specifications, and a cost estimate, including necessary milestone-based design reviews. In addition, the design team incorporates an appropriate amount of detail in the design as specified by the agency's LOD table.

Within the design model, two distinct types of data models are used: one for pay item-related attributes (e.g., item number, item description, and quantities), and another for asset-related attributes (e.g., component type, component description, material properties of assets). Each asset class may employ different data models for contract administration and GIS purposes. The design considers the appropriate survey accuracy for various asset classes, which is a vital step in defining the field location tolerances for these classes.

People Involved/Roles

This step primarily involves the design team that is responsible for developing design packages. A significant amount of collaboration occurs during this step with multiple stakeholders. This includes working with asset stewards and utility managers to encode the asset data in the design model, and with contract administration staff on pay item-related attributes. GIS specialists and surveyors play a vital role in extracting data associated with existing assets from enterprise systems, incorporating survey data, handling GIS layers, providing inputs on location accuracy requirements for various asset classes, and upon completion, transferring the data to the GIS database.

The designer assumes additional responsibility to create attributes that support downstream processes. This work is particularly important when working with construction staff and contractors to clarify design intent, make the models available for field inspection, update the models to reflect as-built conditions, and continue until the final acceptance of the model. It is important to note that many stakeholders have limited exposure and accessibility to digital design tools. Therefore, continuous support from the design team is essential to ensure the success of the project.

Technology Used

This step involves standard design, CAD and productivity software suites, such as Bentley Software Suite (OpenRoads Designer, OpenBridge Modeler, SYNCHRO, and MicroStation Connect) and AutoDesk AutoCAD for plan production.

Illustrative Example—Connecticut DOT

During the design phase, CTDOT integrates intelligent CAD components as design features and embeds asset intelligence into Building Information Modeling (BIM) feature models. This integration can be initiated as early as the preliminary design phase using both 2D and 3D models.

Each asset uses two data models: the "Pay Item Related" model, which includes attributes (e.g., item number, description, bid quantity, and total installed units) and facilitates automated quantity harvesting in the CAD environment. The "Authoritative Asset Features" model aligns with GIS features and records asset-specific attributes like item description, component type, and model type. After completing the design asset features, the CAD model data are extracted, transformed, and loaded into the GIS data layer.

Early in the design process, CAD designers and GIS personnel are engaged in developing these data models, which are then passed to the designer of record and design consultants for each asset class. Designers are not required to perform tasks beyond their current responsibilities, particularly those related to developing data models. As these models advance through the construction phase and reach the final commissioning stage in the authoritative common data environment (CDE) inventory, they provide substantial benefits to asset stewards and the Transportation Asset Management team.

5. Define Contract Requirements

Objective

This step involves detailing the contract requirements for DAB deliverables and identifying any additional survey and data collection needs in the project procurement documents. The agency may choose to share digital design models with contractors for informational purposes or include them as contract documents (i.e., MALD) to communicate the design intent and gain construction-related process efficiencies.

These requirements are communicated through specifications or special provisions that define detailed requirements on which deliverables should be produced, the standards to be adhered to, and the timelines for delivery. They also delineate the roles and responsibilities of various stakeholders, including the agency, the contractor, and the design consultant, if involved. Specifically, when MALD is used, the agency could use the contract document to outline the party responsible for updating the model of record to capture the as-built conditions of the project. The deliverables for the DABs are defined as contractual pay items. Linking these deliverables to payment milestones underscores the importance of compliance during construction.

Phase/Process

This step occurs during the procurement phase. A DAB specification typically includes:

- Construction requirements, including preconstruction coordination.
- A list of as-built deliverables for markups, survey data, asset-specific data, and additional requirements, if applicable.
- The deliverable submittal process.
- The basis of payment.

People Involved/Roles

This step primarily involves contract administration staff (from either the central office of the districts or both) and the construction project/resident engineer. These staff are responsible for clearly defining and communicated the DAB requirements through specifications or special provisions. The construction project engineer, responsible for executing the project, makes sure that the DAB deliverables are produced within the specified timelines in accordance with contract requirements.

Technology Used

Only standard technological resources, such as a productivity software suite, are required.

6. Facilitate Communication

Objective

This step involves initiating communication during the preconstruction meeting to discuss the needs and challenges of meeting the contractual requirements relating to DABs, including enriching the digital models using the asset information gathered in the field. Furthermore, it is essential to gain the contractor's acceptance of the DAB process at this stage, particularly during the initial pilots. The outcome of this step is a coordinated plan for the DAB process that streamlines data collection and verification, and ultimately completes the as-built deliverables.

Phase/Process

This step occurs during the construction phase. The preconstruction meeting allows the agency and contractor to review contract requirements relating to DAB deliverables. The discussion includes a list of deliverables and schedules, a data collection plan, verification and acceptance procedures, updating of design models to reflect as-built conditions, and submittal procedures (e.g., file formats and submittal mode). It also provides an opportunity to discuss the coordination that must happen before, during, and after field inspection and closeout procedures between the State DOT and the contractor, including the designated lines of communication to clarify questions that may arise. Furthermore, the contractor, who would have received access to the design models, can seek clarification with the designer of record.

This meeting can also include a discussion on potential challenges that the contractor may experience relating to the DAB process, such as the challenges in handling multiple tools or licensing issues for information access, and potential mitigation strategies.

People Involved/Roles

This step involves the participation of construction project engineers, contract administration personnel, designer of record, and contractors.

Technology Used

Only standard technological resources, such as a productivity software suite, are required.

7. Prepare for Field Data Collection

Objective

The primary purpose of this step is to prepare the design data for field data collection. At the end of this step, design data are available on mobile devices, allowing inspectors to digitally collect information on as-built assets for the GIS database.

Phase/Process

This step occurs in the early stages of the construction phase and entails converting the data from the CAD models into a format suitable for location-based data collection. The data encoded in the 2D and 3D design models are transformed into inspection tools through an ETL process.

Given the diverse software used by contractors for construction modeling, the agency needs to be aware of the gap between the files supplied and those that contractors can readily use, which often necessitates significant file manipulation. As a result, the agency should contemplate providing files in a standardized format to simplify direct usage.

People Involved/Roles

This conversion of design data to field mobile devices is performed in coordination with design, GIS, and construction staff to ensure a smooth handoff to contractors and construction staff.

Technology Used

This step primarily involves tools, devices, and technologies related to digital design modeling, GIS, ETL, FME, and GIS-enabled mobile construction inspection.

Illustrative Example—Utah DOT

UDOT develops both 2D and 3D CAD models that are subsequently enriched with pay item attributes, asset attributes, and metadata. These models undergo a validation process using an FME application, and are then converted into GIS data.

In comparison with a traditional design process involving a conversion from 3D model to PDF plan, more upfront work is required in the digital workflow. The design models undergo rigorous design reviews using various tools to further enhance the process's efficiency, collaboration, and effectiveness. In addition, design teams incorporate metadata attributes into the models to enhance the visibility of information during digital reviews and project advertising.

In preparation for the construction phase, contractors are often required to convert or manipulate the design models into formats that are suitable for their use. They use various software tools for construction planning and execution, including those for positioning and machine control. For example, they load the converted files onto heavy equipment for automated machine guidance. Contractors also employ various methods for surface validation and staking. Given that UDOT lacks construction survey crews, the contractor's surveyors validate surfaces against grid scales.

8. Conduct Field Data Collection

Objective

This step includes collecting the field data to verify and incorporate as-built conditions in the digital design models. This step involves verifying asset installation locations and attributes; maintaining accurate records of construction activities; capturing deviations from design plans and construction-related changes; collecting additional asset-specific attributes; deriving quantities for pay items; ensuring compliance; and recording material sampling, testing, and certification details. Collecting the field data provides the basis for creating accurate DABs.

After the field data are collected, , the digital design models accurately represent the assets, with all changes and deviations properly recorded. All required data, in line with the contractual information requirements, has been comprehensively completed and recorded.

Phase/Process

This step occurs during the construction phase. Field data collection involves the use of testing, surveying, and inspection tools to collect and verify data. Field inspectors monitor and evaluate the quality of workmanship and materials used in construction. This process follows the agency's quality assurance procedures for inspection to ensure that construction projects comply with design specifications, quality standards, and other requirements.

During field data collection, either contractors or field inspectors, depending on the agency's preference, use various tools and technologies to meet the goals, including data capture tools, such as surveys, and GIS-enabled mobile tools to access design models and verify them. The field data collection process produces digital work products in multiple formats; this information must subsequently be added to the design model and information systems.

Clear guidelines are necessary to ensure that these digital work products are properly incorporated into the design model to maintain the integrity and accuracy of the as-built documentation.

To facilitate decisionmaking, inspectors need well-defined procedures and guidelines on how to handle deviations from the design. These guidelines should specify whether discrepancies from the as-designed location should be flagged or if the as-built location should be documented.

Given the importance of technology in field inspection, the inspection process should consider technology factors from the field users' perspective, including data template accessibility, usability of tools in the field, system integration, and device-related issues. Field inspectors might not have the necessary skills to use technology-based inspection tools effectively or understand how data interact with various systems. Agencies can evaluate the current use of technology-based tools in their practices and provide appropriate training and support to field users to improve their use of these tools to enhance the effectiveness of field inspections.

People Involved/Roles

This step primarily involves construction personnel, including project/resident engineers, field inspectors, material engineers, and contractor staff. Designers, GIS staff, and asset stewards are involved on an as-needed basis to provide any clarifications to questions that may arise.

Technology Used

This step uses tools and technologies for e-Ticketing, document management, surveying, GIS-enabled digital construction inspection, data automation, and information management.

Illustrative Example—Utah DOT

As of 2022, UDOT employed two methods for collecting DABs in the field. In the first method, contractors provide surveys of construction changes, which are then passed back to designers to incorporate into the original design. The design file is subsequently converted to create a DAB in GIS. Storing this information in GIS alongside UDOT's asset data and integrating it into the enterprise data store is crucial. Because UDOT's construction division does not have survey equipment or surveyors, the agency relies on contractors for this task.

Under a second method, UDOT uses a customized Survey123 application to collect asset attribute information for newly installed assets, such as signs and barriers. Asset owners who specified the requirements for the assets define the attributes being collected. The Survey123 application was tailored to collect this information, which is then stored in UDOT's enterprise database.

Field changes are collected using survey methods and passed to the central design group, where they are incorporated into the design file. The designer reviews the changes, and the file is converted into a GIS format. However, adding new features can be a challenge. To address this, a unique ID is used that is connected to both the new asset management system and the asset inventory.

UDOT is also leveraging side scan technology to collect information for a digital twin. This technology allows for end-to-end drone management and direct integration into UDOT's GIS platform to overlay design data, which are then used to verify construction site details compared to design elements. For pavement inspection, UDOT is testing side scan to process Ortho imagery with survey control points to improve the accuracy of pavement replacement estimates and reduce on-site inspections. While the technology aids in collecting DABs or as-maintained data, manual inspection is still needed. UDOT's goal is to automate this process for increased efficiency.

9. Reconcile Deviations

Objective

This optional step is required only if changes are needed to field-recorded data. If no changes are needed, the process proceeds to step 10.

In this step, changes recorded in the field that exceed tolerance levels (e.g., deviations in the location of assets, alterations in materials, or changes in work products that are beyond the acceptable thresholds) are reconciled. Additional field inspections and surveys may be conducted, as necessary.

If necessary, the field inspectors can coordinate with the designers and asset stewards to clarify or reconcile changes that occurred during construction.

Phase/Process

This step occurs during the construction phase.

People Involved/Roles

This step primarily involves the field inspectors or contractors who are responsible for recording the changes and completing the data collection templates. Asset stewards may need to approve changes or take appropriate action to reconcile deviations.

Technology Used

The step involves tools and technologies related to e-Ticketing, document management, and redlining.

10. Enrich the Asset Data Model

Objective

Once reconciliation occurs, the asset and project-specific data are enriched by incorporating findings from inspections and surveys. These updates are then communicated back to the designer of record or design consultant for implementation. The objective is to display a detailed representation of the constructed asset, showcasing pertinent data fields within a form or Excel format upon selection.

Phase/Process

This step occurs during the construction phase.

People Involved/Roles

This step engages construction inspectors, surveyors, and asset stewards.

Technology Used

The step involves tools and technologies relating to surveying, GIS-based data capture, GIS, and other information systems.

Illustrative Example—Connecticut DOT

During the construction phase, CTDOT enhances asset data from the data-rich CAD design model through a well-defined process. Figure 3 illustrates this process.

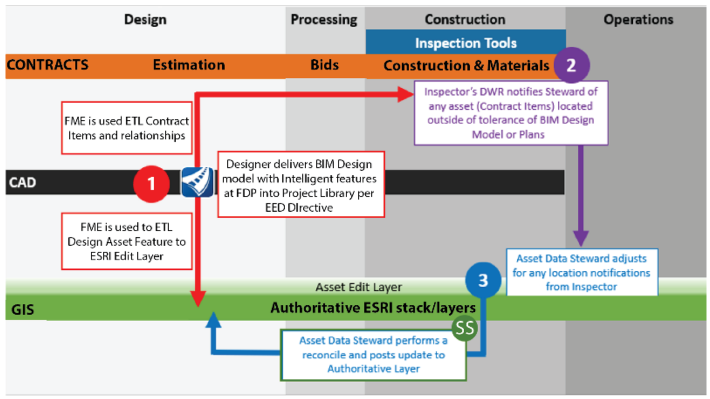

Figure 3. CTDOT's Construction Inspection Process.

The agency's primary objective is to ensure accurate representation and recording of assets without overburdening field inspectors with complex GIS or BIM model management tasks. Inspectors are responsible for identifying discrepancies between the model and the actual placement of features in the field, with allowable tolerances for certain assets like catch basins.

The daily work report (DWR) submitted by the field inspector is a vital component of this process. The DWR alerts the asset data steward of any contract items that fall outside the tolerance levels specified in the BIM model or plans. Upon receiving these location-based notifications, the asset steward makes necessary adjustments to the asset data.

The asset steward also is tasked with extracting data for proprietary contract items, such as attenuators for guide rails or barriers, from the payment system. The steward ensures that assets like guide rails are correctly associated with the asset inventory. Once these actions are completed, the asset steward conducts a reconciliation process and updates the authoritative layer accordingly.

To maintain accuracy and efficiency in the construction process, CTDOT uses an FME that is crucial for data transformations and automated ETL processes. This tool helps streamline the enrichment of asset data during the construction phase.

The authoritative asset inventories are represented in the data mart. For an asset to be included at the production level, it must adhere to governance rules, possess ISO standard metadata, and receive approval from the relevant division chief. The enrichment of asset data is a collaborative effort involving the construction inspector, asset data steward, and the use of specialized tools.

11. Update the Design Model

Objective

This step involves updating the design model iteratively and as needed to incorporate changes that occur during construction. The updated design model serves as the DAB record. It is important to note that the designer of record assumes the responsibility for this process. The contractor sends back any changes to the designer of record or design consultant for review and incorporation into the model.

Updating the design model is highly preferable because it provides the most accurate and up-to-date representation of the project. However, updating the design model is not mandatory and ultimately depends on the agency's preference. This flexibility allows for a process that best suits the needs and capabilities of the agency.

Phase/Process

This step occurs during the construction phase.

People Involved/Roles

This step involves designers, contractors, and design consultants.

Technology Used

The step involves tools and technologies including bridge and road design packages, CAD and GIS applications, field inspection tools, survey tools, and document management systems.

12. Close Out Project

Objective

This step is focused on reviewing the markups and asset data submittals from the previous step, including record changes, asset information record, and any deviations from tolerances in the field, and recording changes resulting from construction process change. Once the record change is reviewed and confirmed, the DAB deliverables is accepted. However, if the DAB is rejected, it is necessary to reconcile the reasons for the rejection. Reconciliation may include performing additional field data collection or other remedial measures at the discretion of the construction engineer. This step ensures that all deliverables meet the required standards and specifications.

Phase/Process

This step occurs during the construction phase.

People Involved/Roles

This step involves the construction project or resident engineer, contract administration staff, and the contractor. The engineer is responsible for reviewing the markups and asset data submittals from the previous step that include the asset information record and any deviations from tolerances in the field. If necessary, the engineer requests assistance from the asset stewards, construction, contract administration, and GIS staff for approvals. The contract administration staff aids the engineer, as necessary, in ensuring compliance with the project requirements, such as certifications. The contractor is responsible for undertaking additional field data collection, surveys, or other remedial measures to ensure that the as-built records are accurate and complete.

Technology Used

This step uses various tools and technologies like e-Ticketing, document management, redlining PDFs, and construction information systems.

13. Post-Processing

Objective

This step involves exchanging asset-specific data from DABs to an enterprise data warehouse or asset repositories using ETL techniques for subsequent post-processing, reconciliation, quality checks, additional attribution, and integration into systems of record.

Phase/Process

This step occurs after the construction phase during the handoff of the project to the O&M phase.

People Involved/Roles

This step involves asset stewards, enterprise information technology (IT) staff, and GIS/LRS staff. Asset stewards verify all recorded data to ensure the accuracy of flagged changes and annotations. The enterprise IT team manages the data warehouse, handling post-processing, reconciliation, quality checks, and integration into systems of record. The GIS/LRS staff add additional attribution to the data and ensure accurate representation and integration of the spatial aspects of the asset data.

Technology Used

This step primarily uses data integration tools and information systems, including construction, geographic, maintenance, and asset information systems, along with an FME.

Illustrative Example—Connecticut DOT

CTDOT uses COMPASS, a customized project management solution hosted within a SharePoint environment, to streamline project review processes. COMPASS is tailored to the CTDOT's specific needs and automates document progression, managing submittals, transmittals, reviews, and approvals. The system ensures efficient document control, tracking, and retrieval throughout the project lifecycle. COMPASS provides access to all stakeholders, including internal CTDOT staff, consultants, and contractors. The system synchronizes with OneDrive, which allows seamless collaboration across diverse environments and non-Microsoft applications.

During the construction phase of a project, CTDOT also employs ATLAS—a tool that scans project-specific data within designated work areas, creating configured asset inventories for automated inclusion in the project scope. The scan results are seamlessly integrated with COMPASS and transferred to the SharePoint project site. This integration allows for automatic upload of asset inventories and other pertinent information within the scanned project footprint to the SharePoint site.

COMPASS and ATLAS facilitate a "connected data" environment by integrating various project development applications such as AASHTOWare Project, Bentley products (OpenRoads Designer and OpenBridge Modeler), Bluebeam, and Trimble. This integrated environment enhances the efficiency and effectiveness of the project management process.

14. Post-Construction Update

Objective

Periodic surveys are conducted during the O&M phase of a facility. Data collected from these surveys are used to update the records. This information, which originates from the construction phase, serves as a foundation for maintaining dynamic and updatable asset records throughout an asset's lifecycle.

Phase/Process

This step occurs during the O&M phase (post-construction).

People Involved/Roles

This step involves the active participation of O&M staff, including asset stewards, maintenance personnel, asset information managers, and emergency response personnel. Together, these staff update the asset records after conducting surveys, scheduled repairs, corrective actions, and emergency repairs. Updates include changes to asset attributes, including inspection details, condition status, damage reports, and repair history. These updates ensure that the asset records remain current and accurately reflect the state of the asset.

Technology Used

This step primarily uses tools for data collection and integration, such as mobile devices, survey equipment, FME tools, and information systems like geographic, maintenance, and asset information systems.

Illustrative Example—Colorado DOT

For CDOT, throughout the O&M phase, continuous updates of DAB records for subsurface utilities are promptly integrated into the PointMan Enterprise dashboard in real-time. This dynamic integration facilitates detailed visualization, quality assurance/quality control, and seamless data export into CAD for design, construction, and model record as-builts. Notably, professional certification is not mandatory for utility contractor as-built submissions; instead, reliance on metadata provides essential "pedigree" information, confirming accuracy through equipment type and survey accuracy data akin to traditional survey notes. The ASCE 75-22 guidelines include accuracy requirements, serving as a valuable communication tool for conveying precision information to various stakeholders. CDOT's strategic approach enables construction field and office personnel to harness data from diverse sources within PointMan and PointMan Enterprise. This integration empowers PointMan Enterprise to stream remote online SUE files, encompassing existing and new utilities, CDOT designs, drone imagery, and OneCall excavation notifications directly to the PointMan mobile application at the project site. This comprehensive utility asset visualization, geolocation, mapping, and documentation process enhances overall project management efficiency.

SUGGESTED NEXT STEPS

Implementing DABs is a journey that requires agencies to gradually progress and scale up their capabilities and maturities over time. A structured assessment of capabilities using a capability maturity matrix (CMM) can be helpful in guiding this process and ensuring a systematic approach to DAB implementation.

A CMM is a framework that outlines the various levels of maturity an agency can achieve in various aspects of DAB implementation, such as data governance, process standardization, technology adoption, and stakeholder engagement. Each level represents a progressively more advanced state of capability, from adopting informal practices (Level 0: Siloed Management) to mainstreaming DABs as a standard practice (Level 3: Governed Enterprise).

The Federal Highway Administration (FHWA) has developed a CMM self-assessment tool to allow agencies to evaluate their organizational capacity to implement DABs. By conducting a capability maturity assessment, agencies can evaluate their current state across various dimensions and identify areas for improvement. This assessment involves several steps:

- Recognizing the key capabilities required for successful DAB implementation, as defined in the FHWA CMM self-assessment tool.
- Understanding the maturity levels within each capability, as defined in the FHWA CMM self-assessment tool.
- Assessing the agency's current maturity level for each capability against critical success factors.
- Selecting the current maturity level for each critical success factor.
- Developing a work plan to close the gaps and progress to higher maturity levels.

The FHWA DAB CMM self-assessment tool has developed four maturity levels for an agency's consideration:

- **Level 0: Siloed Management**: At this level, there is limited awareness of DABs, and business units operate in isolation. Formal data exchange processes are absent, and no coordination is in place for policy, process, data, and system integration.
- **Level 1: Ad-hoc Enterprise**: Some champions are aware of benefits and challenges of DABs, and DAB data are created and exchanged in specific use cases. Preliminary discussions with leadership and stakeholders take place, and there is ad-hoc coordination for data sharing processes.
- **Level 2: Systematic Enterprise**: There is an advancing understanding of DABs within Building Information Modeling (BIM) initiatives, and DAB data are developed through a pilot program. Quality assurance for object-based data models is implemented, and systematic processes for integrating data and systems are established.
- **Level 3: Governed Enterprise**: DABs are mainstreamed as a standard practice, and there is adherence to open standards for DAB object models. Data extraction is performed as per the required Level of Detail/Information, and coordination occurs according to governance policies for processes, data, and systems.

Furthermore, the tool also provides six critical success factors against which an agency can assess their capabilities. Figure 4 presents the six critical success factors and their subfactors. As agencies work through this process, they can prioritize their efforts and resources based on their current maturity level and the most critical capabilities needed to advance their DAB implementation. For example, an agency at the Ad-hoc Enterprise level may focus on creating data collection templates for a limited number of asset classes and pilot them using special provisions, while an agency at the Systematic Enterprise level might make data collection for all asset classes a part of its contract requirement using standard specifications.

By using a CMM and assessment, agencies systematically assess their readiness and develop a clear path toward achieving higher levels of maturity in DAB implementation. Using the CMM and assessment also allows agencies to adopt a gradual and structured approach for the DAB implementation journey scaling up capabilities in manageable milestones.

Awareness	Systems and Programs that Support Digital As-builting	Culture and Organization that Support Innovations such as DABs	Innovation Supportive Staff	External Collaboration	Software Systems, Hardware Systems, Data Modeling and Exchange
• Context awareness around DABs and how it fits within the larger context of BIM • Specific awareness • Performance awareness and application	• Research and development (R&D) • Pilot program • Institutional knowledge management systems • Ease of funding access • Legal and regulatory challenges • Software systems, applications and tools • Hardware devices and technology	• Leadership support, collaboration and teamwork • Support from internal partners • Organizational barriers • Risk-reward response	• Staff capacity • Knowledge acquisition and sustainability	• Interaction with construction sector stakeholders • Communication beyond the transportation community	• Information requirements • Data standards • Data modeling and quality • Data interoperability and integration • Data use

Figure 4. FHWA DAB CMM Self-Assessment Tool Critical Success Factors.

CONCLUSION

In conclusion, the integrated lifecycle digital workflow presents a comprehensive and cohesive approach to project management, seamlessly bridging the gap between different phases. By leveraging sophisticated data intelligence and modeling techniques, this workflow ensures the smooth transfer of information from design to construction and beyond, enhancing project efficiency and accuracy. With an emphasis on object-based data modeling and structured information management, the integrated workflow facilitates informed decisionmaking and supports ongoing operations and maintenance activities. Overall, the integrated lifecycle digital workflow represents a forward-looking strategy to optimize project outcomes and maximize asset lifecycle management.

GUIDE FOR DIGITAL AS BUILTS USING INTEGRATED DIGITAL WORKFLOWS

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Key Words — Digital As-Builts, BIM, Building Information Modeling, Data Management, Data Lifecycle, Integrated Digital Workflow

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