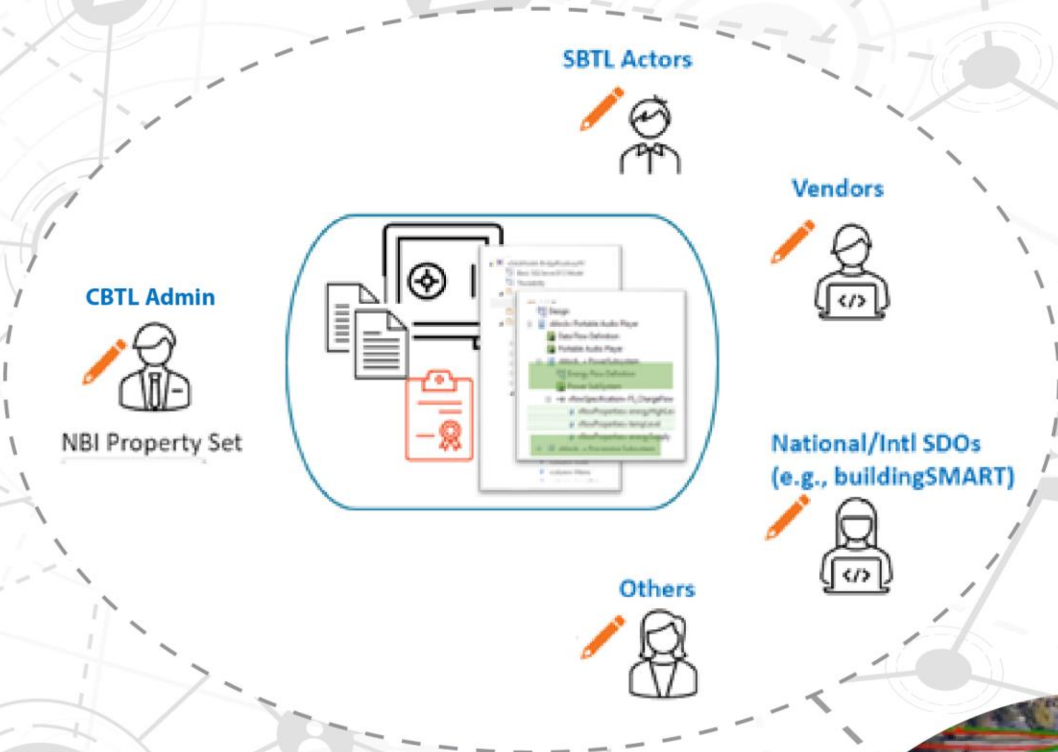
Building Information Modeling (BIM) Workflows and Centralized BIM Transportation Library for Bridges and Roadways

Publication No. FHWA-HIF-24-004

January 2024



U.S. Department of Transportation
Federal Highway Administration

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Technical Report Documentation Page

1. Report No. FHWA-HIF-24-004	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A
4. Title and Subtitle BIM Workflows and Centralized BIM Transportation Library for Bridges and Roadways		**5. Report Date**
		6. Performing Organization Code **N/A**
7. Author(s) Abhishek Bhargava, Lance Parve, Tim Chipman, Sedrick Bouknight and Jagannath Mallela		**8. Performing Organization Report No.** N/A
9. Performing Organization Name and Address WSP USA Inc. 1250 23rd Street NW Suite 300, Washington, DC 20037		**10. Work Unit No. (TRAIS)** N/A
		11. Contract or Grant No. DTFH61-14-C-00043
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Bridges and Structures 1200 New Jersey Avenue, SE Washington, DC		**13. Type of Report and Period Covered** Final Report
		14. Sponsoring Agency Code **N/A**

15. Supplementary Notes Task Order Contracting Officer's Representative: Tuonglinh Warren

16. Abstract - Building Information Modeling (BIM) is a collaborative work method for structuring, managing, and using digital data about transportation assets throughout their lifecycle. Implementation of BIM involves establishing data and process standards, policies, tools and technology, people, and organizational structure. This research identifies traditional workflows that could be transitioned to BIM-based workflows to gain efficiencies and improve productivity. Ten process workflows from planning, survey, design, construction, and asset management are analyzed to identify the data modeling, management, and use opportunities. Additionally, artifacts to deploy BIM-based workflows are identified, including business process models, data terminology, classification systems, object-type libraries, information needs, information delivery manuals, information exchange specifications, model view definitions (MVD), and sample digital model and data to facilitate construction. For development and administration of these BIM artifacts, creation of a centralized BIM transportation library (CBTL) is suggested. The CBTL is presented as a repository used to maintain open standards-based BIM artifacts in a version-controlled environment. An architecture for an CBTL was developed based on the metadata model for libraries in The Open Group Architecture Framework. Deployment of a recommended open standards-based national repository is suggested so stakeholders can use the content in the repository and contribute to its development. In addition to a CBTL, the concept and vision for potential deployment of State BIM transportation libraries is presented.

17. Key Words Building Information Modeling (BIM), Data Modeling, Data Management, Data Use, Model View Definitions (MVDs), Common Data Environment (CDE), Industry Foundation Classes, Centralized BIM Transportation Library (CBTL), State BIM Transportation Library (SBTL), Digital Data Models, Data Dictionary, Version Control		**18. Distribution Statement** No restrictions	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages**	**22. Price** N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

The Federal Highway Administration is the source of all figures and photographs within this document unless noted otherwise.

ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
AASHTO	American Association of State Highway Transportation Officials
AIM	asset information model
AIR	asset information requirements
AISC	American Institute of Steel Construction
AMG	automated machine guidance
API	application programming interface
ARNOLD	All Roads Network of Linearly Referenced Roads
BCF	BIM Collaboration Format
BIM	Building Information Modeling
BME	Bridge Management Elements
bSI	buildingSMART International
CAD	computer-aided design
CBTL	Centralized BIM Transportation Library
CDE	common data environment
DA	design and analysis
DCA	design, construction, and asset
DOT	Department of Transportation
DTM	digital terrain model
EIR	exchange information requirements
FDOT	Florida Department of Transportation
FEA	finite element analysis
FHWA	Federal Highway Administration
FTMS	Freeway Traffic Management System
GIS	geographic information systems
GNSS	Global Navigation Satellite System
HPMS	Highway Performance Monitoring System
iBIM	Integrated Building Information Modeling
ID	identification
IDM	information delivery manual
IFC	Industry Foundation Class

ILS	Information Exchange Specification
iPaaS	Integration Platform as a Service
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
LiDAR	Light Detection and Ranging
LOD	Level of Development
MIRE	Model Inventory of Roadway Elements
MnDOT	Minnesota Department of Transportation
MSE	mechanically stabilized earth
MVD	model view definition
NBE	National Bridge Elements
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
NIBS	National Institute of Building Sciences
NSBA	National Steel Bridge Alliance
NSR	national strategic roadmap
NURBS	non-uniform rational B-spline
OGC	Open Geospatial Consortium
OIR	Organizational Information Requirements
OTL	object-type library
PIM	project information model
PIR	project information requirements
PS&E	plans, specifications, and estimates
PSD	planning, survey and design
QA/QC	quality assurance/quality control
QTO	quantity take-off
REST	representational state transfer
ROW	right-of-way
RTK	real-time kinematic
SBTL	State BIM Transportation Library
SDO	standards development organization
SoR	system of record
TRB	Transportation Research Board
UAS	unmanned aerial system

UML	unified modeling language
USDOT	U.S. Department of Transportation
W3C	World Wide Web Consortium

UNIT CONVERSIONS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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CHAPTER 1. BUILDING INFORMATION MODELING

1.1 BUILDING INFORMATION MODELING

The Federal Highway Administration (FHWA) Building Information Modeling (BIM) National Strategic Roadmap (NSR) (Mallela and Bhargava, 2021*)* defines BIM as:

> . . . a collaborative work method for structuring, managing,[1] and using data[2] and information about transportation assets throughout their lifecycle.

BIM[3] processes and technology have been used in building construction for many years, and the motivation to adopt their use in transportation has been on the rise over the past decade (Mallela and Bhargava, 2021). BIM—as applied to transportation infrastructure projects and subsequent asset management—enables a holistic digital representation of the physical and functional characteristics of a facility. BIM is about preparing the ground rules, frameworks, and workforce at highway agencies so that data and information about built assets move seamlessly in a manner that is easily interpreted and used by humans and machines alike.

1.2 BIM COMPONENTS

Given that BIM is a collaborative work method, BIM development involves advancing along four separate fronts, referred to as BIM components (Mallela and Bhargava, 2021). As illustrated in Source: Mallela et al. (2021).

Figure 1-1, these components are:

- Data and Process Specifications.
- Tools and Technology.
- Capacity-Building Activities.
- Leadership, Collaboration, and Policies.

Deploying data and process standards involves identifying and standardizing the business processes and the data models that are created as part of these processes. Industry BIM specifications also should be established for the data to be exchanged between the business processes so that the data models created in these processes can be based on standard

[1] Includes modeling, storage, security, provisioning, exchanging, and sharing of data.

[2] Includes geometric and non-geometric data, sometimes also referred to as graphical and non-graphical data. Geometric data includes spatial or geolocated data, as well as drawings that define the form of a physical asset in the infrastructure and the volume it occupies in space with the help of geographical information systems and computer aided design (CAD) systems. Non-geometric data are information about the physical asset—such as name, type, install date—that describes details that business users can use to manage and operate the asset and make decisions associated with it.

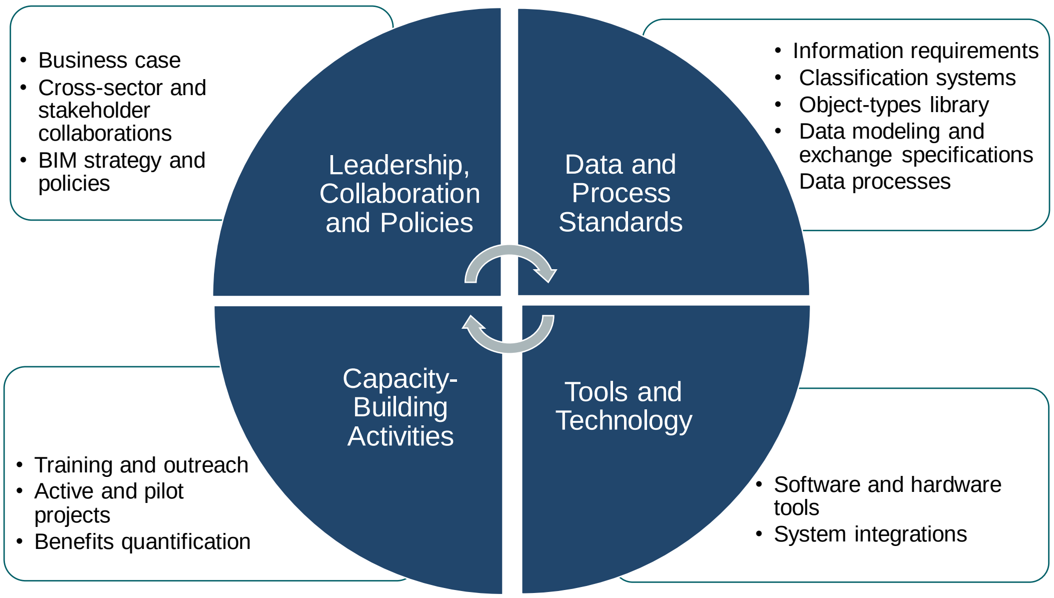
[3] The use of BIM is not a Federal requirement.

information. This BIM component focuses on enabling data management throughout the asset lifecycle.

Leadership and collaboration among stakeholders as well as enterprise-level policies related to processes, data, and business operations support the development of data and process specifications. For developing such data and process standards and collaboration among stakeholders and enterprise-level policies related to processes, data and business operations are used. The "collaboration and policies" BIM component has been established to address this need.

Tools and technology solutions can ensure that the data that are created and the BIM processes that are executed can be managed efficiently. Federated enterprise information systems[4] that all stakeholders in the organization can use and that facilitate integration of data and processes are deployed as part of this BIM component.

The capacity-building activities and leadership components focus on incremental, staged, and planned deployment of the data and process standards, policies, tools, and technology through proof-of-concept and pilot projects. Implementing this component allows for research, innovation, development, and deployment of the artifacts associated with the other BIM components.



Source: Mallela et al. (2021).

Figure 1-1. Chart. Components and Subcategories to Advance BIM Maturity.

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[4] A collection of autonomous information systems and applications with a centralized information management approach.

1.3 RESEARCH OBJECTIVES

The objectives of this research study are as follows:

- Identify the business processes that are executed during the planning, survey, design, construction, operation, and maintenance phases of the highway infrastructure lifecycle.
- Determine the current approach (i.e., data, standards, tools, technology, collaborations) associated with a prioritized subset of business processes to establish the baseline BIM process as it exists today (across most agencies).
- Identify opportunities to enhance the workflows in the current BIM business processes and develop an outline of the envisioned future BIM process based on a published BIM maturity scale. As part of accomplishing this objective, the research should focus on laying out a vision for deploying the updated data modeling, integration, and exchange and use related workflows that would be deployed under the more mature BIM framework.
- Establish the artifacts that are needed for deploying the mature BIM business processes. The types of content and tools needed should consider open standards associated with BIM execution.
- Establish a framework that management can use to identify BIM artifacts in a library at the national and State level. Develop a blueprint for management of such national and State BIM transportation libraries that hold the content that agencies need to successfully deploy the mature BIM processes.

1.4 REPORT ORGANIZATION

This report is organized into seven chapters.

Chapter 1 introduces BIM and presents the BIM components that have been established in FHWA's BIM NSR, as suggested pillars around which the BIM-based workflows could be designed. This chapter also presents the research objectives and how the report is organized to accomplish these objectives.

Chapter 2 presents a comprehensive analysis of business processes drawn from various phases of asset lifecycle (i.e., planning, survey, design, construction, and asset management), and lays out how the BIM maturity of these business processes can be enhanced by adopting BIM workflows. The data modeling, data management, and data-use improvement opportunities are identified across the processes used in all phases of asset lifecycle to assist an organization in transitioning to a higher BIM maturity level. These BIM maturity improvement opportunities are presented as BIM use cases. Ten high-value BIM use cases are presented. Each case was identified as a priority use case for BIM maturity improvement based on deliberations held with State Departments of Transportation (State DOTs) roadway and bridge design, construction, and asset management staff. The findings lay out the specific opportunities for improvement that were identified as part of this research. Chapter 2 also describes the foundation for identifying the artifacts used to deploy BIM-based workflows. The information presented in this chapter about the existing and BIM-based information management workflows will describe needed BIM artifacts and how a centralized BIM transportation library (CBTL) and a State BIM transportation library (SBTL) modeled on the CBTL would manage the artifacts.

Chapter 3 presents the types of BIM artifacts to be developed, standardized, and managed to enable deployment of BIM-based workflows in transportation business processes. These artifacts were identified based on the information about BIM-based workflows and business processes presented in Chapter 2 and are based on the artifacts identified in the FHWA research on the BIM NSR (Mallela and Bhargava, 2021). The following types of BIM artifacts for enabling BIM processes are presented in this chapter:

- BIM processes, workflows terms, and definitions.
- BIM information needs.
- BIM Object-Type Library (OTL) and Data Dictionary.
- BIM Information Delivery Manuals (IDM).
- BIM Information Exchange Specification (ILS).
- BIM Model View Definitions (MVDs).

The current state of practice in managing these BIM artifacts is also presented through descriptions of the BIM libraries and artifacts that have been created at the national and State levels by transportation agencies and standards development organizations (SDOs). The platforms and tools used for management of the libraries and the artifacts in these libraries have also been identified. The chapter establishes the benefits of hosting all BIM artifacts in a centralized library.

Chapter 4 introduces one possible method to manage the BIM artifacts. A CBTL is suggested to enable BIM-based workflows at transportation agencies. The suggested characteristics for a CBTL are presented, followed by examples from countries where such national libraries have been deployed to advance BIM. A high-level architecture of a CBTL is presented to establish how BIM artifacts could be managed in the library, as well as how stakeholders such as State DOTs could leverage the content in a CBTL to develop State-specific BIM artifacts.

Chapter 5 uses the BIM artifacts (i.e., the OTL and data dictionary) to illustrate how the content in a CBTL could be set up, managed, and provisioned for use. The chapter builds on the OTL and data dictionary information and uses examples presented in Chapters 3 and 4 to show how a CBTL data architecture could store and manage versions of various national and international standard OTLs and data dictionaries and how such content could later be used to develop the centralized OTL and data dictionary that would cover all information associated with asset lifecycle.

Chapter 6 describes the technical aspects associated with development, deployment, and administration of a CBTL. This chapter builds on an CBTL concept and vision presented in Chapter 3 and describes the following:

- The people, roles, responsibilities, and process interactions associated with CBTL development and administration.
- The central database that could be deployed to store the BIM artifacts that are managed in a CBTL.
- The version control management system and processes that could be used to administer the changes to the BIM artifacts stored in the library.
- The application programming interface (API) that could be deployed to provide CBTL resources to stakeholders.
- The community portal that could be used to host the APIs associated with the BIM artifacts in a CBTL.

Chapter 6 uses the BIM data dictionary as an example to present these five aspects associated with CBTL development, deployment, and administration. In presenting a CBTL database, APIs, version control system, and collaboration portal, the chapter uses the BIM data dictionary as the basis to explain how each of these aspects could be realized. However, the concepts could be extended to other BIM artifacts that are identified in Chapter 3 (i.e., the BIM processes, information needs, OTL, data dictionary, IDMs, ILS, and MVDs).

Chapter 7 summarizes the contributions of this research and presents concluding remarks and high-level suggestions associated with deploying BIM-based workflows for business processes and creating a BIM library to manage artifacts to enable the BIM workflows.

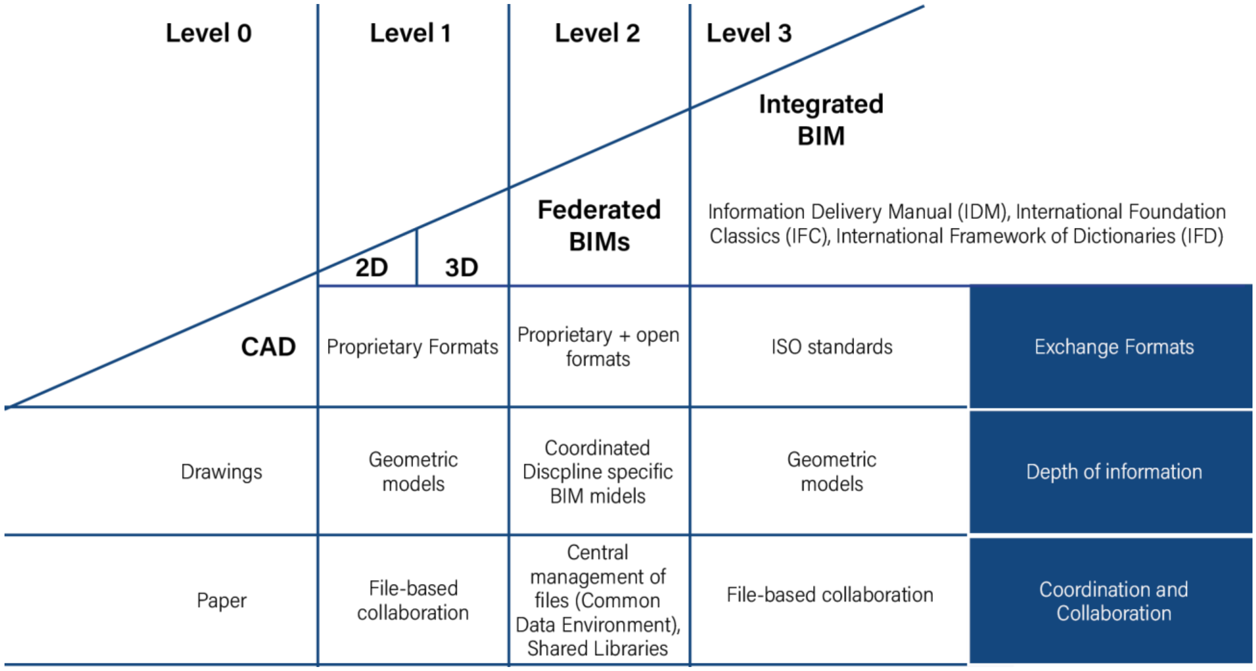
CHAPTER 2. BIM-BASED WORKFLOWS FOR BUSINESS PROCESSES

2.1 INTRODUCTION

This chapter discusses BIM maturity levels and identifies BIM workflows and high-value BIM use cases within these workflows as identified by State DOTs. The chapter then uses the BIM maturity scale to lay out improvements that could be made to enhance and deploy data modeling, data management, and data-use processes for enabling BIM-based digital workflows.

Figure 2-1 shows a maturity scale that was identified for use in this research to help communicate the type of improvements that could be made in existing information management business processes. Variants of this maturity scale are used in the industry currently to deploy BIM and measure progress, e.g., FHWA’s BIM NSR (Mallela and Bhargava, 2021). In general, most of these maturity scales focus on moving away from existing computer-aided design (CAD) drawings and document- or file-based information modeling processes to data- or object-based, integrated BIM processes. These maturity scales identify possible milestones as document-centric modeling processes migrate to integrated BIM (iBIM) processes. Figure 2-1 shows these different milestones. Some milestones include:

- Developing two-dimensional (2D) and three-dimensional (3D) geometric data models that use proprietary formats, followed by enabling import and export of data captured in these data models using open-data modeling and exchange specifications.
- Adding intelligence to geometric data models by capturing asset information in the data model from various individual disciplines and creating BIM models as opposed to CAD drawings or geometric data models. Achieving this milestone would involve increasing the depth of information in the data model.
- Enabling a federated system for integrating data from authoritative systems of record (SoRs) to create the coordinated discipline-specific and integrated interoperable building information models. The focus would be to ensure that the data needed to enhance the geometric data models and create the building information models can be acquired efficiently and automatically from various discipline-specific SoRs.



Borrmann et al. (2018).

Figure 2-1. Chart. Building information modeling maturity.

As shown in the figure, BIM maturity increases as data modeling, data management, and data-use processes for enabling BIM-based digital workflows mature. Explanations of these terms as used in this report are presented in the following subsections.

2.1.2 Data Modeling

Data modeling involves recording data in hard copy or in electronic flat files in an unstructured or semi-structured format (e.g., excel spreadsheets), or recording data using object-based data models using standard semantics (i.e., meanings) for object name, description, and properties.

In a mature BIM process embodied by iBIM, data modeling steps involve:

- **Defining the data creation needs using standards and guidelines**, such as those specified in International Standard Organization (ISO) 19650[5], to emphasize defining information needs both during project delivery (e.g., exchange information requirements [EIRs] and project information requirements [PIRs]) and outside project delivery (e.g., organizational information requirements [OIRs], asset information requirements [AIRs]). This involves establishing the level of development (LOD) specification for each data model (referred to as Level of Information Need in ISO 19650[5]). As shown in Table 2-1, the LOD specification lists the level of accuracy in geometry, as well as the level of information with non-graphical content. An LOD specification should be associated each model during the different asset lifecycle

[5] Use of ISO 19650 is not a Federal requirement.

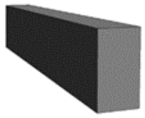
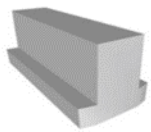
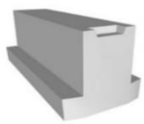
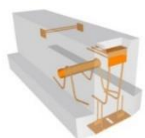
phases to establish what information is captured in the model. For example, at LODs 200 through 500, Table 2-1 indicates that non-geometric or non-graphical information may be attached to the model. The amount of non-graphical information developed at an LOD stage is termed level of information. Examples of level of information captured in a data model include:

- Historical and projected traffic and safety information that is spatially and temporally referenced.
- Maintenance of traffic information.
- Project schedule and phasing information.
- Project cost estimation information.
- Environmental commitments.
- Sustainability-related information, such as energy analysis and sustainable element tracking information.
- Information about lifecycle strategies, as-built data, and maintenance plans.

Overall, in a BIM-enabled business process, the LOD specification (Table 2-1) and level of information are both parts of the BIM data model definition. Figure 2-1 shows that at federated and integrated BIM maturity levels, the design models created are not simply geometric models and contain increased depth of information. More interdisciplinary coordination happens at BIM maturity Levels 2 and 3 to incorporate more intelligent data concerning the built assets.

- **Establishing the format in which data would be captured in the model** (e.g., drawings, documents, space model). Survey, design, and construction data models are currently created as 2D/3D geometry models with little or no structured information about the properties of the physical infrastructure object represented by the geometry. Information associated with dimensions and classification of the object that is modeled in the data model is stored as alphanumeric text that is annotated on digital drawing files. It is hard to extract information about object properties in this format and hand this information off to asset managers. Therefore, data could be better modeled by defining a structured property data form. The structured data format may be referred to as item types at most State DOTs or as property sets in open-data standards such as Industry Foundation Classes (IFC). According to Figure 2-1, when information is modeled and exchanged using such IFC standards, Level 3 BIM maturity is reached.

Table 2-1. BIM level of development specifications.

Level of Development	3D View	Description
LOD 100		Model elements that indicate quantity, area, height, volume, size, shape, location, and orientation are modeled geometrically or graphically represented by other data (**pre-design geometry**) (e.g., symbol — G — for a gas line or a pump symbol for a pump). They are graphically represented within the model as a conceptual-design system, object, or assembly with pre-design geometry (do not satisfy LOD 200 specifications). Information related to the model element can be derived from other model elements.
LOD 200		Model elements are modeled as generalized systems, objects, or assemblies in terms of approximate quantity, size, shape, location, and orientation (**approximate geometry**). They are graphically represented within the model as a preliminary or detailed design generalized system, object, or assembly with approximate geometry. Non-geometric or non-graphical information may also be attached to model elements.
LOD 300	 	Model elements are modeled as specific systems, objects, or assemblies that are accurate in terms of quantity, size, shape, location, and orientation (**precise geometry**) and with interfaces with other components (**precise geometry with connections**). They are graphically represented within the model as a detailed or final design or construction-specified system, object, or assembly with precise geometry with interfaces with other components. Model elements are precisely defined with exact dimensions and outline an element's relation and connection with other infrastructure or building system components and can be measured directly from the model without referring to nonmodeled information such as notes or dimension callouts. The program origin is defined, and the element is located accurately with respect to the program origin. Non-geometric or non-graphical information may also be attached to model elements.
LOD 400		Model elements are modeled as specific systems, objects, or assemblies that are accurate in terms of quantity, size, shape, location, and orientation (**fabrication-ready geometry**). They are graphically represented within the model as a fabrication specific system, object, or assembly. Model elements include detailing, fabrication, assembly, and installation information about the construction of various elements and can be measured directly from the model without referring to nonmodeled information such as notes or dimension callouts. Non-geometric or non-graphical information may also be attached to model elements.
LOD 500		Model elements are modeled as specific systems, objects or assemblies that are field-verified representations in terms of quantity, size, shape, location, and orientation (**field-verified geometry**). They are graphically represented within the model either as a field-verified either as a specific system, object and assembly or verified to practical completion. Model elements are field-verified representations with real-life functions of the elements of the infrastructure or building system components with associated operational information. Non-geometric or non-graphical information may also be attached to model elements.

Adapted from AIA (2008) and BIM Forum (2020c).

2.1.3 Data Management

At higher BIM maturity levels, as shown in Figure 2-1, data from multiple disciplines are integrated in a cloud-based BIM hub. Data integration is needed to create data models to support cost, schedule, asset maintenance and operations and asset management. Achieving this state involves data management, wherein the following aspects would be built into the BIM data and standards ecosystem:

- Testing and validation of data models can be created in each discipline through implementation of data quality assurance/quality control (QA/QC) rules and processes for data at each stage of the model development process. Tests could include validating how an object in the data model is tagged using the item type description and how it is classified using an open standards-based classification system. Tests could also include parametric modeling calculations based on parametric formulations and rule sets that were configured in the design system. Ensuring that data are checked through QA/QC processes and comply with enterprise data modeling standards can assist an agency in integrating data across disciplines.
- Paper documents, files, and data models can be shared across different business users, processes, applications, tools, and technology. File directories, content management systems, data warehouses, enterprise databases, data lakes, or federated web servers can be used to establish a common data environment (CDE) that facilitates sharing data.

The data management steps described above specifically highlight that the non-geometric data needed in the data model at LODs 300 through 500 (as mentioned in Table 2-1) can be incorporated into the data model.

2.1.4 Data Use

Data use involves establishing the various business processes and stakeholders that could use the data model created during a certain process. Currently, many data models are created for a limited number of stakeholders. For example, design data models are typically created for use in the design and construction phases. AIMs are typically created for use across different business processes and users in the planning, operation, and maintenance phases of the asset lifecycle. In a mature BIM framework, data models created during any phase of the asset lifecycle could be carried over and used across multiple downstream business processes. For example, construction engineers and asset managers could use design data models to determine what assets are planned for construction. Construction data models (e.g., as-builts) could be handed off to asset managers for use in asset management during the operation and maintenance phase. However, the LOD or the Level of Information Need per ISO 19650 associated with the data model varies by the BIM use case or business process it supports within a lifecycle state.

2.2 BIM WORKFLOWS, BUSINESS PROCESS, AND USE CASES

As noted in Chapter 1, BIM is a work method that involves structuring, managing, and using data, tools, and technology so that data flow across all asset lifecycle phases efficiently. To deploy and operationalize BIM, an organization should embrace BIM-based policies; process steps; workforce upskilling; data standards; and enhanced data modeling and data management practices, tools, and technologies across all relevant business units.

The asset data lifecycle has traditionally been divided into following phases: planning, survey, design, construction, and asset management (Mallela and Bhargava, 2021). The research team identified workflows that involve data modeling, management, and use across multiple phases as a first step and labeled them BIM workflows. Next, the research team identified the business processes and sub-processes from across asset lifecycle phases that should be systematically integrated and considered in each phase to have a unified workflow view (as opposed to treating them as separate business processes). The processes and sub-processes within these BIM workflows were combined so each workflow achieves a certain goal (i.e., produces the right deliverable(s) to the right end user). This allows the data exchanges that happen across processes from different lifecycle phases to be envisioned as data modeling, management and use frameworks that need to be deployed to achieve the organizational goals associated with each workflow. The various BIM workflows considered in this research are discussed in the following paragraphs.[3]

- **BIM Workflow 1: Planning, Survey and Design (PSD) Processes:** The first workflow is created by integrating the following business processes from the planning, survey, and design (conceptual and preliminary) phases:
    - Project scoping documents development.
    - Environmental analysis.
    - Survey.
    - Alternatives development.
    - Alternatives analysis and selection.
    - Preliminary roadway geometry and corridor design modeling.
    - Development of right-of-way (ROW) and access plans.

At a higher level, the strategic goal of an agency is to prepare a project for detailed design and analysis (DA) by conducting these initial project development activities. At the end of these processes, the goal is to have a project information model (PIM) that can be used to visualize the project site and the roadway assets contained within it and the roadway geometry in the ROW corresponding to the project design alternative that has been selected after environmental analysis.

- **BIM Workflow 2: Design and Analysis (DA) Processes:** This second workflow involves integrating business processes from preliminary design, detailed design, structural analysis, and final design. After the conceptual project site visualization model has been created, and the preliminary design for roadway geometry and assets are available, stakeholders in each of the design disciplines (e.g., highway design, safety, structural, geotechnical, hydraulic) use the information to conduct analysis). Detailed design models are created for each discipline. The information is integrated into a final design model, which can be provided to the construction contractor as a digital model to facilitate construction.
- **BIM Workflow 3: Design and Construction (DC) Processes:** This third workflow involves integrating business processes that involve the following:

   - Developing the final design model.
   - Delivering the final design model to the construction contractor.
   - Developing detailed models for use in fabrication and construction.
   - Construction inspection
   - Acceptance and payment

  The workflow starts with the use of a digital construction model that was provisioned to the construction contractor at letting. This model may be used for further development by adding details needed for automated machine guidance (AMG) based construction, fabrication of structural components, and construction.

- **BIM Workflow 4: Design, Construction, and Asset Management (DCA) Processes**: This fourth workflow involves integrating business processes after construction that involve:
   - Delivery of the as-built data model that meets the agency's information requirements (e.g., AIRs and EIRs).
   - In-service safety inspection
   - Condition assessment and load rating data

  This workflow involves integrating data models from final design and construction into an asset information model (AIM), and therefore relies on the integration of business processes from the design, construction, and asset management phases of an asset's lifecycle.

Corresponding to each of these workflows, the research team identified certain business processes for comprehensive analysis. The objective of this analysis was to lay out the specific data modeling, data management, and data-use processes and standards that should be deployed during these processes to increase BIM maturity. These business processes were identified so that they can serve as an example of how data and process standards can be enhanced to deploy an iBIM workflow. Across the 4 BIM workflows, 10 specific business processes were shortlisted as priority ***use cases*** to illustrate how data and process standards could be incorporated for achieving iBIM deployment. These are as follows:

- Business processes in BIM Workflow 1 that were identified as priority use cases:
   - PSD.1 - Create project scoping documents for design engineers from planning data.
   - PSD.3 - Create visualizations for alternatives evaluation and public outreach.
- Business processes in BIM Workflow 2 that were identified as priority use cases:
   - DA.9 - Provide data for interdisciplinary coordination and clash detection.
   - DA.11 - Develop final structural analysis model.
   - DA.12 - Produce final plans and model.
- Business processes in BIM Workflow 3 that were identified as priority use cases:

- DC.2 - Create detailed quantity take-off and estimate.
- DC.3 - Provide design information for AMG.
- DC.6 - Develop and review shop drawings and models.
- DC.7 - Verify construction results and record as-built data.

- Business processes in BIM Workflow 4 that were identified as priority use cases:
  - DCA.3 - Provide routine bridge inspection data for asset management.

Table 2-2 presents the model production and delivery table that shows the LOD of data models created in each of the 10 priority iBIM business processes or use cases. Figure 2-2 presents how these data models may interact for iBIM deployment along with all other data models (including those for both the priority use cases as well as other important use cases that did not fall in the top 10).

Table 2-2. Object-based model production and delivery during BIM-enabled business processes.

ID	Priority Use Case	Planning (P)	Surveying (S)	Conceptual Design (CD)	Preliminary Design (PD)	Detailed Design (DD)	Final Design (FD)	Fabrication & Construction (C/F)	Asset Management (AM)
1	PSD.1 - Create project scoping documents for design engineers from planning data.	Planning Model *LOD 100, 200*	Existing Conditions Model *LOD 200,300*	—	—	—	—	—	—
2	PSD.3 - Create visualizations for alternatives evaluation and public outreach.	Existing Conditions Model *LOD 200, 300*	Existing Conditions Model *LOD 200, 300*	Conceptual-Design Visualization Aesthetic Model *LOD 200*	Preliminary Design Visualization Aesthetic Model *LOD 200, 300*	Detailed & Draft Design Visualization Aesthetic Model *LOD 300*	Final Design Visualization Aesthetic Model *LOD 300*	—	—
3	DA.9 - Provide data for interdisciplinary coordination and clash detection.	—	—		Preliminary Design Model[1] *LOD 200, 300*	Advanced Design Model[1] *LOD 300*	Final Design Model[1] *LOD 300*	—	—
4	DA.11 - Develop final structural analysis model.	—	—	—	—	Final Structural Analysis Model *LOD 300*	—	—	—
5	DA.12 - Produce final plans and model.	—	—	—	Preliminary Design Model[1] *LOD 200,300*	Advanced Design Model[1] *LOD 300*	Final design model[1] *LOD 300*	—	—
6	DC.2 - Create detailed quantity take-off and estimate.	—	—	Conceptual Design Model[1] *LOD 200*	Preliminary Design Model[1] *LOD 200,300*	Advanced Design Model[1] *LOD 300*	Final Design Model[1] *LOD 300*	Construction Contract Model *LOD 300, 400*	—
7	DC.3 - Provide design information for AMG.	—	—	—	—	—	Final Design Model[1] *LOD 300*	Final AMG-Ready Model *LOD 300*	—
8	DC.6 - Develop and review shop drawings and models.	—	—	—	—	—	—	Final Detailing Model *LOD 400*	—

ID	Priority Use Case	Planning (P)	Surveying (S)	Conceptual Design (CD)	Preliminary Design (PD)	Detailed Design (DD)	Final Design (FD)	Fabrication & Construction (C/F)	Asset Management (AM)
9	DC.7 - Verify construction results and record as-built data.	—	Existing Conditions Model *LOD 300, 500*	—	—	—	—	As-Built Model *LOD 300, 500*	—
10	DCA.3 - Provide routine bridge inspection data for asset management.	—	—	—	—	—	—	—	Asset Information Model (Geographic Information Systems [GIS]) *LOD 300, 500*

[1] Design models for (a) roadway geometry, (b) structural design, (c) pavement, (d) geotechnical, (e) hydraulic design, (f) traffic and safety, (g) utilities, and (h) grading.

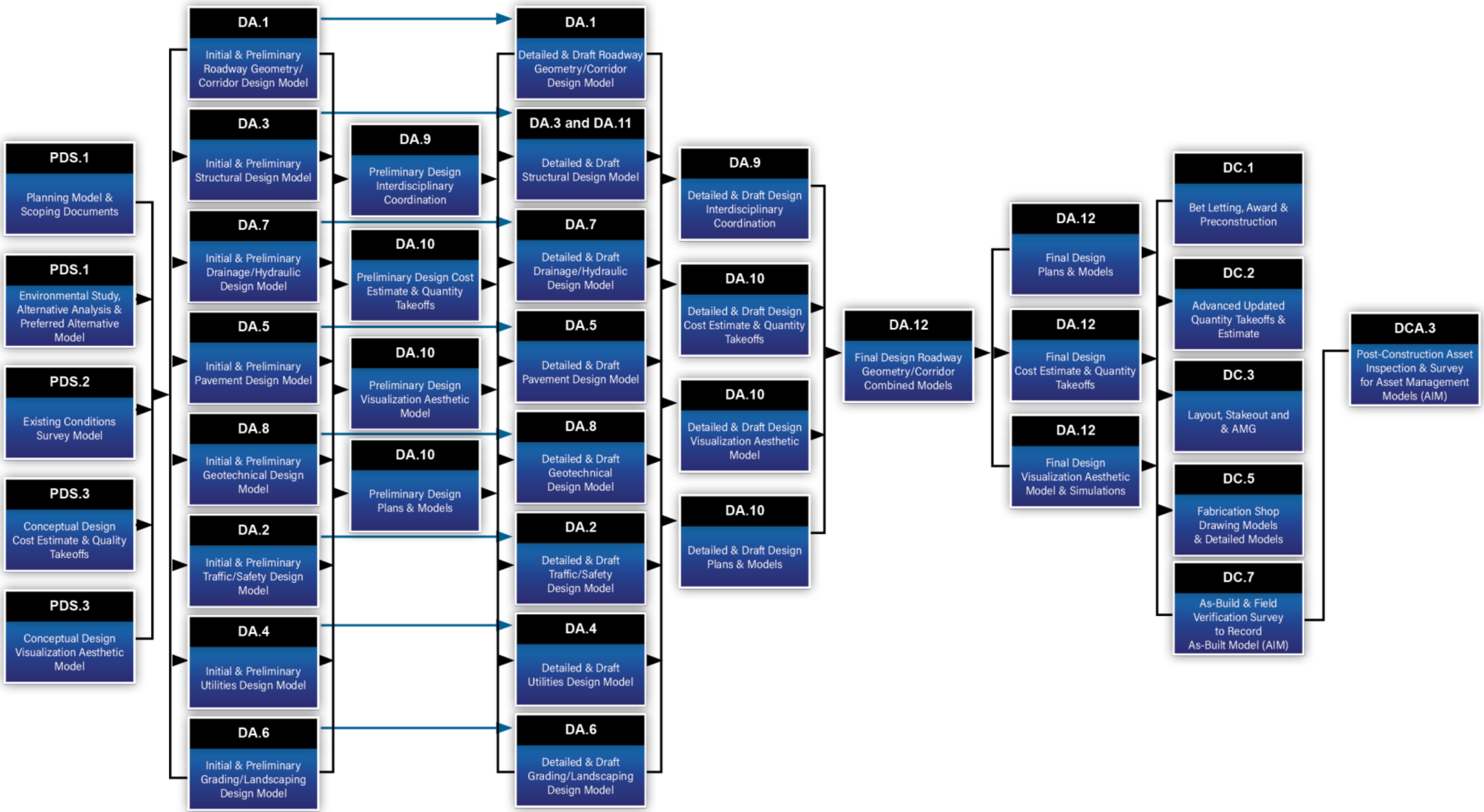


Figure 2-2. Flowchart. BIM use cases and data models created and exchanged during project delivery and asset handover.

2.3 BIM WORKFLOW 1: DATA AND PROCESSES ACROSS PLANNING, SURVEY AND DESIGN

This section presents an example of the data and process standards that could be used to create an iBIM workflow across select business processes in PSD. Figure 2-3 presents the data and processes that could be integrated to create this iBIM workflow. As stated in section 2.1, the objective of integrating these data and processes in Figure 2-3 is to have a PIM to visualize and understand the project site and its existing conditions (e.g., assets, traffic, safety, environmental) to better to assist with public outreach, alternatives selection, and conceptual design. The data models created at the end of this workflow are provided to the designers to develop detailed designs.

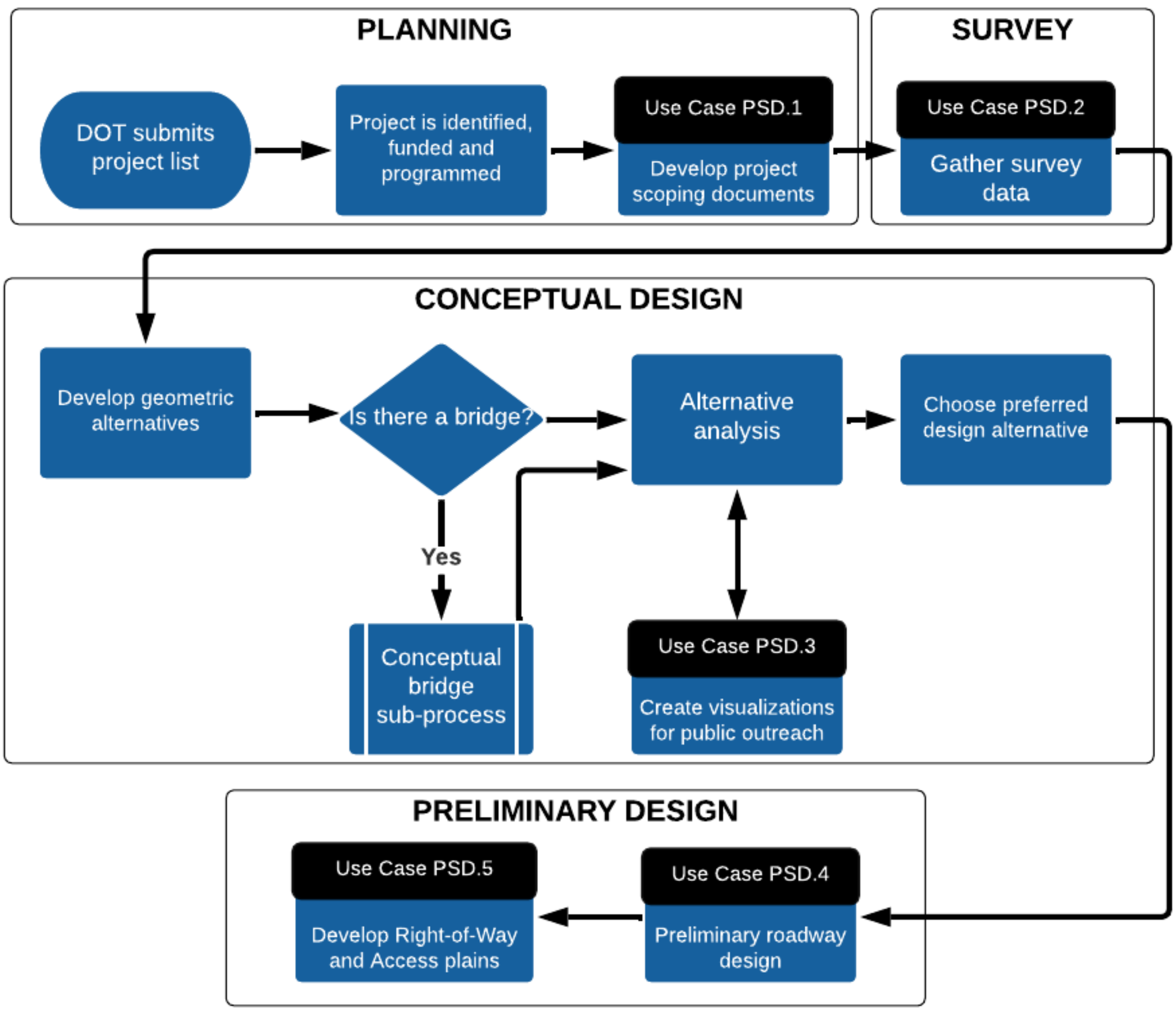


Figure 2-3. Flowchart. Integrated BIM workflow 1 depicting data and process flow across business processes and sub-processes in the planning, design, and survey phases.

This workflow starts when a list of potential candidate projects is compiled and made available for planning and programming. The list of capital projects is compiled from various stakeholders who identify the repair, rehabilitation, replacement, and new construction work that needs to be carried out across the network to improve system condition and performance. The projects are evaluated, and the selected projects are programmed into a transportation improvement program. Funding is assigned as part of programming to individually selected projects. Once a project is funded and authorized to proceed, planners initiate development of project scoping documents, and field activities related to project planning commence with an initial survey. The project scoping information and survey information are used to develop alternative designs for analysis and selection of a preferred design alternative. After the alternative is selected, it is delivered for preliminary design development, which involves creating a preliminary roadway design data model, followed by development of ROW and access plans.

The next section discusses the BIM data and process standards in the prioritized use cases "Create Project Scoping Documents for Design Engineers from Planning Data" business process (PSD.1) and in the "Create Visualization for Alternatives Analysis and Public Outreach" (PSD.2). With the discussion on each of these business processes, the goal is to present an example of how an iBIM collaboration (Figure 2-3) could incorporate such standards in each process that is part of the workflow.

2.3.2 Use Case PSD.1 - Create Project Scoping Documents for Design Engineers from Planning Data

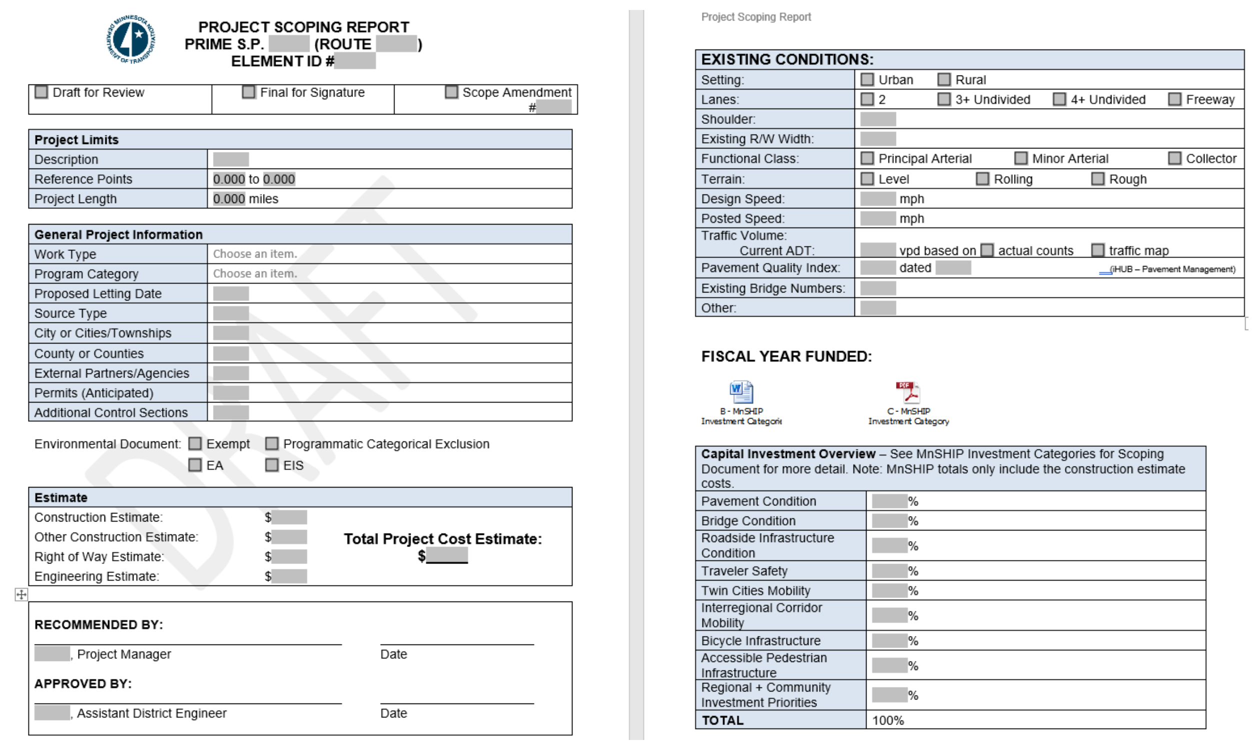
During the planning and scoping stage, the project purpose and need is defined. The initial alternatives generated are evaluated against the purpose and need with criteria that include cost, impacts, adherence to design standards, and performance. Performance is determined based on how well a given alternative satisfies the project's purpose and need. The project scoping activities and findings are documented in a project scoping document that defines the project and sets up the next stage of project approvals and environmental approvals. A traffic study or safety analysis supports the development of the initial alternatives. The environmental document and project approval document add engineering detail to the scoping alternatives previously developed and evaluate the environmental impacts to the local environmental resources of each alternative. The project approval document screens the alternatives for cost, ROW impacts, and performance. The approved document identifies a preferred alternative for final design after an objective and rigorous analysis of alternatives.

To help develop design alternatives for roadways, bridges, and structures, project scoping documentation provides a project's existing conditions such as project location, project maps, assets, and other pertinent information (e.g., past studies including traffic analysis, safety analysis, geotechnical studies, environmental analysis). The scoping report supports the development of project scoping alternatives.

Project scoping data are modeled in a document as opposed to in an object-based data model with project site, roadway and asset objects, and associated properties. To prepare the scoping document, existing data are retrieved from multiple authoritative SoRs manually or, in some cases, using semi-automated processes, tools, and techniques.

2.3.2.1 Data Modeling

In an iBIM workflow (Figure 2-4), an object-based data model could be created using open standards like the IFC to improve the definitions of data requirements and modeling. However, IFC is just a classification shell that provides standard classes that can be used to model infrastructure objects and does not define property sets or properties. For example, IFC specifies how project site, roadway, bridge, culvert, and other such assets can be modeled using IFC classes. IFC provides agency administrators with the ability to define property sets and identify properties that should be part of each set. Property sets and properties should be defined consistently and should be considered when statewide or national standards for how properties will be modeled and associated with infrastructure objects are developed.



PROJECT SCOPING REPORT
PRIME S.P. (ROUTE)
ELEMENT ID #

☐ Draft for Review	☐ Final for Signature	☐ Scope Amendment #

Project Limits	
Description	
Reference Points	0.000 to 0.000
Project Length	0.000 miles

General Project Information	
Work Type	Choose an item.
Program Category	Choose an item.
Proposed Letting Date	
Source Type	
City or Cities/Townships	
County or Counties	
External Partners/Agencies	
Permits (Anticipated)	
Additional Control Sections	

Environmental Document: ☐ Exempt ☐ Programmatic Categorical Exclusion ☐ EA ☐ EIS

Estimate		
Construction Estimate:	$	Total Project Cost Estimate: $
Other Construction Estimate:	$	
Right of Way Estimate:	$	
Engineering Estimate:	$	

RECOMMENDED BY:

, Project Manager Date

APPROVED BY:

, Assistant District Engineer Date

DRAFT

Project Scoping Report

EXISTING CONDITIONS:	
Setting:	☐ Urban ☐ Rural
Lanes:	☐ 2 ☐ 3+ Undivided ☐ 4+ Undivided ☐ Freeway
Shoulder:	
Existing R/W Width:	
Functional Class:	☐ Principal Arterial ☐ Minor Arterial ☐ Collector
Terrain:	☐ Level ☐ Rolling ☐ Rough
Design Speed:	mph
Posted Speed:	mph
Traffic Volume: Current ADT:	vpd based on ☐ actual counts ☐ traffic map
Pavement Quality Index:	dated (iHUB – Pavement Management)
Existing Bridge Numbers:	
Other:	

FISCAL YEAR FUNDED:

B - MnSHIP Investment Categories C - MnSHIP Investment Category

Capital Investment Overview – See MnSHIP Investment Categories for Scoping Document for more detail. Note: MnSHIP totals only include the construction estimate costs.	
Pavement Condition	%
Bridge Condition	%
Roadside Infrastructure Condition	%
Traveler Safety	%
Twin Cities Mobility	%
Interregional Corridor Mobility	%
Bicycle Infrastructure	%
Accessible Pedestrian Infrastructure	%
Regional + Community Investment Priorities	%
TOTAL	100%

Source: MnDOT (2022).

Figure 2-4. Screenshot. Sample contents of a project scoping report.

Table 2-3 presents an example of the types of property sets and properties for a project planning data model (with data relevant for project scoping). A project planning data model that contains this information in a structured or semi-structured geodatabase would be considered a BIM-mature, object-based data model. The non-geometric properties in the data model reflect the level of information needed.

Table 2-3. Example of BIM-mature object-based data model for the planning data model.

Property Set	Properties Description
Project location	**Non-Geometric**: Work locations (i.e., road name, begin and end points, or asset identification (ID)) **Geometric:** Project site, route, and asset(s) geometry
Project information	**Non-Geometric**: Project ID, name, description, program category, letting date, county, city
Asset information (existing as-built data)	**Geometric:** Roadway alignments, bridge location, linear geometry **Non-Geometric:** Condition data
Work information	**Non-Geometric:** Work code, work description
Roadway characteristics	**Geometric**: Shoulder width, lane width, median width, side slope characteristics, profile grades, cross slope grades, toll lanes **Non-Geometric:** Barrier type, median type, design speed, posted speed, traffic volume (average annual daily traffic), pavement surface type, tolling information, staging, and traffic handling
Cost estimates	**Non-Geometric:** ROW cost estimate (including utility costs), unit costs, engineering cost estimate, escalation, contingency
Traffic estimates	**Non-Geometric:** Opening year and design year forecast model, traffic operations (maintenance of traffic)

2.3.2.2 Data Management

The geometric and non-geometric attributes captured in the project planning data model (as shown in Table 2-3) are typically acquired from multiple authoritative SoRs. In the iBIM workflow, this would involve integrating data, processes, and systems that are owned by multiple disciplines within the transportation organization. For example, to acquire and integrate the properties shown in Table 2-3, the following data systems would likely need to be integrated:

- **Project Management System** typically holds information about project identification, name, description, location, work type, assets, and cost estimates.
- **Asset Management System** would be used to provide information about asset location in the project ROW.
- **Linear Referencing System** would provide the inventory of road locations and roadway characteristics that would be used as the master list for identifying the subset that are part of the project scope.
- **Traffic Management System** would provide information such as annual average daily traffic, peak-hour traffic, and average weekday and weekend traffic. The data would be referenced using linear or spatial location referencing methods so that traffic information for each segment of the road would be available for traffic and safety analysis and could be made available for alternatives evaluation and selection.

- **Safety Management System** would provide information on georeferenced crashes, high-volume crash locations, land use, and road network inventory.

The current process of bringing in information for the project scoping document from multiple sources follows several manual steps. The report is typically stored as PDF document(s) on a file directory or in a document management system. Some State DOTs have developed geospatial information systems that allow for the project scoping report to be attached as a document to a spatial feature (typically the road, asset, or other such feature that depicts the project site). For example, at the Minnesota Department of Transportation (MnDOT), project scoping reports can be retrieved using a web-based internal system that retrieves documents from a repository based on spatial queries on a map. Realistic materials, textures, and other enhancements are used to create varying levels of visual quality. At this stage, the models produced for visualization purposes are not typically accurate or data-rich for use in design (because designs would not have progressed adequately at this stage of the project).

The envisioned model-centric process needs to facilitate the collection and use of data associated with the project from and across all business functional units. The envisioned object-based project scoping data model may be provisioned to stakeholders using a CDE, which could be a geospatial data portal or a digital twin platform. Such a data-provisioning hub would allow the entire project delivery team to access the data in the project planning data model. Data would be seamlessly available from authoritative data sources such as project management systems, geographic information systems (GIS), asset management systems, and traffic management systems via APIs, and the interface would ensure that there is no loss of data. Data from each of the authoritative SoRs would be federated to ensure that the most recent version is available in the CDE.

To deploy the more integrated BIM workflow for this business process activity, the following steps may need to be conducted:

- Identify available geospatial data from project management.
- Perform a gap analysis of available data.
- Perform an initial data gathering process to fill in the data gaps.
- Send the geospatial data package from project management systems to conceptual-design software.

Once the authoritative systems are integrated using a federated architecture where data from the systems are made available through system-specific services, the PIM would be automatically generated with the project data needed for project scoping. To deploy such integrated BIM workflows, better linking of data and systems would be needed, along with well-defined information for project classifications because the current process follows several manual steps to compile information from multiple sources. Efficiency would be gained by automating manual processes for combining data, which would also provide a more consistent and better quality scoping document.

QA/QC of the data is an important step to integrate the data across systems. Such checks could be standardized at each agency, so that they can be consistently deployed across all applications. For example:

- For repair, rehabilitation, or replacement projects, a completeness check would confirm that all information about project assets is retrieved from the asset management system for establishing project context.
- A project and location check may occur to confirm that the location is correctly referenced and that the referencing system (linear or spatial) used to reference the location is up to date. For example, if a bridge location was retrieved from a bridge management system, the bridge latitude and longitude would have to be confirmed to map the bridge.

Table 2-4 presents the data quality checks that could be implemented in each of the data models in the authoritative system and the project planning data model that would be created by integrating data from these systems.

Table 2-4. Example data model QA/QC checks for the planning data model.

Property Set	QA/QC Check Description
Project Location	Geometric checks can be performed on project road geometry, project asset geometry, and project site geometry to ensure that all locations of work are correctly identified and are within the project site boundary. The road identification information (e.g., route ID, road name, functional class, facility type) align with the data in the authoritative system of record that is used to manage highway routes.
Asset Information	Asset identification information such as asset ID, asset name, and asset type are populated for all assets in the project.
Work Information	Work codes used to describe the type of work align with the standard work codes library (e.g., the highway performance monitoring system presents a standard list of work codes that most agencies use in their linear referencing systems). Project work codes can be aligned with this list.
Element Geometry	Visually check model against asset information and project location. Spot-check geometry through manual calculations. Spot-check quantities through manual calculations. Document quality control.

2.3.2.3 Data Use

The following stakeholders could use the project planning and scoping data model through the CDE:

- **Project managers** could oversee the design team and circulate the project scoping documents among the design engineers. Decisions made using the data in the model may be those associated with conducting a survey, planning the conceptual design work, or creating preliminary roadway geometry design. Typically, most of the data in the project scoping report are not carried over into the preliminary design data models (e.g., preliminary roadway geometry model or preliminary structural data model or aesthetic project site visualization model). The information captured in project scoping documents is usually referenced as stored and managed in the document and available via access to the file or document repository. However, with a project planning model, information related to project scope and extent, locations, assets, and their condition may be directly imported into the conceptual and preliminary design models in certain types of projects.

- The **environmental team** could use the object-based project planning model to ensure that the environmental impacts and requirements are included in the design documents to inform alternatives evaluation and accurately define environmental impacts, support analysis for technical documents, and support overall evaluation of project impacts and thus define the level of environmental documentation needed.
- The **design team** could use the data in the project planning model to develop conceptual level design alternatives, define criteria to evaluate the design, develop estimates, and apply the criteria to advance to a preferred alternative. Preliminary visualization models could be created using these data.
- **Surveyors** may use the information about project extent, assets, and routes to plan the survey. The light detection and ranging (LiDAR) and imagery data collected from the survey may be complemented by data in the geospatial project planning model to create aesthetic design data models or visualization models with additional information about project sites.

Figure 2-5 presents the data models from various disciplines and systems that may be integrated as part of this iBIM workflow to create the project planning model, and the data models that would use the information in the project planning model once it is created and provisioned through the CDE.

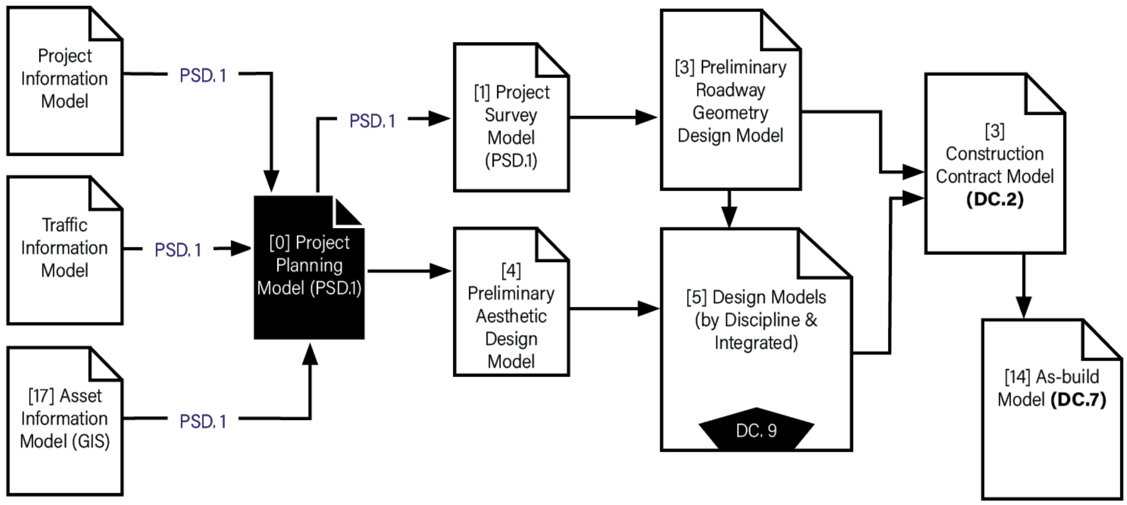


Figure 2-5. Flowchart. Example project planning data model use in downstream data models.

Note: The numbers in the square brackets in this and subsequent flowcharts represent the cataloged master BIM use case numbering used in this research.

2.3.3 Use Case PSD.3 - Create Visualizations for Alternatives Analysis and Public Outreach

The goals and uses of existing conditions and conceptual design visualizations (e.g., renderings, video simulations, and digital models) for transportation projects involving decision-makers, community leaders, stakeholders, and the public are to increase knowledge dissemination, assist in providing a better understanding of a project and its impacts, help evaluate conceptual alternatives, and generate consensus to select a preferred feasible alternative. Further visualizations are used to convey project design concepts to community stakeholders to evaluate alternatives and make decisions, and they are also used throughout the various design and construction phases (Table 2-2). However, the specific iBIM opportunity ensures that the data modeling and management processes around visualizations—initiated in the conceptual-design and existing conditions survey stage—are organized to support not only alternatives evaluation and selection but also other downstream visualization needs (LOD changes as design progresses).

Traditionally, visualizations for project alternatives selection overlay the design on 2D conceptual-design plans or 2D conceptual-design renderings with the project site, imagery, and features' existing conditions. In some cases, 3D design physical contextual models are overlaid on a map. After a preferred conceptual alternative is selected, designers can use 2D design plans, profiles, and cross sections generated from 2D/3D CAD models with imagery underlays or overlays when needed to generate design plans, specifications, and estimates (PS&E).

2.3.3.1 Data Modeling

The key discipline data models incorporated into the conceptual-design visualization aesthetic models and existing conditions survey models are described below. Much of the data needed for the visualizations in this stage flows from data modeled and gathered in PSD.1 (discussed in the previous section) and PSD.2—the survey workflow to capture existing conditions, which is not discussed herein but is important.

Alternatives Visualization Model during Conceptual Design

The key data (summarized below) for conceptual design data visualization models include discipline designs, existing digital as-builts, and ROW.

- **Roadway geometry data:** roadway centerline, pavement edge, grade, median, access, curb and gutter, sidewalk, shoulder, lane, and railroad.
- **Structural data:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects such as superstructure, substructure, deck, bridge type, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall (crash wall), wingwall, and slope protection.
- **Drainage data:** inlets, storm sewers, culverts, and outfalls.
- **Traffic and safety data:** traffic control signal, traffic sign, Intelligent Transportation Systems (ITS), Freeway Traffic Management System (FTMS), barrier, and lighting.
- **Utilities data:** existing utilities to be relocated.
- **Grading data:** grading for roadway, ramp, median, gore, and intersections.
- **Environmental data:** grading, wetlands impacts, ponds, and architectural buildings (to be relocated).
- **ROW, parcel, and easement data:** parcels, easement, and ROW.

Existing Conditions Survey Model

The key data incorporated and fused into the existing conditions survey model using geospatial reality capture methods are summarized below including aerial photogrammetry, unmanned aerial systems (UAS), LiDAR and global navigation satellite system (GNSS) real-time kinematic (RTK) and robotics total station technologies, existing digital as-builts, parcels, ROW, and statewide LiDAR data collection.

Many of these data types are similar to the conceptual-design models but, in this data model, existing conditions from historical as-builts or other project data would be updated with new survey captures.

- **Roadway geometry data:** roadway centerline, pavement edge, grade, median, curb and gutter, sidewalk, shoulder, lane, and railroad.
- **Structural data:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects that include

superstructure, substructure, deck, bearing, curb, sidewalk, median, deck drain, joint, haunch, girder, parapet, railing, abutment, pier, pier cap, pier column, pier wall (crash wall), wingwall, and slope protection.

- **Drainage data:** inlets, storm sewers, culverts, and outfalls.
- **Traffic and safety data:** traffic control signal, traffic sign, ITS, FTMS, barrier, and lighting.
- **Utilities data:** electric, telecommunications, utility poles, and other surface utilities.
- **Grading data:** grading for roadway, ramp, median, gore, and intersection.
- **Environmental data:** grading, vegetation cover, delineated wetlands, ponds, and architectural buildings.
- **ROW, parcel, and easement data:** parcel, easement, and ROW.

Table 2-5 presents the specific property sets and property descriptions for the alternatives visualization and aesthetic model and the existing conditions visualization aesthetic models.

Visualizations using traditional processes do not fully leverage the existing conditions survey models and geometry, features, and surface textures from 3D engineering models as aesthetic design models. Additions and revisions to these traditional design data visualizations are not transferred back for iterative re-engineering purposes. Figure 2-6 shows a static design rendering of a bridge overlaid on an existing photograph image used for evaluating a conceptual design alternative.

Source: © Caltrans (2022).

Figure 2-6. Image. Typical bridge design rendering on photo image.

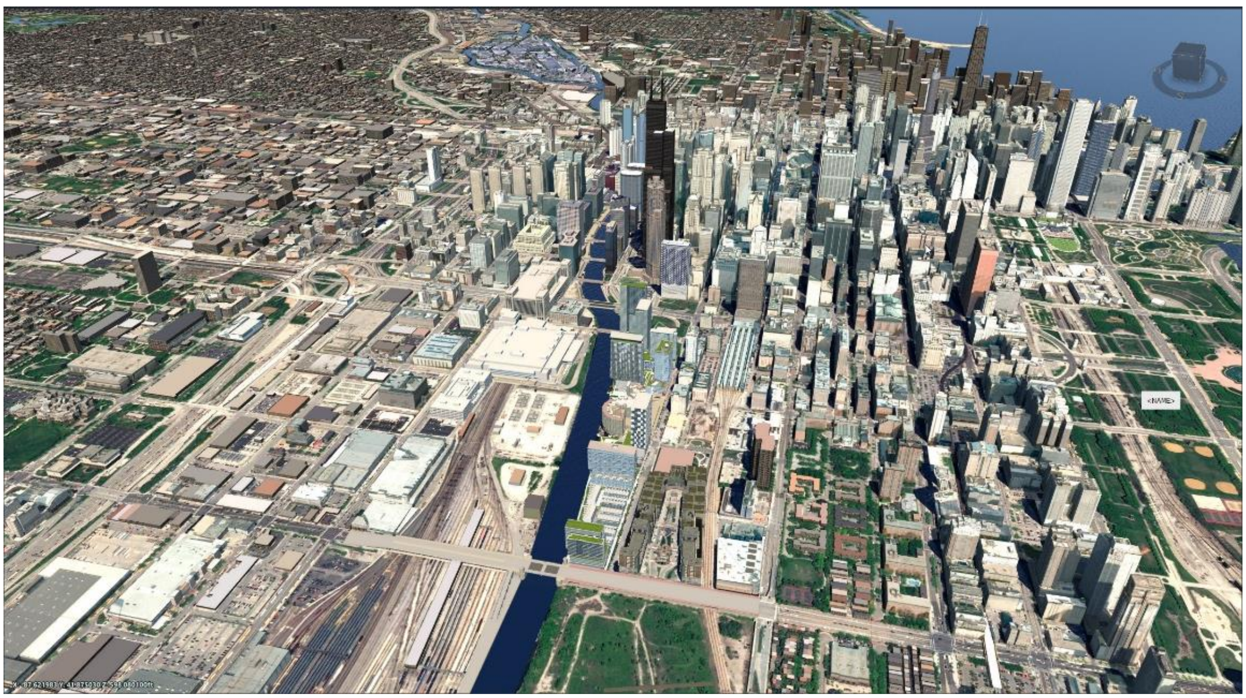
With BIM-enabled digital model-based processes, data-rich existing conditions and design 2D/3D data models are generated by discipline and combined as federated 2D/3D georeferenced data models with asset elements’ object geometry, attributes, and metadata. The design data are incorporated in key discipline data models:

- Roadway geometry.
- Pavement.

- Structural.
- Geotechnical.
- Hydraulic.
- Traffic and safety.
- Utilities.
- Grading.
- Other data models, including parcels, easements, ROW, environmental, architectural.

Using 3D data models, augmented reality models can be generated to show the existing conditions and future projection of vehicular traffic, relocated subsurface utilities, and construction sequencing phasing.

Figure 2-7 shows an example of a, 3D reality mesh of existing conditions generated from imagery, LiDAR, and surface data collected from surveys.



Source: FHWA

Figure 2-7. Example. Aerial imagery linked to a digital model (City of Chicago).

Figure 2-8 shows a 3D-digital design model underlay with imagery data to add new design and evaluate complex construction areas, contractor equipment access areas, and sequencing 4D stages with the construction schedule.

Figure 2-8. Visualization. 3D Digital design model underlay with imagery data.

Figure 2-9 shows a 3D-digital design model overlaid with a 3D reality mesh of existing conditions.

Source: © Dodge Data & Analytics (2017).

Note: LiDAR and reality mesh surfaces are not shown.

Figure 2-9. Visualization. Augmented reality simulated traffic and 3D digital design model overlaid on existing conditions 3D model imagery (Wisconsin DOT Zoo Interchange).

Figure 2-7 through Figure 2-9 showcase the full power of an iBIM process—in these examples, visualization quality improves as existing conditions survey data from multiple sources are fused and enhanced when the conceptual model is fused with survey data. To achieve greater levels of visualization and the attendant benefits, existing condition data and conceptual data models should be structured purposefully. Table 2-5 presents examples of property sets and properties for BIM-mature object-based data models for alternatives and existing conditions visualization.

Table 2-5. Example of a BIM-mature object-based data model for alternatives and existing conditions visualization.

Model	Property Set	Properties Description
Alternatives Visualization Models	Roadway geometry	**Geometric:** roadway centerline, pavement edge, grade, median, access, curb and gutter, sidewalk, shoulder, lane, railroad, etc. **Non-Geometric**: conceptual-design roadway pavement (lanes, shoulders, etc.)
Alternatives Visualization Models	Structural	**Geometric:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects, including superstructure, substructure, deck, bridge type, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall (crash wall), wingwall, slope protection, etc. **Non-Geometric**: conceptual bridge and structures (type, lanes, etc.)
Alternatives Visualization Models	Drainage	**Geometric:** inlets, storm sewers, culverts, outfalls, etc. **Non-Geometric**: conceptual drainage
Alternatives Visualization Models	Traffic and safety	**Geometric:** traffic control signal, traffic sign, ITS, FTMS, barrier, lighting, etc. **Non-Geometric**: conceptual-design traffic and safety (volumes, crashes, etc.)
Alternatives Visualization Models	Utilities	**Geometric:** electric, telecommunications, utility poles, and other surface utilities relocations **Non-Geometric**: conceptual utility relocation (type, depths, location, etc.)
Alternatives Visualization Models	Grading	**Geometric:** grading for roadway, ramp, median, gore, intersection, etc. **Non-Geometric**: design grading
Alternatives Visualization Models	Environmental	**Geometric:** grading, wetlands impacts, ponds, architectural buildings (to be relocated), impacts **Non-Geometric**: environmental impacts
Alternatives Visualization Models	ROW, parcel, and easement	**Geometric:** ROW, parcels, easement, etc. **Non-Geometric**: ROW impacts
Existing Conditions Survey Model	Roadway geometry	**Geometric:** roadway centerline, pavement edge, grade, median, access, curb and gutter, sidewalk, shoulder, lane, railroad, etc. **Non-Geometric**: roadway section as-built PDFs

Model	Property Set	Properties Description
Existing Conditions Survey Model	Structural	**Geometric:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects including superstructure, substructure, deck, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall (crash wall), wingwall, slope protection, etc. **Non-Geometric**: bridge and structure as-built PDFs
Existing Conditions Survey Model	Drainage	**Geometric:** inlets, storm sewers, culverts, outfalls, etc. **Non-Geometric**: drainage as-built PDFs
Existing Conditions Survey Model	Traffic and safety	**Geometric:** traffic control signal, traffic sign, ITS, FTMS, barrier, lighting, etc. **Non-Geometric**: traffic and safety as-built PDFs
Existing Conditions Survey Model	Utilities	**Geometric:** electric, telecommunication, utility poles, and other surface utilities. **Non-Geometric**: utility as-built PDFs
Existing Conditions Survey Model	Grading	**Geometric:** grading for roadway, ramp, median, gore, intersection, and surrounding topographic digital-terrain model (DTM) survey fused with imagery data collection **Non-Geometric**: spot-check elevations
Existing Conditions Survey Model	Environmental	**Geometric:** existing grading, delineated wetlands, ponds, architectural buildings, etc. **Non-Geometric**: environmental documents
Existing Conditions Survey Model	ROW, parcels, and easement	**Geometric:** parcels, easement, and ROW, etc. **Non-Geometric**: property PDFs and photographs

2.3.3.2 Data Management for the Alternatives and Existing Conditions Visualization Models

In a BIM-enabled process, design model creation is the first step (e.g., for a conceptual design). Authoring tools model data in proprietary formats (e.g., .dgn, .dwg, .rvt) support export to IFC for viewing the model. As the conceptual model is set up, the non-geometric data listed in Table 2-5, such as property lines and environmental feature data, can be incorporated. Such non-geometric data can be stored in GIS repositories and incorporated into the geometric data model, which presents a great iBIM opportunity.

The next step is visualization. Progressing the geometry model from the previous step into a visualization model constitutes the second major iBIM opportunity to understand project alternatives and design concepts. There are several standard design visualization applications that work easily with direct inputs from the geometric model. Extended reality immersive game engines can also be used for visualization. These tools support development of navigation and movement control, sound, scripting, animations, artificial intelligence, networking, streaming, virtual reality, and real-time photorealistic simulation.

Table 2-6 presents the data quality checks that could be implemented in each of the data models used in the alternative conceptual-design aesthetic models and existing conditions survey model that are created for visualizations.

Table 2-6. Example alternatives and existing conditions visualization data model QA/QC checks.

Model	Property Set	QA/QC Check Description
Alternative Visualization Models	All key conceptual design discipline elements	Geometric geospatial coordinate system and projection checks and visual QA/QC checks would be performed on all needed alternative design disciplines.
Existing Conditions Survey Model	All survey elements	Geometric geospatial coordinate system and projection checks, QA/QC spot checks, visual QA/QC checks, and data fusion checks would be performed on all survey data elements involved in the existing conditions survey model.

2.3.3.3 Uses for the Alternatives and Existing Conditions Visualization Data Model

The following stakeholders could use the alternatives analysis and conceptual design alternatives visualization models:

- Project managers could use the alternatives analysis and conceptual-design alternatives visualization models to work with the community to explain the project and impacts and to select a preferred alternative.
- The environmental team could use the object-based visualization models to ensure that the environmental impacts, requirements, and commitments are met in the approved environmental study and that public outreach is incorporated into the design to ensure that environmental regulations are followed.
- Community leaders could use the alternatives analysis and conceptual-design alternatives visualization aesthetic models to understand and evaluate the project and its impacts and to select a preferred feasible alternative.
- The design team could develop the alternatives analysis and design alternatives visualization models to generate conceptual designs, criteria, impacts, costs, and initial schedule using project scoping documents from PSD.1 to advance to a preferred conceptual-design alternative, initial design, and preliminary design data models.
- Surveyors could provide the existing conditions survey model using geospatial reality capture methods, including UAS, LiDAR, and GNSS RTK technologies; subsurface location methods such as ground-penetrating radar, electromagnetic, and subsurface utility and pipeline mapping technologies; and E-construction data collection methods such as mobile tablets, survey data collectors, smartphone devices, and mobile applications to compile and fuse survey base maps for designers to generate conceptual design alternatives visualization models.

The existing conditions model could support the development of the preliminary roadway geometry model and the conceptual design model, which could be progressed to support discipline-specific models for the chosen alternative as the LOD is increased.

Figure 2-10 presents the conceptual design alternative visualization data models and existing conditions survey data model that may be integrated as part of this iBIM workflow to create the initial design models to generate preliminary design discipline data models provisioned through the CDE.

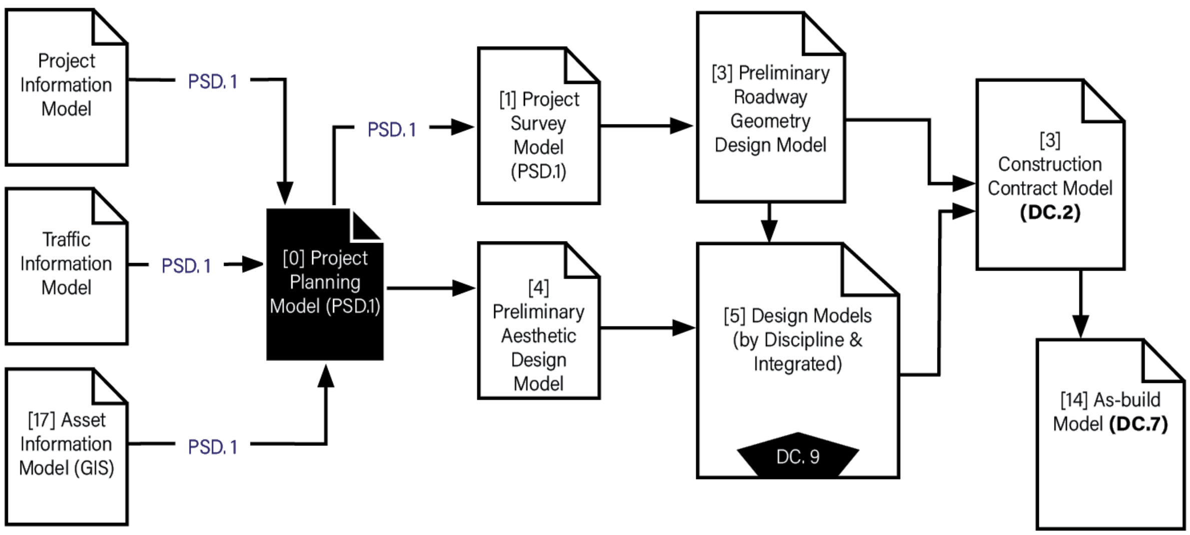


Figure 2-10. Flowchart. Integrated BIM workflows indicating downstream uses for the existing conditions and conceptual-design models.

Note: The numbers in the square brackets in this and subsequent flowcharts represent the cataloged master BIM use case numbering used in this research.

2.4 BIM WORKFLOW 2: DATA AND PROCESSES ACROSS DESIGN AND ANALYSIS

Figure 2-11 shows the business processes and sub-processes in the iBIM workflow that span the DA phases. This process relies on coordination between disciplines because it involves all disciplines. As the design progresses from preliminary design to final design, all disciplines need to coordinate interdisciplinary conflict review and resolution and exchange critical design information. This phase has traditionally been the target of many BIM maturity discussions. Because of the extensive use of modeling tools in both the bridge structural design process and geometric design process, the research team affords it special attention in this report. Figure 2-12 illustrates how bridge designs are advanced from preliminary to final design.

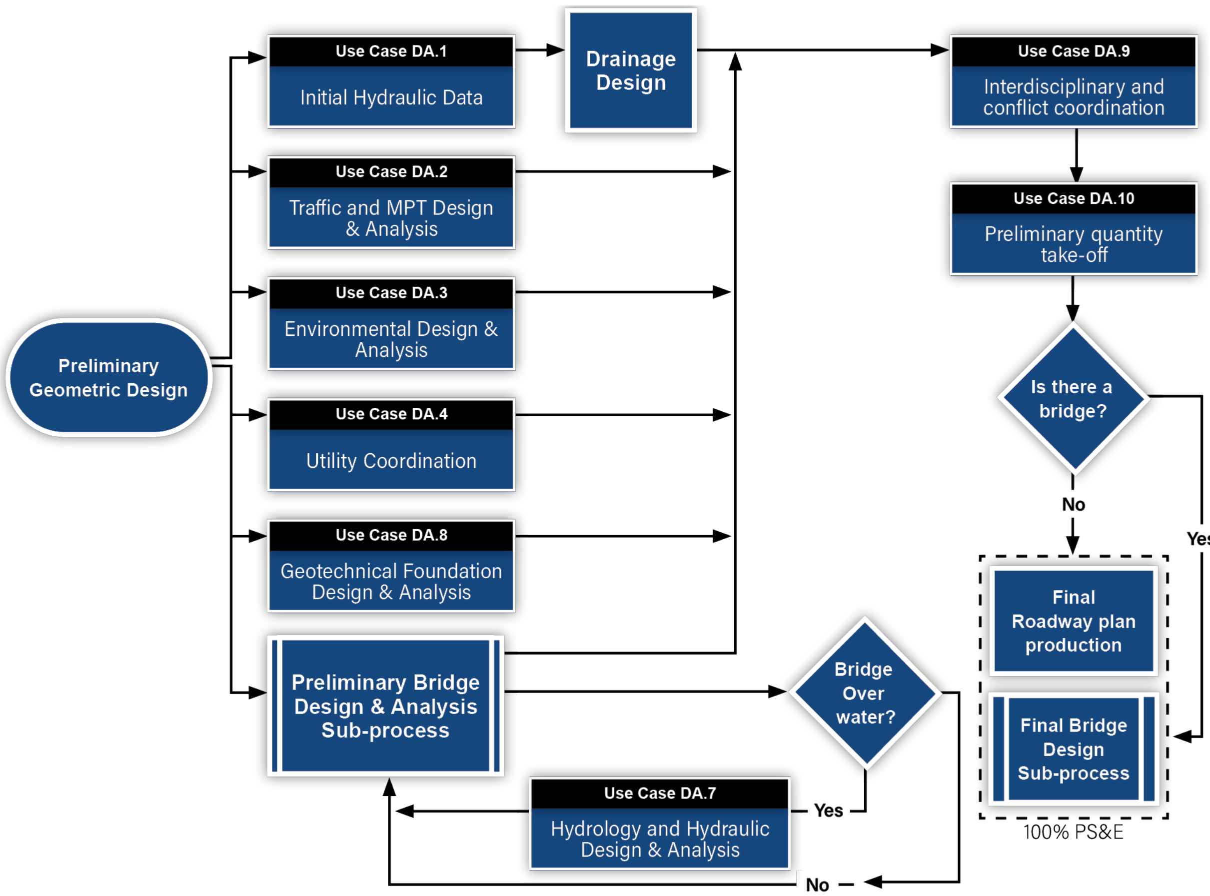


Figure 2-11. Flowchart. Integrated BIM Workflow 2 depicting data and process flow across business processes and sub-processes in the design and analysis phases.

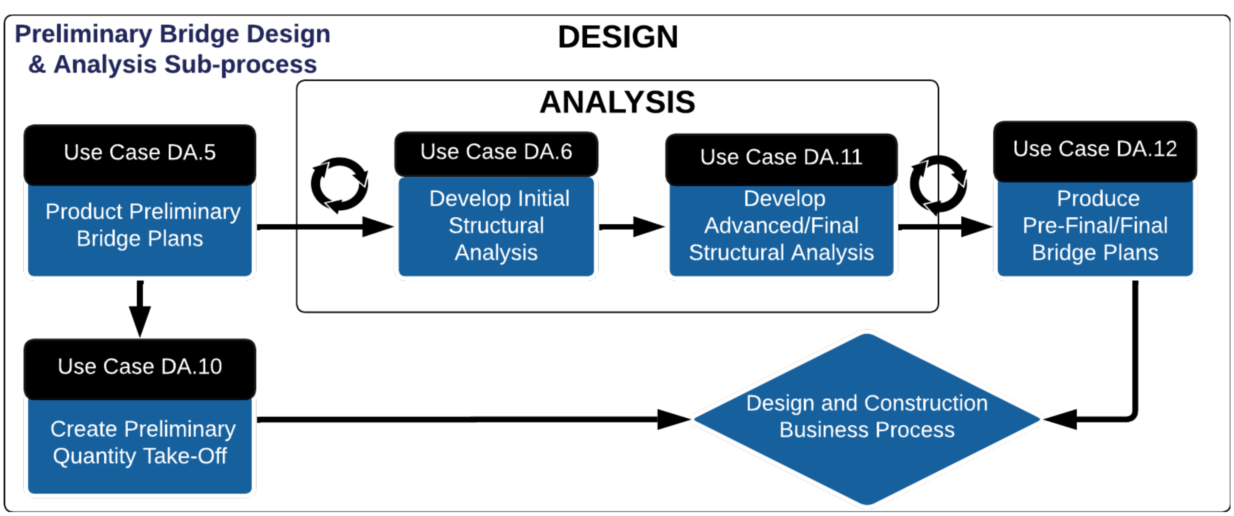


Figure 2-12. Flowchart. Integrated BIM sub-process for bridge design.

The following subsections discuss the BIM data and process for the specific business processes listed below. The goal is to present an example overview of the current data and processes of how the entire iBIM workflow in Figure 2-11 could incorporate such specifications.

Figure 2-13 shows the interrelationships between the DA.9 – Provide Data for Interdisciplinary Coordination and Clash Detection, DA.11 – Develop Final Structural Analysis Model, and DA.12 – Produce Final Plans and Model.

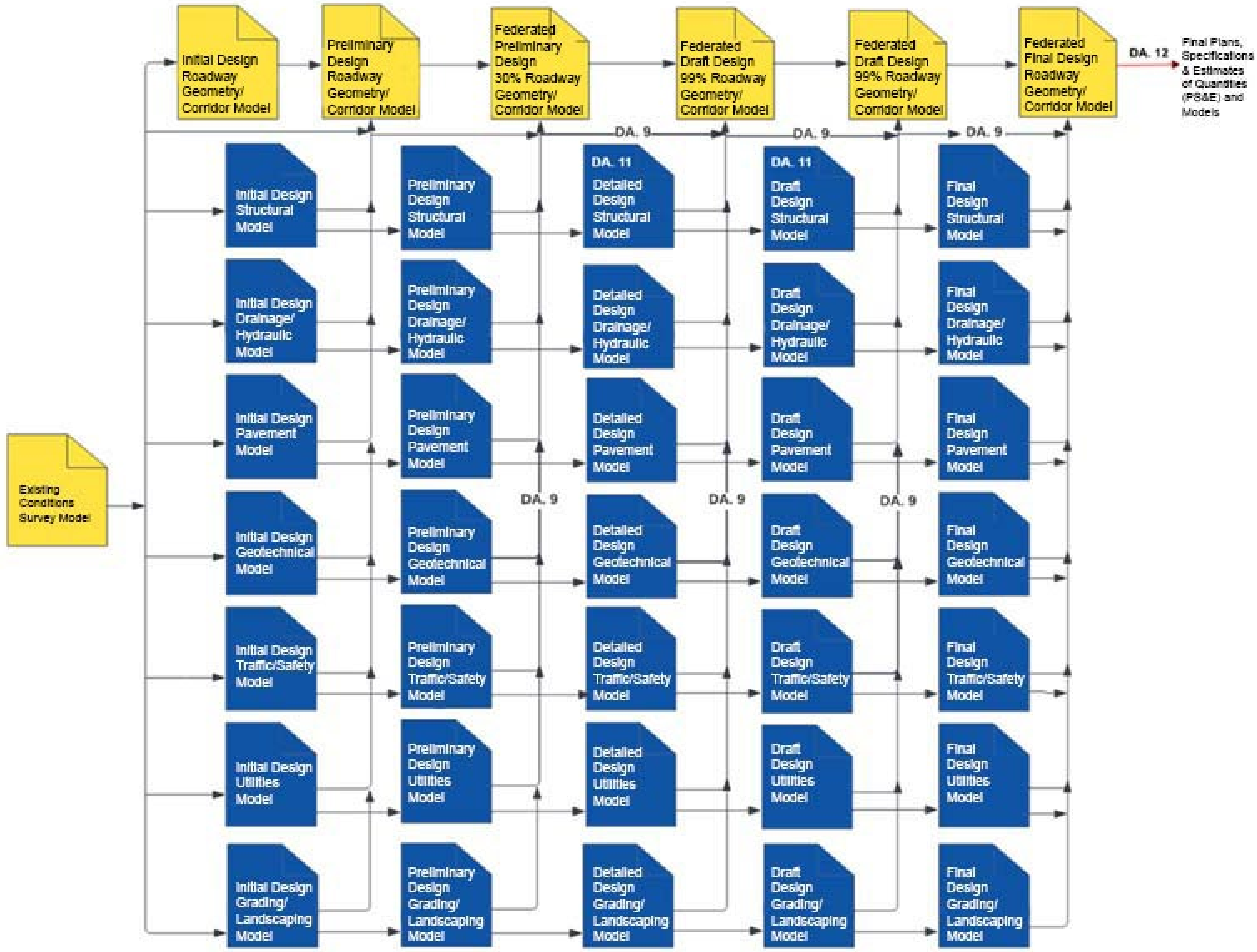


Figure 2-13. Flowchart. Interrelationships between use cases DA.9, DA.11, and DA.12.

2.4.2 Use Case DA.9 - Provide Data for Interdisciplinary Coordination and Clash Detection

During the design phase, transportation asset object elements are authored in data models by discipline, including roadway geometry, structural, geotechnical, pavement, hydraulic, traffic, safety, utilities, and grading. All data models can be combined as a federated model to generate construction documents. Interdisciplinary coordination in DA.9 (Table 2-2) is conducted during key design phase milestones to reduce conflicts and resolve interferences between various disciplines. As shown in Figure 2-11, conflicts/interferences of object elements are identified involving each data model internally and with all other data discipline models in the preliminary, detailed, and draft design phases. The primary purpose is identifying geometric data conflicts in the combined federated models for discipline lead designers and BIM information managers to resolve. While CAD/BIM 2D/3D data are geometric, attribute or non-geometric data and metadata can also be coordinated as a deliverable. The goal is to generate highway and bridge PS&Es derived from and with data-rich information models to enable DA.12 as construction contract documents for bidding. Such information is typically shared with contractors as a “for information only” document.

The value of interdisciplinary coordination, conducted as a part of the QA/QC process of producing the PS&Es, is to produce construction contract documents that effectively communicate design intent; improve contractor bids and design quality; and reduce errors, costs, schedule delays, and risk during construction. Interdisciplinary coordination could also be conducted during the construction phase; however, this section focuses on interdisciplinary coordination around design to discuss the data that are modeled, exchanged, quality checked, managed, and used by the involved stakeholders. In this section, both traditional and envisioned iBIM-enabled workflows are presented, and the opportunities for improvement in current data creation and exchange processes are discussed.

With BIM-enabled workflows, designers could create transportation design data according to information requirements and delivery specifications in a BIM Execution Plan for each discipline as data models. Design data could include the following:

- Roadway.
- Pedestrian facilities.
- Bridges.
- Tunnels.
- Geotechnical.
- Railway.
- Drainage.
- Lighting.
- Signs.
- Traffic signals.
- ITS.
- FTMS.
- Utilities.
- Surfaces.

- Buildings.
- Environmental features.
- ROW.

Design data are incorporated in key discipline data models: roadway geometry, pavement, structural, geotechnical, drainage, hydraulic, traffic, safety, utilities, and grading. The data models for these discipline designs are summarized in the next section (Section 2.4.1.1). The design data entities and property sets are linked to LOD and project delivery phase milestones based on the project delivery method (design-bid-build, design-build, construction manager/general contractor). LOD, as shown in Table 2-2, is used to advance the design model to increased level of geometry, level of accuracy, and level of information. LODs are listed as a number:

- For pre-design or conceptual at 100 (covered in PSD.3).
- For detailed to final design ranging from 200 to 300.
- For construction and fabrication at 400.
- For as-built, field verified, or practical completion for data handover for asset management at 500.

The design data entities and property sets are linked with the LOD applied for each data model involving each project delivery phase milestone (e.g., conceptual design, survey, preliminary design [30 percent], detailed design [60 percent], draft design [90 percent], final design, construction, and asset management) and are provided in Tables B-1 to B-8 in Appendix B.

The 2D/3D CAD and other BIM data include geometric data, non-geometric attribute data, and metadata for asset elements geolocated in the data models. Interdisciplinary QA/QC processes are initially run to reduce geometric conflicts and resolve interferences for the discipline internally and then iteratively with the other disciplines. The interdisciplinary coordination process schedules vary but can be conducted weekly and are formally performed typically at preliminary design (30 percent), detailed design (60 percent), and draft design (90 percent) project delivery phase milestones prior to final design. The data models and interdisciplinary coordination provide the needed information exchanges. Conflict or interference detection and resolution between asset object elements in data models discipline sets is an important part of the QA/QC process for design and construction BIM.

2.4.2.1 Data Modeling for Interdisciplinary Coordination

The data models involved in interdisciplinary coordination for design with data incorporated are summarized below, listed in Table 2-7, and referenced in greater detail in Tables B-1 through B-8 in Appendix B.

- **Hydraulic design data model:** The hydraulic engineer develops an analytical drainage model using existing terrain, proposed terrain, soil, vegetation, rainfall, and size, location, and capacity of the existing and proposed drainage conveyance structures. These data come from the existing conditions survey digital-terrain model (DTM), proposed grading DTM, and roadway geometry data models. The analytical drainage model locates proposed inlets, storm sewers, culverts, outfalls, and size conveyance structures to ensure that the design satisfies hydraulic criteria to drain the roadway, bridge, and surrounding areas effectively. The drainage engineer uses the output from the analytical model along with the location of the roadway to place drainage structures, pipes, ditches, flumes, outfalls, and ponds. If the roadway and bridge designs are changed, the drainage engineer needs to update the analytical model; iterate the analysis; and update the drainage plans, profiles, cross sections, and tables to reflect the changes. Furthermore, design changes to flumes or drainage ditches can trigger updates to roadway grading. In a non-BIM workflow, this process is semi-automated but still prone to oversights and omissions such as showing an incorrect rim elevation, invert elevation, or pipe size. In a BIM-enabled environment, these changes could occur more dynamically, and therefore minimize the potential for error or omissions; however, the need for 3D spatial coordination of drainage design elements with other discipline elements is still important.

- **Geotechnical design data model:** The geotechnical engineer generates support data for the structural and geotechnical design data models. Boring data are incorporated to generate geotechnical design data for deep foundations, shallow foundations, and cofferdams for the geotechnical design data model, which can be linked to the structural and hydraulic design data models.
- **Grading design data model:** The transportation and drainage engineers design grading and vegetation cover for roadway, ramp, median, gore, intersection, and other transportation assets. In a non-BIM workflow, grading cut/fills can be difficult to view, and grades are typically viewed using cross-section plan sheets with often limited utility data or other discipline data that has been added manually. In a BIM-enabled workflow, viewing grading in 3D with combined discipline data can reduce risk and enable ready identification of conflicts.
- **Pavement design data model:** The pavement engineer uses roadway data, traffic data, and geotechnical boring data to generate specifications for pavement layer types and their thicknesses for surface, base, and subbase courses in conjunction with subgrade properties (provided by the geotechnical discipline) to arrive at a pavement design section data model. The pavement design data model also includes underdrain, geotextile, centerline striping, lane marking, rumble strips, safety edge, and other data types. The typical existing section (from the existing conditions model and as-built data) is matched to align with the planned typical section and earthworks cut and fill areas for subgrade that are designed by the transportation engineer.
- **Roadway geometry design data model:** The transportation engineer incorporates various roadway data (including roadway horizontal alignment, vertical profile, cross section, grade, median, curb and gutter, sidewalk, shoulder, and lane width) to design an intelligent parametric roadway corridor section data model. The roadway geometry design data model combines all discipline design data models into a federated design data model for use with the federated existing conditions survey design data model. The pavement design data model is closely linked to the roadway geometry design data model. In a non-BIM workflow, it is challenging to incorporate this process into all the design disciplines to enable conflict detection using plans and overlays. In a

BIM-enabled environment, automated conflict detection provides a coordinated environment to identify and resolve issues in design prior to becoming issues in the field during construction.

- **Structural design data model:** The structural engineer generates various bridge, retaining wall, sign structure, approach slab, and other structural asset objects involved in the structural design data model. Extensive structural data can be incorporated, including bridge horizontal alignment, vertical profile, cross section, clearance, span, bridge type, superstructure, substructure, deck, bearing, curb, sidewalk, median, deck drain, joint, haunch, , railing, wingwall, and slope protection. The structural design data model is aligned with the roadway geometry design data model and the geotechnical design data model. While bridges and structures have traditionally been designed in a non-BIM workflow, the geospatial and iterative design process is enhanced in a BIM-enabled workflow.
- **Traffic and safety design data model:** The traffic and electrical engineers design traffic control signals, traffic signs, ITS, FTMS, barriers, and lighting for roadways, pedestrian facilities, intersections, and other safety assets. Traffic signals include signals for freeway, ramp, tollway, pedestrian beacon, flashing beacon, emergency vehicle access beacon, lane-use control, and others. Traffic signs include regulatory, warning, guide, and others, while ITS and FTMS include freeway, ramp, intersection, traffic detection, and others. Barriers include guardrail, turndowns, and terminal, and lighting includes lighting for freeway, collector-distributor road, local road, intersection, and others. In a non-BIM workflow, traffic and safety assets are often not in 3D and can be enhanced in a BIM-enabled model-based workflow.
- **Utilities design data model:** The utility engineers from other providers design utilities that are considered in transportation designs, including water, sewer, gas, electric, steam, telecommunication, and other utilities. Utilities are one of the most important design data models to be considered in transportation designs and clash detection, often having a low-quality level of accuracy both horizontally (up to 1.5 feet) and vertically. In a non-BIM workflow, utility data are often in 2D with the potential for major conflicts. In a BIM-enabled workflow, utility data can be viewed in 3D, and when data are inaccurate, a buffer around the solid element can be added to reduce risk and identify soft conflicts in addition to hard clashes.

Table 2-7. Example of BIM-mature object-based data model for interdisciplinary coordination (Preliminary Design (30%), Detailed Design (60%), and Draft Design (90%)).

Property Set	Properties Description
Drainage	**Non-Geometric**: drainage assets attribute data **Geometric:** inlets, storm sewers, culverts, vaults, outfalls, outlet control structure, detention/retention ponds, etc.
Geotechnical	**Non-Geometric**: geotechnical assets and borings attribute data **Geometric:** borings, deep and shallow foundations, cofferdam, etc.
Grading	**Non-Geometric**: grading attribute data **Geometric:** grading for roadway, ramp, median, gore, intersection, ditches, etc.

Property Set	Properties Description
Pavement	**Non-Geometric**: pavement section, subgrade, earthworks, underdrain, geotextile, centerline striping, lane marking, rumble strips, safety edge assets attribute data **Geometric:** surface, base and subbase courses, subgrade, etc.
Property ROW, parcel, and easement	**Non-Geometric**: parcel attribute data **Geometric:** 2D ROW, parcel, easement, etc.
Roadway geometry/corridor	**Non-Geometric**: roadway assets attribute data **Geometric:** roadway centerline, pavement edge, grade, median/access, curb and guttersidewalk, shoulder, lane, railroad, superelevation, etc.
Structural	**Non-Geometric**: bridge and structure assets attribute data **Geometric:** bridge, retaining wall, sound wall, sign structures, , approach slab and other structural asset objects including superstructure, substructure, deck, bridge type, curb, sidewalk, median, deck drain, railing,, wingwall, slope protection, etc.
Traffic/safety	**Non-Geometric**: traffic and safety asset attribute data **Geometric:** field-verified traffic control signal, traffic sign, ITS, FTMS, barrier, lighting, etc.
Utilities	**Non-Geometric**: utility easement attribute data **Geometric:** electric, telecommunications, utility poles, and other surface utilities within the State DOT ROW

2.4.2.2 Data Management for the Interdisciplinary Coordination Model

With BIM workflows as part of the data management and QA/QC processes, discipline designers author designs as CAD/BIM models in proprietary and open-platform formats that are combined in a federated georeferenced model that detects and resolves conflicts. Prior to approval and publishing, the discipline designers create design data models that are works-in-progress in shared states for review and QA/QC checks using model viewer tools by other design stakeholders. The discipline design data models are generated as 2D/3D data in proprietary formats.

Federated models of shared-asset element data are made available in a CDE, which is typically a connected cloud environment. Clash detection and model review analysis are performed early and throughout the design process using model clash detection, review, and QA/QC tools to check for interferences between the designs of the discipline models and QA/QC rules checks. Many of these tools are continuing to embrace open-data exchange formats such as IFC, which is useful in the collaborative review process to perform interference checks, even if the issue resolution is done in a proprietary authoring model. Open-platform/openBIM BIM Collaboration Format (BCF)—a file-based structured format and server-based BCF-API for issues—is also used to define views and associate object-based clash issues. Additionally, middleware application tools are used to validate and extract data.

Clashes detected in the collaborative process are generally classified as either hard or soft. A hard clash is when two (or more) physical objects occupy the same space. An example of a hard clash would be if a drainage pipe element is placed where there is a bridge structural element. Such a clash could be resolved in design by rerouting the pipe, moving the structural element, or creating a space near the bridge structure. A soft clash is when the positioning of two (or more) objects interfere with necessary clearances, tolerances, or access spaces. An example would be a gas main that is too close to an overhead structural member of a sign bridge and not maintaining proper clearances. For models that have less accurate 2D/3D data (e.g., utility models), buffers are used.

Model QC compliance checks based on business value rules for the discipline and federated models include the following:

- Visual checks.
- Interference checks.
- Model integrity checks.
- Standards checks (e.g., fonts, dimensions, line styles, levels, parametrics, platform).

These checks are run often and typically at weekly frequencies. In conjunction with these checks, formal automated clash detection reports at key milestone frequencies (preliminary design [30 percent], detailed design [60 percent], and draft design [90 percent] project delivery phases milestones prior to final design) are used for model QC and interdisciplinary design and construction review with corrective action plans. To review, document, and manage BIM design and construction and interdisciplinary coordination workflows, a collaboration physical space "big room" or virtual model environment site is typically used. A key deliverable for this interdisciplinary coordination is the identification of conflicts early in the process when changes are easier and relatively less expensive to make. If the conflicts are not identified until construction is underway, the cost of making changes can be high, and delays are inevitable.

With current non-BIM traditional processes, coordinating design disciplines—which involve paper or electronic plans derived from information models by many State DOTs—employ processes that can be time consuming, inefficient, and prone to errors. Traditional design methods use 2D/3D CAD models of roadways, structures, and key discipline data with existing conditions data captured to generate 2D drawing sheets for PS&E production. Design data are traditionally coordinated by overlaying 2D/3D CAD file layers or levels and combined using discipline external-reference data, which are aligned to survey coordinate data and projections and referenced to existing conditions DTM surfaces, features, imagery, and combined reality meshes.

The CAD 2D/3D data are typically geometric graphical data with limited attribute non-graphical data and metadata. The design data from disciplines include roadway, bridges, retaining walls, sound walls, sign structures, tunnels, geotechnical piles, railway, barriers, drainage, pedestrian facilities, lighting, signs, traffic signals, ITS, utilities, grading surfaces, buildings, environmental features, fences, parcels, and ROW. The CAD design data and existing conditions survey data vary in LOD, geometry, accuracy, and detail for delivery phase.

As drawing sheet plans derived from 2D/3D models are produced, discipline leads detect and resolve QA/QC conflicts by visual inspection with limited automation and often without the benefit of 3D for each of the disciplines, which then requires manual updates to CAD models and plans. Discipline design leads and project managers conduct interdisciplinary review and coordination via in-person meetings using marked-up, redlined paper prints or virtual meetings with marked-up PDFs of 2D plans, profiles, and cross sections at project delivery milestones (i.e., preliminary design, detailed design, and prior to final design). A spreadsheet is often used to track, document, and resolve captured issues and conflicts with extensive manual QA/QC efforts to update design data for PS&Es. Various disciplines (e.g., bridges by designers) are often designed in a local coordinate space with limited tie-in to the geolocation of the roadway or other data. Additionally, utilities often have limited, incomplete, or inaccurate 2D/3D data from a one-call hotline, State DOT or municipality data, or as-built data for underground and above ground utilities, in spite of modern survey methods available such as aerial, mobile, static and UAS LiDAR, ground-penetrating radar, SPAR and electromagnetic subsurface location, and advanced data collection methods. Interdisciplinary coordination by traditional processes also typically use legacy on-premises electronic document management systems instead of transitioning to modern applications platforms and enterprise cloud-based or hybrid cloud/on-premises information and communication technologies for data retrieval, analysis, and storage. Using traditional processes to identify and resolve conflicts and interferences of graphical geometric CAD data by visual checks, paper or electronic PDF document markups, and manual updating for information exchanges is inefficient during design and construction. Using these processes results in increased requests for information, costly contract modifications, and schedule delay issues arising from conflicts in construction.

With BIM-enabled workflows, all stakeholders could view, use, and extract data using proprietary design platforms, BIM/CAD/GIS integrations, and open platforms to provide useful information exchange formats and interoperable data models. Design teams (and construction teams as needed) would use clash interference detection tools to create a fully coordinated design within each discipline—across all disciplines and all authoring platforms—and to confirm that the design and construction methods before field installation meet all applicable requirements, codes, and regulations. The benefits of BIM model-centric interdisciplinary coordination and conflict interference detection and resolution during design include improved quality plans. The key feature of these model-centric data exchanges is that all the data can be viewed and understood within the context of the project, based on the geolocation and integration of all the combined data.

To attain BIM maturity, design teams could develop roadway geometry, structural, geotechnical, pavement, hydraulic, traffic and safety, utilities, and grading discipline data models and use clash interference detection tools in a CDE to ensure a fully coordinated design within each discipline and across all disciplines and all authoring platforms, which helps in delivering the model as the contract document. Mature data standards for information exchanges—MVDs for specific exchanges, LOD, and QA/QC—are used for model federation, clash detection, and digital deliverables for letting and construction.

The model views are subsets of data contained in the parent data model. They contain the data that were used, extracted, or transformed from the parent data model and provisioned for use by the target data model; these extracts are defined as MVDs. For example, MVDs provide key information data exchanges for the process of interdisciplinary coordination to resolve geometry conflicts between discipline-specific design data models. Models from disciplines are combined or federated using open bSI IFC data schema or XML schema or native proprietary data schema. The interdisciplinary model data exchanges for QA/QC geometry data checks are shown in the matrix as MVD 1 in Table 2-8.

- **MVD 1 –** This model view would use exchange geometric data attributes from the roadway geometry design data model for collaboration and conflict resolution with the other design geometric data models (e.g., pavement, structural, geotechnical, hydraulic, traffic and safety, utilities, and grading design data models). In this MVD, information to resolve point, line, polygon, solid, and surface geometric conflicts would be available for model coordination. Additionally, the roadway geometry design data model would be a federated corridor data model container. The data exchanges would be facilitated by using an open standard like IFC to identify conflicts and assign responsibility for resolution by discipline modelers.

  Each discipline would be checked internally with geometric conflict interferences in a geospatial environment and then externally in a federated combined model against each design discipline. The primary deliverables from DA.9 are geometric data conflicts for discipline lead designers for their internal discipline data models; for resolution and geometric data conflicts for project managers, lead designers and BIM information managers; and for resolution involving the federated combined data for all disciplines together. Automated reports would be provided as clash detection reports at key milestone frequencies (preliminary design [30 percent], detailed design [60 percent], and draft design [90 percent] project delivery phase milestones prior to final design). While CAD/BIM 2D/3D data are geometric data, attribute non-geometric data and metadata, the attribute non-graphical level of information data could also be coordinated as a deliverable. The interdisciplinary coordination design deliverables would enable final design models to generate highway and bridge PS&E.

  An iBIM opportunity beyond this primary deliverable in the envisioned process would be the exchange of critical data from discipline models to the final roadway geometric model. The types of potential MVDs in the envisioned process are described below and shown in Table 2-8.

Table 2-8. Interdisciplinary model data exchanges and QA/QC geometric data checks (design and existing conditions survey models).

	Roadway Geometry Design Model	Pavement Design Model	Structural Design Model	Geotech Design Model	Hydraulic Design Model	Traffic and Safety Design Model	Utilities Design Model	Grading Design Model
Roadway GeometryDesign Model	NA	MVD 1	MVD 1	MVD 1	MVD 1	MVD 1	MVD 1	MVD 1
Pavement Design Model	MVD 2	NA	NA	NA	NA	NA	NA	NA
Structural Design Model	MVD 2	NA	NA	NA	NA	NA	NA	NA

	Roadway Geometry Design Model	Pavement Design Model	Structural Design Model	Geotech Design Model	Hydraulic Design Model	Traffic and Safety Design Model	Utilities Design Model	Grading Design Model
Geotech Design Model	MVD 2	MVD 3	MVD 3	NA	NA	NA	NA	NA
Hydraulic Design Model	MVD 2	MVD 4	MVD 4	MVD 4	NA	NA	NA	NA
Traffic and Safety Design Model	MVD 2	MVD 5	MVD 5	NA	NA	NA	NA	NA
Utilities Design Data Model	MVD 2	NA	NA	NA	NA	NA	NA	NA
Grading Design Model	MVD 2	NA	NA	NA	NA	NA	NA	NA

*MVD: model view definition

Note: An existing conditions survey data model would also have similar MVDs.

- **MVD 2 –** In this model view, the specific data exchange captures final design details in the form of 2D drawings, GIS shape files, Excel sheets, or other artifacts that are not a part of the 3D data model. Such data are important and should be sent to the final federated corridor model for downstream use during construction and asset management. Examples of such data could be as follows:
    - **Pavement discipline model:** jointing detail including dowel and tie bar placement (for concrete pavements), pavement layer material specifications, edge drain or trench detail, subgrade soil type, rumble strip detail, and a detailed design report.
    - **Bridge discipline model**: markings, maintenance of traffic, drainage, standard details, and detailed design reports.
    - **Geotechnical discipline models:** soil properties, rock profiles and properties, boring logs, and subsurface investigation reports.
- **MVD 3** – This model view generates and sends data models from the geotechnical discipline to other disciplines. Traditionally, this is a document that disciplines consume (e.g., a geotechnical report). However, the data items (typically non-geometric) within this report could be communicated in a more structured manner to other disciplines during the model coordination process. Specifically, pavement and structural disciplines consume processed geotechnical information (e.g., strength, modulus, Atterberg limits, rock depth), which could be structured in data tables and coordinated.
- **MVD 4** – This model view focuses on data exchanges between drainage and hydraulic designs and other discipline designs such as pavements (e.g., for subsurface drainage design in pavements), bridges (e.g., to assist with hydraulic design of bridges), and geotechnical features (e.g., to help embankment design, retaining wall design).
- **MVD 5** – This model view focuses on data exchanges between the traffic and safety design and other discipline designs such as pavements and structures. The specific

data exchanges include data sets to facilitate the design of pavement and structures (e.g., traffic volumes and weights, crash locations).

Table 2-8 presents the data exchanges and QA/QC checks that could be implemented in each of the discipline data models used in the federated design models (preliminary design [30 percent], detailed design [60 percent], and draft design [90 percent]). The table also lists the MVDs that transfer data between the various models.

2.3.1.3 Uses of the Interdisciplinary Coordination Model

Stakeholders who use the federated design models and existing conditions survey model could include:

- Design project managers overseeing the design team and third-party consultants, who sign and approve the PS&E construction contract documents.
- Design team and third-party consultant leads who use the federated design models to resolve identified conflicts within their discipline data models to generate disciplinary PS&E construction contract documents.
- Surveyors who use and update the existing conditions survey model involved to generate existing conditions data in the PS&E construction contract documents.

2.4.3 Use Case DA.11 - Develop Final Structural Analysis Model

This section describes the traditional and envisioned BIM-enabled workflows for developing the final structural analysis model at LOD 300. The final structural analysis model is created typically for the following types of projects:

- New bridge construction.
- Bridge replacement.
- Bridge deck replacement.
- Bridge rehabilitation.
- Seismic retrofit.

Traditionally, structural engineers start with their initial geometric and structural analysis and either update using similar structural analysis methods or start over with a different approach. The analysis is additionally refined with final span lengths, cross sections, and other information. However, simplified geometry recreated just for the structural analysis (e.g., ignoring vertical roadway geometry on the bridge) is typically used. Depending on the complexity or type of structure, approximate methods of analysis or more refined methods, including 3D finite element modeling techniques, may be used. The analysis incorporates information from other disciplines as appropriate, including final details such as geotechnical parameters, traffic, and hydraulics. With traditional workflows, no information is shared between the structural analytical model and the CAD drawings, and both are continually reviewed manually to ensure consistency. Engineers review and markup 2D CAD drawings and then expert CAD technicians generate and update them. CAD technicians are not involved in the design process and are not trained designers; however, their line of expertise focuses on generating CAD drawings and keeping them updated per the design engineer’s instructions.

Many structural engineers use finite element analysis (FEA) applications to create a finite element model. The engineers rely on 2D drawings as backgrounds to create FEA models using the FEA application's graphical user interface. This method of working has been employed for decades and is engrained in most engineers' design practices. Because these FEA models are not connected directly to a BIM geometry model, changes to the FEA model are made manually using the FEA program's graphical user interface. The deliverable from this process is a stamped set of calculations that can be reviewed by a State DOT to verify that the project has been designed in accordance with all applicable codes and directives.

Depending on the geometric and structural complexity of the bridge, structural analysis is typically performed using spreadsheets, State DOT in-house applications, or FEA software. For many projects, the final structural design is done using all three methods, depending on the element or the load that is investigated. Although most commercial FEA software has a user-friendly graphical user interface that is often used by the modeler, some are still bonded to text inputs. The programs still bonded to text input are often used for uniquely complex investigations and are not used for most projects. Neither spreadsheet, State DOT in-house applications, nor FEA software are connected to 2D/3D BIM models or workflows. In addition, the analytical computations are not typically connected to the 2D CAD drawings, meaning that every change to the analytical model is made independently working backward to CAD drawings and vice versa.

As part of a more mature BIM workflow, the business process activities that constitute this use case would use an advanced or final structural model for similar analytical purposes as the current workflow. However, the analytical model would use the digital roadway geometry model directly in the analysis and include automated data exchanges for other applications including the final design model, which would be a shift from the current parallel processes of analysis and 2D CAD drawing production. Mature open-platform data specifications for IFC bridge exchanges (structural analysis-to-design MVD), LOD, and QA/QC processes could accelerate use. With such specifications in place, wider adoption of importing roadway geometry by structural analysis software, and improved import and export capabilities of structural software for interoperability with more advanced design models, could occur. Additionally, technology and workflow processes used by structural engineers to analyze structures with shared models would be more collaborative. More efficient processes gained through this adoption include the reuse of geometry, attribute, and document data; inclusion of more accurate data; and the improved ability to incorporate other models (e.g., roadway, geotechnical, pavement, drainage, utilities, and other models). This collaborative model-based process and ability for common data to be exported and imported lends itself to more widespread use of 3D FEA, which can provide more efficient designs and enables the models to be used for other purposes as well, such as reviews, detailing, fabrication, interdisciplinary coordination clash detection, plans production, and visualization. The envisioned model-centric process would involve the use of an intelligent link between the analytical model and the structural model used to create the deliverables (i.e., plans and quantities). The deliverable in the form of the structural analytical model can contain very different data but have a similar process because they contain shared data for data exchanges, where changes in one model are automatically updated in the other model. Additionally, the BIM model-centric process could leverage parametric modeling.

Regardless of the method of analysis, shared model data would be connected. Various structural applications can extract FEA models from 3D models based on preset idealization rules. Because users have limited control on FEA idealization, it would not be suitable for bridges with complex geometry. A few visual scripting tools, allow engineers to use scripts to programmatically extract the FEA model from the 3D model with full control on the FEA idealization. These tools can be used to create 3D models and FEA models for the bridges with complex geometry. Figure 2-14 depicts how an FEA model can be extracted from a 3D structural model.

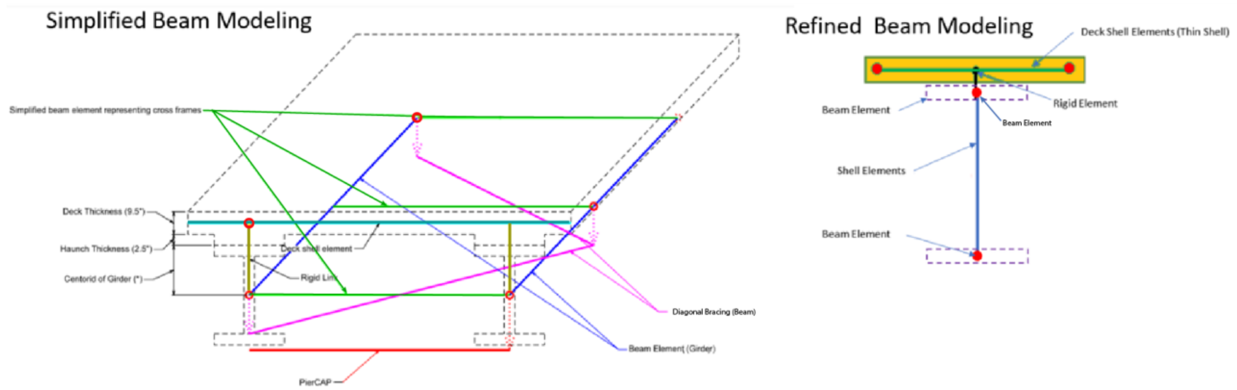


Figure 2-14. Diagram. 3D model extracted as finite element analysis model (FHWA).

2.4.3.1 Data Modeling for the Final Structural Analysis Model

Table 2-9 presents the model features, property set item types, and properties for key design element data that would be captured in a BIM-enabled, object-based final structural analysis model and associated roadway geometry, pavement, geotechnical, drainage, traffic and safety, utilities, and grading models.

When coordinating a BIM-based geometry model for structural analysis, it is important to recognize the type of geometry that needs to be exported to support the structural analysis. For skewed and curved steel bridges, the following references provide suggestions for the dimensionality of structural analytical methods for various bridge geometries:

- National Cooperative Highway Research Program (NCHRP) Report 725 "Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges" (White et al., 2012).
- American Association of State Highway Transportation Officials (AASHTO)/National Steel Bridge Alliance (NSBA) "Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges (AASHTO, 2014)."

Based on these references, either 1D, 2D, or 3D FEA modeling may be suitable for I-girder bridges, depending on the bridge geometry types. Such awareness assists in the purpose and need and content, form, and format of the data exchanges between the BIM geometry model for the roadway and bridge sections and the bridge structural analysis model.

Table 2-9. Example of BIM-mature object-based final structural analysis data model.

Model	Property Set	Properties Description (Examples)
Final Structural Analysis Model	Structural elements	**Geometric:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects, including superstructure, substructure, deck, bridge type, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall (crash wall), wingwall, and slope protection **Non-Geometric**: bridge and structure asset attribute data
Final Structural Analysis Model	Roadway geometry/ corridor elements	**Geometric:** roadway centerline, pavement edge, grade, median, access, curb and gutter, sidewalk, shoulder, lane, railroad, and superelevation **Non-Geometric**: roadway asset attribute data
Final Structural Analysis Model	Pavement elements	**Geometric:** structures deck pavement surface, base, and subbase courses **Non-Geometric**: pavement section, subgrade, earthworks, centerline striping, lane marking, rumble strips assets attribute data
Final Structural Analysis Model	Drainage elements	**Geometric:** inlets, outlets, and deck drains **Non-Geometric**: drainage asset attribute data
Final Structural Analysis Model	Geotechnical elements	**Geometric:** deep and shallow foundations including drilled shaft, micropile, augercast pile, driven pile, spread footing, and cofferdam for structures support **Non-Geometric**: geotechnical assets and foundation attribute data
Final Structural Analysis Model	Traffic and safety elements	**Geometric:** field-verified traffic control signal, traffic sign, ITS, FTMS, lighting, and barrier-guardrail/guiderail on structures **Non-Geometric**: traffic and safety assets attribute data
Final Structural Analysis Model	Utilities elements	**Geometric:** electric, telecommunication, utility poles, and other surface utilities interfering within the structures or permitted on structures **Non-Geometric**: utilities (in ROW) asset attribute data
Final Structural Analysis Model	Grading elements	**Geometric:** slope protection for structures **Non-Geometric**: grading asset attribute data
Existing Conditions Survey Model	All existing conditions survey asset elements	**Geometric:** 2D ROW, control, parcels, and easements **Non-Geometric**: existing conditions roadway, bridge and structures, pavement, drainage, geotechnical, traffic and safety, utilities (in ROW), grading, and ROW, control assets attribute data

Most senior structural design staff have spent their careers developing and perfecting traditional design methods that are based on 2D CAD drawings, and it may not be an easy transition for them to adapt to BIM-enabled workflows. To overcome this obstacle in the short term, structural design staff could be trained in the fundamentals, so that they are comfortable with creating and navigating BIM geometric models and can understand the attribute and metadata behind them.

They would then provide senior staff with the information and processes to perform QA/QC in their preferred format.

2.4.3.2 Data Management for the Final Structural Analysis Data Model

For BIM-enabled workflows, Figure 2-12 shows the structural design processes. The preliminary structural design model (DA.3) is developed from the preferred conceptual-design structural alternative that was selected based on the environmental study and National Environmental Policy Act process. This preliminary structural design model is developed to do the following:

- Validate feasibility of design.
- Prepare cost estimates and quantities.
- Generate plans.

These items are needed for the structure type selection process. Ideally, a structural model could be developed for two structure types at a minimum (i.e., precast girders and cast-in-place box girder) to be presented at a type selection meeting, which involves all the functional disciplines involved in the project (roadway, hydraulics, geotechnical, maintenance, construction). The detailed structural design model (DA.11) is then developed based on the selected structural type and has two basic uses:

- Structural analysis.
- Detailed delivery model.

The structural analysis model is used to perform the necessary calculations to prove that the design meets the design specifications and to provide the backup calculations for the project. The detailed project delivery model is used to provide the following:

- Bridge plans.
- Bridge specifications.
- Bridge cost estimates used for the structures' PS&Es.

The bridge PS&Es are combined with the roadway and other disciplines. A full review is done with all the disciplines to check for consistency and make sure there are no conflicts (DA.9) and with key data models associated with the structural data model (Table 2-10). Construction personnel familiar with contractors means and methods perform a constructability review to identify potential conflicts and assess the quality of the deliverables. The final design model (DA.12), including the structural model, generates PS&Es with models which may be used for traditional design-bid-build procurement delivery type method.

Table 2-10. Key QA/QC checks for structural analysis data model.

Model	Elements	QA/QC Check Description
Structural Analysis Data Model	All elements	Conflict resolution
Roadway Geometry Data Model	All elements	Conflict resolution
Geotechnical Design Data Model	All elements	Validation
Pavement Data Model	All elements	Validation
Hydraulic Data Model	All elements	Conflict resolution

2.4.3.3 Uses for the for the Final Structural Analysis Data Model

Stakeholders that would use the final structural analysis model could include:

- Design project managers overseeing the design discipline leads and teams and third-party consultants, including the structural lead designers, who review and approve the final structural design data model to be added to the construction contract documents for project bidding.
- Structural lead designers overseeing the structural design team and third-party design consultants, who oversee design, review, and coordination of the structures (bridges, retaining walls, sound walls, sign bridges, and large culverts greater than 20 feet in diameter).
- Structural designers and third-party design consultants, who design, review, and coordinate the structures (bridges, retaining walls, sound walls, sign bridges, and large culverts greater than 20 feet in diameter).
- Design consultants and contractors, who review and conduct QA/QC of the structural analysis design models, calculations, specifications, and work.

2.4.4 Use Case DA.12 - Produce Final Plans and Model

To put a highway project out for bid, construction documents are created. The final design plans and PS&Es are developed from final design models in conjunction with existing conditions survey models advanced during key project delivery design milestones shown in Figure 2-13. At the project delivery design milestones for each phase, plans are produced, specifications are defined, and quantity estimate costs are compiled at conceptual design, preliminary design (30 percent), detailed design (60 percent), and draft design (90 percent) to generate final design documents for construction. The PS&Es and final design model and existing conditions survey model are deliverables provided to contractors as construction contract documents for bidding.

Traditionally, the construction contract documents consist of 2D electronic PDF plans or sheet drawings generated from 2D/3D design models, specifications documents, and estimates of quantities documents that incorporate individual State DOT's standard specifications. Designs are authored with 2D CAD drawing sheets from 3D models using CAD design tools. Design reviews are typically done manually or with electronic tools for all disciplines. The current process for generating and reviewing electronic PDF plan construction contract documents is that they are stored typically in a document management system hosted on-premises of an agency and accessed through local area network. To provide a bid proposal estimate with 2D electronic plans or sheet drawings, the contractor re-engineers the 3D model from 2D-scaled plans and supplemental data throughout the contract documents and any supplemental limited 3D models or construction data packets included in the contract documents to detail design scope of work, conditions, equipment needed, labor, materials, quantities, risk assessment, base schedule delivery, and costs. This traditional process is inefficient, because historically, a State DOT owner provides limited 3D model data to the contractor.

With BIM-enabled workflows, designers author transportation design data according to information requirements and delivery specifications in a BIM Execution Plan for each discipline as design data models. These design data models are then combined in a consolidated design model after interdisciplinary coordination of conflicts (DA.9) to generate PS&E construction documents with data-rich model deliverables (DA.12). Designs are authored with 2D/3D CAD models using CAD design tools. In modern practice, designs are authored using advanced multi-disciplinary 3D models and intelligent roadway corridor and bridge structure parametric design models in proprietary platform tools and open-platform design tools.

The data elements with geometric data, attribute data, and metadata with property sets and properties of each asset object to be constructed are linked with LOD applied for each design discipline data model (typically as LOD 300 level with elements that have precise geometry and connections and non-graphical attribute data also attached to model elements). The data elements involving each project delivery phase milestone are successively advanced in the design model to an increased level of geometry, accuracy, and information.

The data models are provisioned typically in a cloud-based CDE or enterprise hybrid on-premises network and cloud-based CDE to enable collaborative workflows. Additional specifications and associated data needs for constructing the roadway and structure assets are provided in supporting documents, including tables, notes, materials to be used, reports, logs, and links to databases in conjunction with the data models. With BIM-enabled workflows, a State DOT owner would provide the model as the legal document or PS&E documents with multi-disciplinary 2D/3D design data models (for information only) as construction contract documents (design model and existing conditions survey model) for contractors to use to provide timely bid proposal estimates; reduce model-intensive re-engineering effort and streamline workflows by using the 3D model directly; or modify 3D models provided for densifying models, estimating, and after award survey layout, stakeout, and machine control.

Typical transportation PS&E contract documents generated from design data models for improvement, reconstruction, and new construction and abbreviated perpetuation, resurfacing, restoration, and rehabilitation project types compiled from following various State DOT guidance manuals include the following design drawings, plans, and data:

- Project title and general notes.
- Project overview.
- Typical roadway sections.
- Removal details.

- Construction details.
- Intersection details.
- Interchange details.
- Curb ramp details.
- Plan details.
- Pavement grading details.
- Topographical details.
- Cross section matchline details.
- Erosion control details.
- Storm sewer details.
- Utility details
- Landscaping details.
- Lighting details.
- Sign structure details.
- Traffic signal planning and phasing details.
- ITS and FTMS.
- Electrical details.
- Pavement marking details.
- Traffic control and construction staging details.
- Detour details.
- Alignment details.
- ROW and easements.
- Bridge and structure details.
- Environmentally sensitive areas.
- Temporary facilities.
- Earthwork cut and fill quantities.
- Cross sections.

2.4.4.1 Data Modeling for Final Design

The final design plans described above are generated at LOD 300 from the following key final design models and existing conditions survey model:

- **Roadway geometry design data model:** roadway centerline, pavement edge, grade, median, curb and gutter, sidewalk, shoulder, lane, and railroad.
- **Structural design data model:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects including superstructure, substructure, deck, bearing, curb, sidewalk, median, deck drain, joint, haunch, girder, parapet, railing, abutment, pier, pier cap, pier column, pier wall (crash wall), wingwall, and slope protection.
- **Pavement design data model:** pavement layer types and thicknesses for surface, base and subbase courses and subgrade earthworks. Often, salvaged materials are used, including full-depth reclamation, recycled concrete aggregate, and recycled asphalt pavement. The pavement data may also include underdrain, geotextile (if needed), centerline striping, lane marking, rumble strips, and safety edge (if needed).
- **Drainage design data model:** inlets, storm sewers, culverts, vaults, outfalls, outlet control structure, and detention and retention ponds.
- **Geotechnical design data model:** deep and shallow foundations, including drilled shaft, micropile, augercast pile, driven pile, spread footing, and cofferdam data linked to structural and drainage data.
- **Traffic and Safety design data model:** traffic control signal, traffic sign, ITS and FTMS, barrier, and lighting.
- **Utilities design data model:** utilities and easements within the ROW.
- **Grading design data model** grading for roadway, ramp, median, gore, and intersection.
- **Property ROW, parcel, and easement design data model:** 2D parcel, easement, and ROW.
- **Existing conditions survey data model:** all asset elements.

Similar discipline data are also captured and incorporated into the existing conditions survey model using geospatial high-accuracy reality capture methods including:

- UAS, LiDAR, GNSS RTK, and robotics total station technologies.
- Subsurface location methods such as ground-penetrating radar, electromagnetic and SPAR subsurface utility and pipeline mapping technologies.
- E-construction data collection methods such as mobile tablets, smartphone devices, and mobile applications.

Table 2-11 summarizes the details of the specific object-based data models summarized in the preceding paragraphs of this section.

Table 2-11. Example of BIM-mature object-based data model created with property sets and properties for final plans or data model.

Model	Elements	Properties Description (Examples)
Final Design Model	Roadway geometry elements	**Non-Geometric**: roadway assets attribute data **Geometric:** roadway centerline, pavement edge, grade, median/access, curb and gutter, sidewalk, shoulder, lane, railroad, superelevation
Final Design Model	Structural elements	**Non-Geometric**: bridge and structures assets attribute data **Geometric:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects including superstructure, substructure, deck, bridge type, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall (crash wall), wingwall, slope protection
Final Design Model	Pavement elements	**Non-Geometric**: pavement section, subgrade, earthworks, underdrain, geotextile (if needed), centerline striping, lane marking, rumble strips, safety edge (if needed) assets attribute data **Geometric:** surface, base and subbase courses, subgrade
Final Design Model	Drainage elements	**Non-Geometric**: drainage assets attribute data **Geometric:** inlets, storm sewers, culverts, vaults, outfalls, outlet control structure, detention and retention ponds
Final Design Model	Geotechnical elements	**Non-Geometric**: geotechnical assets and foundation attribute data **Geometric:** deep and shallow foundations including drilled shaft, micropile, augercast pile, driven pile, spread footing, cofferdam
Final Design Model	Traffic and safety elements	**Non-Geometric**: traffic and safety assets attribute data **Geometric:** field-verified traffic control signal, traffic sign, ITS and FTMS, barrier, and lighting
Final Design Model	Utilities elements	**Non-Geometric**: utilities (in ROW) assets attribute data **Geometric:** electric, telecommunication, utility poles, and other surface utilities within the State DOT ROW
Final Design Model	Grading Elements	**Non-Geometric**: grading assets attribute data **Geometric:** grading for roadway, ramp, median, gore, intersection, ditches, breaklines
Final Design Model	ROW, parcel, and easement elements	**Non-Geometric**: parcel assets attribute data **Geometric:** 2D ROW, monumentation, parcel, easement
Existing Conditions Survey Model	All existing conditions survey asset elements	**Non-Geometric**: existing conditions roadway, bridge and structures, pavement, drainage, geotechnical, traffic and safety, utilities (in ROW), grading, and ROW, control assets attribute data **Geometric:** 2D ROW, control, parcel, easement

2.4.4.2 Data Management

Over the past decades, roadway, structural, and other design discipline engineers provided preliminary and detailed design 2D drawings using CAD software to CAD technicians. These technicians then created 2D views for final design 2D sheet drawing documents as hard copy or electronic final plans to add to specifications and estimates for construction contract documents. Transportation engineers designed roadway plans using plans, profiles, and cross sections at design-corridor interval frequencies (e.g., 50 feet or 100 feet) in conjunction with existing topographic and features survey data. Structural engineers also designed using advanced analysis and 2D methods. Structural engineers designed bridges, retaining and sound walls, large culverts, and sign structures with 2D CAD bridge and structure plans (Figure 2-15) that are typically drawn to scale, but contractors and fabricators are not permitted to scale from the plans.

For practicality, dimensional callouts are used rather than measuring the drawing. Additionally, the plan, elevation, and section views are drawn independently, creating an inherent risk of conflict between the views. This process is time consuming and relies on experienced staff to identify these conflicts. Moreover, the information needed for contractors to build the structure is in multiple places in the project standard plans, specifications, and other supplemental information. One method commonly used to address this issue is for State DOT construction personnel to perform constructability reviews—that is, to review the plans and provide comments based on their experience in dealing with challenges in the field. Although it may be argued that this has reduced the problems encountered in the field, whether it is the optimal use of resources is questionable.

Additional advanced survey technologies are used to collect more accurate existing conditions features, surfaces, and assets, especially using UAS, and aerial, mobile, and static LiDAR to produce an existing conditions survey model. There also has been improvement in the interoperability of CAD software platforms. Over the decades, CAD standards have also advanced with State DOTs development of statewide CAD standards (https://highways.dot.gov/federal-lands/std-drawings/state).

Over the past decade, several developments have led to the adoption of open BIM-based workflows as a way of the future to improve information interoperability across all phases of the highway infrastructure lifecycles and to preserve the data value chain to save time and money. Some of these developments include, but are not limited to, the focused impetus provided by FHWA's Every Day Counts (EDC) Rounds 2 and 3 to 3D engineered modeling (FHWA, n.d.), NCHRP Report 831 (O'Brien et al., 2016), FHWA's focused efforts to advance BIM for Bridges and Structures (Chen and Shirole, 2013; NIBS, 2016; Brenner et al., 2021) and BIM for Infrastructure (Mallela and Bhargava, 2021, and Mallela et al. 2021), as well as the BIM for Bridges and Structures Transportation Pooled Fund Study TPF-5(372) and BIM for Infrastructure Pooled Fund Study TPF-5(480).

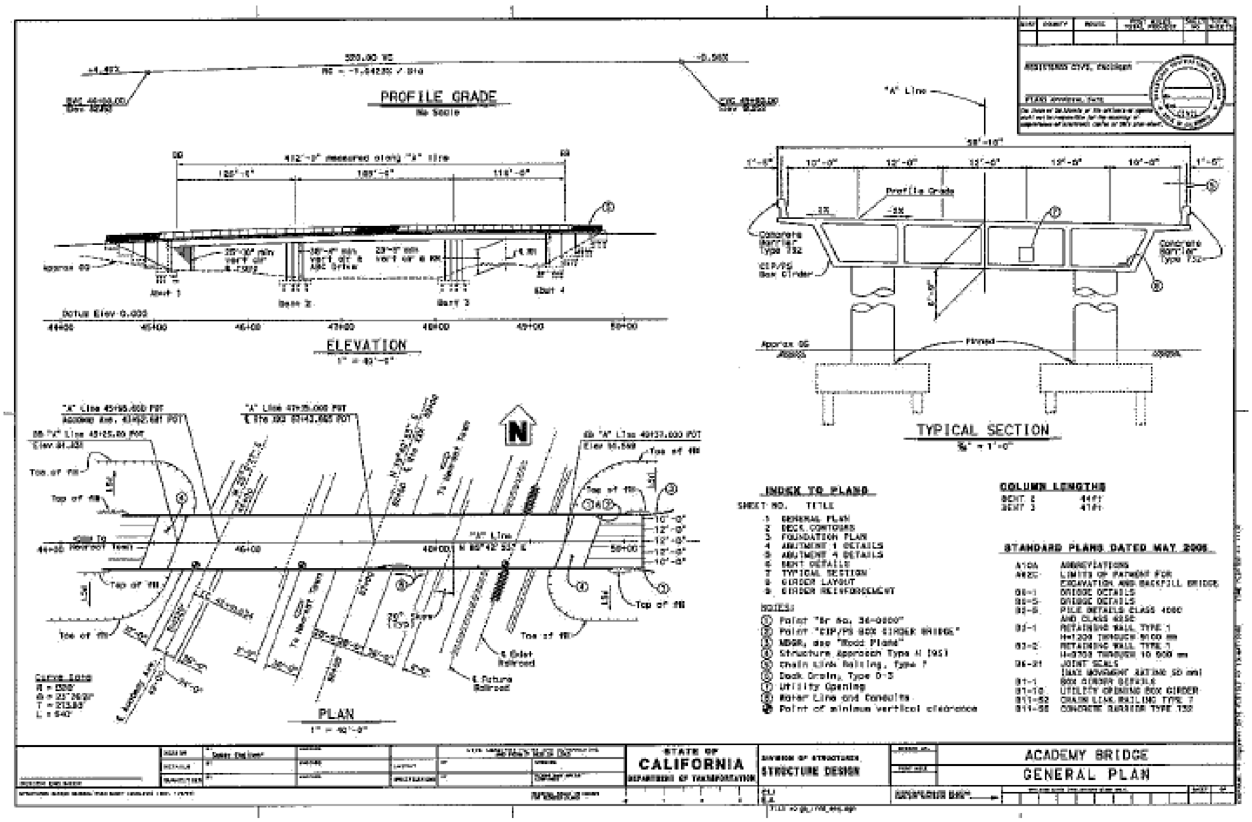


Figure 2-15. Image. Caltrans general plan.

As described in several of these documents and resources, in an envisioned model-centric BIM workflow of the future, the final design model would be the contract document, and the deliverable would be the 3D model with plans as outputs from the model. Recently, based on work advanced under the BIM for Bridges and Structures Transportation Pooled Fund Study (TPF-5(372)), AASHTO published an IDM for design-to-construction data exchange use case for highway bridges (AASHTO, 2023). An MVD for this use case was developed as part of previous FHWA research (Chipman et al., 2016).

In this scenario, the final design data models would replace a traditional 2D contract plan set. The model would include saved views, attribute data, and linked information. Roadway and bridge drawings would be detailed, and models comprehensive, incorporating asset object elements and design data from multiple disciplines, including roadway, structural, pavement, geotechnical, hydraulic, utilities, traffic and safety, grading, and other data models. In addition to construction contract plans production, the design data models can be used for reviews, detailing, fabrication, interdisciplinary coordination, and visualization.

Model-based interdisciplinary coordination of conflicts is discussed in detail in DA.9. An example of a State DOT QA/QC BIM review process is shown in Figure 2-16. More recently, CAD and BIM proprietary tools have continued to advance with connected platforms and parametric workflows. Federated design models of shared-asset element data are stored in a CDE, typically a connected cloud environment. Open BIM standards (ISO19650) and open data standards (IFC, GML, and others) have developed suggested standardized process structures and formats for improved data delivery, interoperability, and data exchanges. In 2019, the AASHTO adopted IFC as a standard data schema for exchange of electronic engineering data within the highways sector.

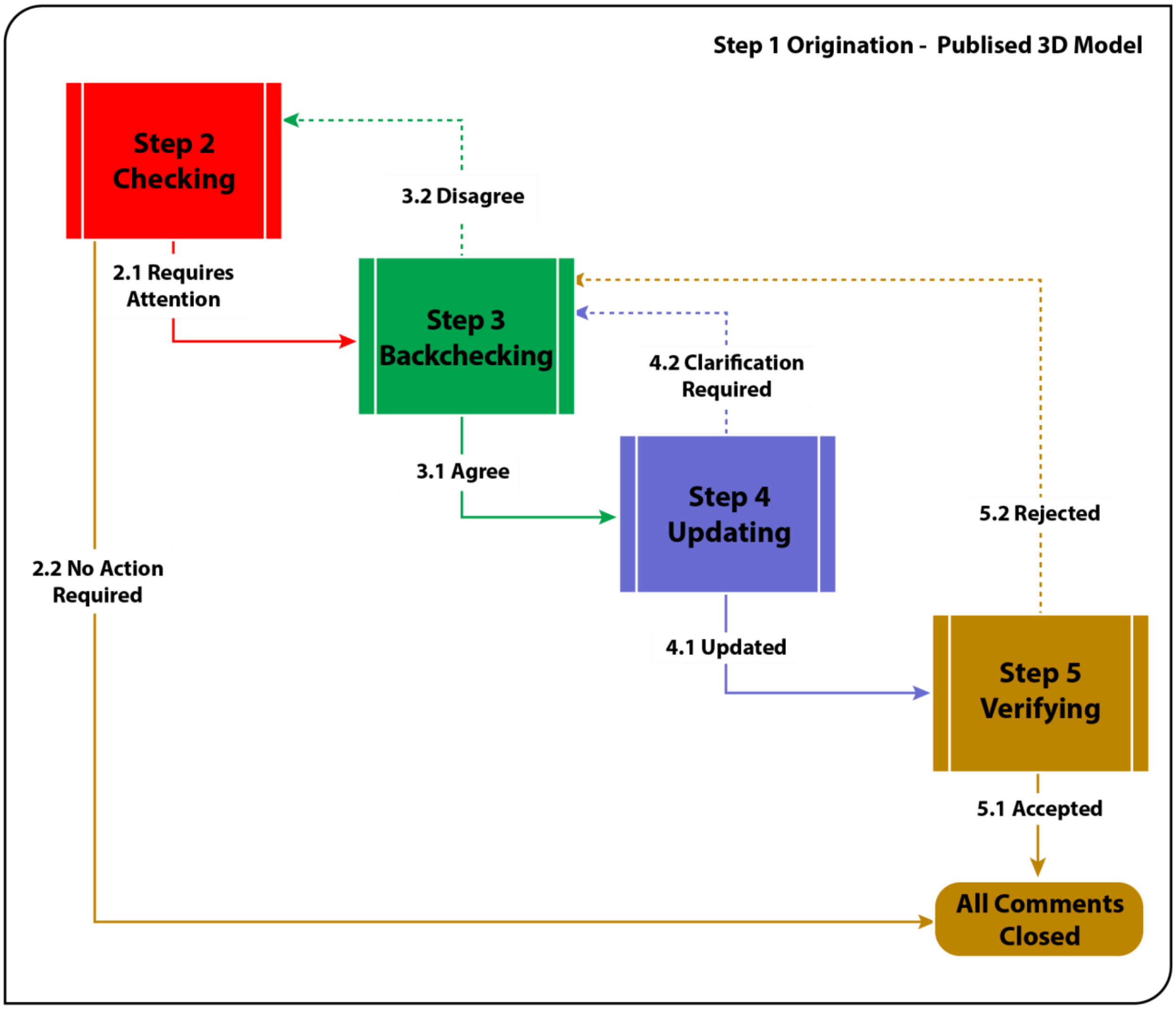


Figure 2-16. Screenshot. Florida DOT BIM model review QA/QC

Table 2-12 presents the data quality checks implemented in each of the data models used in the final design model and existing conditions survey model. Formal automated clash detection reports are conducted at key milestone frequencies (preliminary design [30 percent], detailed design [60 percent], and draft design [90 percent] project delivery phase milestones prior to final design) for model QA/QC and interdisciplinary design and construction review with corrective action plans.

Table 2-12. Example BIM data model QA/QC checks for the final design model.

Model	Elements	QA/QC Check Description
Federated Final Design Model	All key discipline elements in all discipline data models	Developmental reviews (conformance, completeness, consistency), Design Analysis reviews (data contained in project reports), interdisciplinary coordination reviews (all disciplines and federated models), geometric geospatial coordinate system and projection checks, visual QA/QC checks, digital reviews (origination, checking, backchecking, updating, verifying) would be performed on all disciplines' elements
Existing Conditions Survey Model	All survey elements	Geometric geospatial coordinate system and projection checks, QA/QC spot checks, and visual QA/QC checks would be performed on all survey data elements involved in the existing conditions survey

2.4.4.3 Data Uses for the Final Design Model

The following stakeholders could use the final PS&Es and final design models and existing conditions survey model:

- Design project managers overseeing the design team who approve, sign, and post the PS&Es and final design models for project bidding and third-party consultants.
- Construction project managers overseeing the construction team and the third-party contractor who construct and install assets involving the project.
- Surveyors, survey technicians, and construction engineering inspectors who field verify and QA/QC the installed assets as a new existing conditions survey model to generate the record as-built model (DC.7) and contractor survey staff for layout, stakeout, and machine control.

2.5 BIM WORKFLOW 3: DATA AND PROCESSES ACROSS DESIGN AND CONSTRUCTION

The DC business process includes the final design tasks related to delivering a project for construction and managing the actual construction of the project (Figure 2-17). The plans developed in design are reviewed for constructability, a baseline construction schedule is developed, and final quantities are produced in preparation for the bidding process. The process continues with the awarded contractor producing a critical path method construction schedule and logistics plan, developing shop drawings for fabricated components, and constructing the project. The final step is to field-survey verify the construction and record the as-built information for asset management purposes.

The existing use cases identified in this business process are:

- DC.2 Create Detailed Quantity Take-off and Estimate.
- DC.3 Provide Design Information for AMG.
- DC.6 Development and Review of Shop Drawings.

- DC.7 Verify Construction Results and Record As-Built Data.

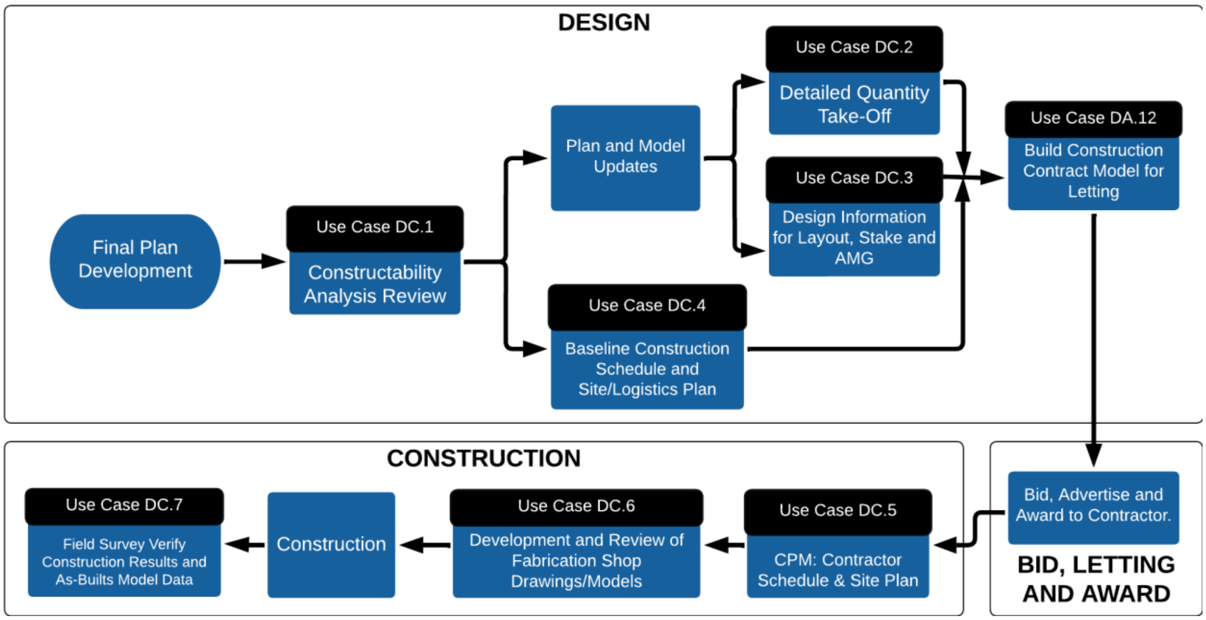


Figure 2-17. Flowchart. Integrated BIM Workflow 3 depicting data and process flow across business processes in the design and construction phases.

2.5.2 Use Case DC.2 - Create Detailed Quantity Take-off and Estimate

2.5.2.1 Data Modeling for the Quantity Take-Off and Estimation

The engineer’s cost estimate plays an important role throughout the design phase of a highway infrastructure project. At the conceptual and preliminary design milestones, the engineer’s estimate provides valuable input for establishing the baseline budget for the project and serves as a mechanism for monitoring if the current estimate of construction costs is within budget. When the highway infrastructure project is put out to bid, an engineer’s estimate is prepared and included in the bid package. The engineer’s estimate is based on itemized quantity take-offs based on the final contract plans. In the design-bid-build procurement method, the itemized quantities are also used for progress payments to the contractor. Pay-item categories are based on industry classification systems and typically contain a unique identifier, specification reference, unit of measure, and description. The project estimator reviews the project and identifies the pay-item categories per project component and develops a systematic and organized approach for collecting and recording the necessary quantities for each component. Pay-item categories and related quantities become more detailed as the project progresses from conceptual design through final design. Establishing the unit cost for each pay item and overall contingency depends on several factors, including the experience of the estimator, knowledge of projects of similar scope and complexity in the same geographic area, availability of contractors, price trends of materials, means and methods, and others.

In the current process, engineers, or engineering technicians along with estimating technicians, calculate quantities based on the current design, often relying on PDFs or CAD files and spreadsheets. These data are imported directly into the cost estimating software (model) from the relevant design data models. Quantities for each pay item are calculated using the criteria file managed by the estimating software. The quantities are extracted from the design files as XML/CSV exports or in the form of spreadsheets and provided to the cost estimator. The estimator combines the constituent spreadsheet files into a master quantities file and assigns the appropriate pay-item code for each quantity sum and unit cost. The estimator then prepares the complete cost estimate by totaling all the extended costs per pay item and adding any contingencies. Estimation applications are used to import the quantities for the pay items directly from design data models in either 2D or 3D. The pay-item quantities can be expressed in linear, area, volumetric units, or by weight. The design data entities and property sets are linked to LOD phases for each data model and are provided in Tables B-1 to B-3 in Appendix B. A criteria file is established that defines the pay-item code, related model element name, layer or material, and units. A material report is then generated from the model, which lists the quantities of the model elements related to a pay-item code in the criteria file. The reports from different data models can be imported into a spreadsheet for full tabulation or imported into a cost estimating software program that applies a unit cost to each pay-item quantity to produce the overall estimate.

In the envisioned model-centric process, the pay-item and quantity information corresponding to each element in the design data models would be used to calculate cost estimates associated with the model elements using parametric equations and formulas that are part of the model. As a result, the model itself would be a repository of cost information. Table 2-13 shows the properties in each model that would be used with the model element pay items to calculate and incorporate costs in the model. The model and the modeling application could also incorporate a library of historical pay-item costs separated by region. This library would provide data on the last six months, previous year, and last year cost of different pay items to provide engineers and estimators with a solid background for the cost estimate. The use of parametric models with calculated cost line-item properties (derived from the pay-item and quantity properties) would significantly simplify the number of data exchanges that currently occur (as described above).

Table 2-13. Example BIM-mature object-based data model with property sets and properties for the quantity take-off and estimation.

Model	Properties	Properties Description
Roadway Geometry Model	Road width, lanes, shoulder, daylight slope limits, pavement layers, edge treatment, guardrail, barriers, subgrade earthwork, ROW	Length (feet) of linear elements, slope areas, cut and fill volume, pavement layer volumes
Traffic & ITS	Traffic signs, ITS equipment	Location and quantity of equipment
Hydraulic Model	Ditch, swale, flumes, pipes, pipe end sections, structures	Length of linear elements, pipe length by material and size, drainage structure diameter and height
Bridge Model	Approach slabs, abutments, piers, pier foundations, beams, deck, barriers, sensors, deck joints, deck drains, electrical and mechanical equipment for movable bridges	Length of linear elements, volume of concrete for abutments, piers and pier foundations, piles, beams (precast concrete), deck as well as tonnage (steel beams), location, quantity and layout of deck joints, drains, electrical mechanical equipment

2.5.2.2 Data Management for the Quantity Take-Off and Estimation Model

The intelligent iBIM design data models (with quantity, pay item, and calculated cost data) would be federated with a CDE to ensure that the quantity take-off (QTO) technicians and engineers can use the information to create an aggregated project cost estimate for the project and use the federated data sets for analytics. Once federated, the design model authoring applications would allow QTO technicians and engineers to generate business intelligence reports from the integrated data model that are available through the CDE (see Figure 2-18).

In the envisioned iBIM processes, the data management business process activities that constitute this use case would involve directly integrating digital roadway and bridge quantities data into the estimate. In addition, the digital data and visualization would be used to better understand site and major construction elements and carbon footprint. The digital exchange of quantities is possible today either by a data export into a spreadsheet or xml format or by providing proprietary files. The challenge in attaining iBIM maturity would be consistency with bid item breakdown because it varies by State DOT and interoperability with cost estimating software. Efficiencies can be gained through the direct use of accurate quantities from 3D data into cost estimate software and calculations.

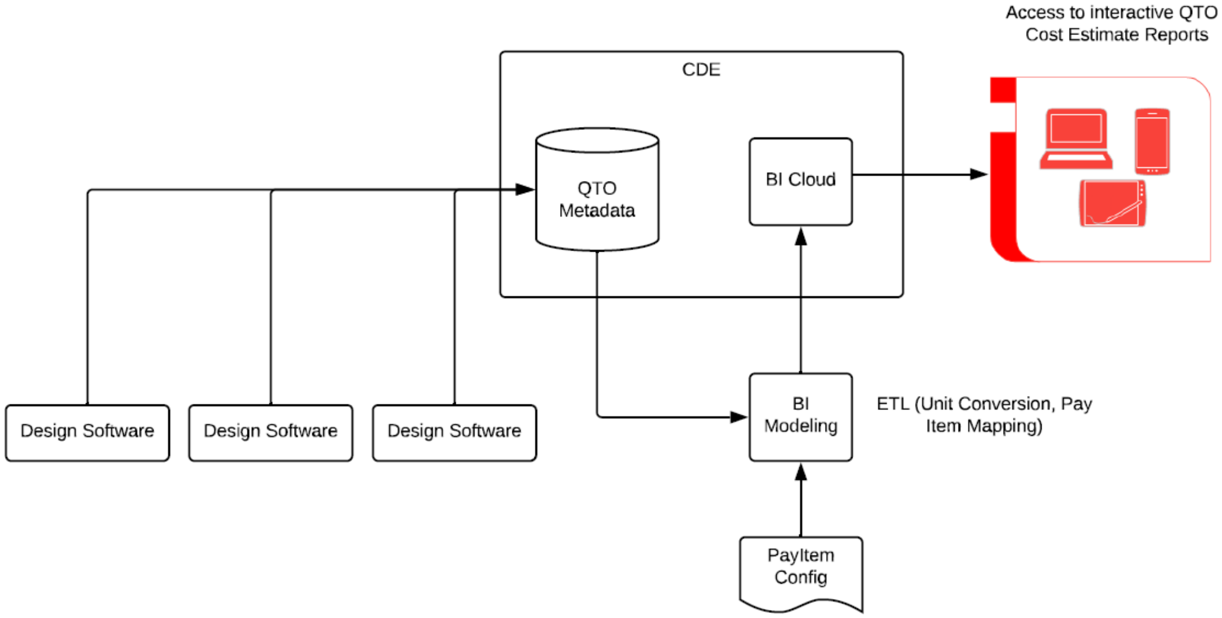


Figure 2-18. Flowchart. Examples of data flows to and from a CDE.

As part of data management, a key aspect would be to conduct QA/QC at all steps, starting from the design modeling application to when the data models are integrated in the CDE. While standard design model QA/QC checks would catch most model deficiencies, an additional set of QA/QC checks at the design model level would ensure that the model elements are of correct size, shape, material, and location per LOD specification prior to initiating the QTO process. This is especially true of 3D surfaces used to calculate earthworks and pavement layer elements contained in the roadway corridor model because the design software does not always generate these elements correctly (e.g., per design intent). In addition, upfront planning is helpful, typically as part of the BIM Execution Plan process, to ensure that all model elements to be captured during the QTO process are created in each relevant design model. The QTO process cannot extract quantities from elements that do not exist in the model. For a more manual QTO process, QA/QC checks would verify measurements from CAD or PDF and that the values were transposed correctly into the spreadsheet. The cost estimator would also perform checks to ensure unit price assignments are correct and spreadsheet calculation logic is error free.

Table 2-14. Sample data model QA/QC checks for BIM-enabled process for quantity take-off and estimation.

Model	Elements	QA/QC Check Description
Roadway Corridor Model	Finished grade surface, bottom of subbase surface, pavement layers	Verify finished grade and bottom of subbase surfaces are built correctly and have correct boundary element (no over or under shoots) by displaying cross sections at regular intervals. Verify pavement layers are built correctly by displaying cross sections at regular intervals.
Drainage Model	Pipe size, material and length, structure size, shape, and height	Verify pipe size, material, and length are correct for each pipe instance by dynamically annotating these parameters from the model elements in plan view. Verify structure size and material are correct for each structure by dynamically annotating these parameters from the model elements in plan view.
Structural Model	Girder, abutment, pier, deck, cross frames, bearing size, shape, material, and location	Verify girder, abutment, pier, deck, cross frames, and bearing size, shape, material, and location match design criteria by comparing parameter values in model to values in design calculation worksheets.

2.5.2.3 Use of the Quantity Task Off and Estimation Data Models

The QTO and cost estimates data model would be used in the following business processes:

- **Bid package development**: Currently, this is the primary use case that uses the QTO and cost estimate data. Engineer's cost estimates and quantities are used to prepare the bid package.
- **Unit cost estimation analysis**: Some agencies have deployed applications that analyze the cost estimates by pay item and model elements to determine unit costs that would be used in estimating future construction projects. With the model-centric approach to management of cost and quantities data for each element and the federation of the various design data models, the process associated with unit cost estimation would benefit, and more agencies and software applications would be able to adopt the features for unit cost estimation.
- **Post-construction cost analysis:** Analysis of construction cost overruns and underruns involves comparing actual construction costs with engineer's cost estimates and preliminary planning estimates. Many agencies do not deploy this process because data about costs and quantities are not modeled consistently and systematically in a single data model. With iBIM data models and data federation, this process would become easier to implement.
- **Asset work history and costs history tracking**: Asset management systems track project and cost estimates for each asset (e.g., bridge, retaining wall, culvert). An iBIM data model development would be key because it would allow for extraction of cost details by asset and asset component.

2.5.3 Use Case DC.3 - Provide Design Information for Automated Machine Guidance

This section describes the current and envisioned BIM-enabled workflows for survey layout, stakeout, and machine control (e.g., AMG and stringless paving). The design-to-construction workflow follows Figure 2-17.

The traditional method of highway grading and earthworks uses slope stakes set by the survey team to define the grade and grade stakes to mark finish grades for pavement courses (top surface course [e.g., hot mix asphalt], base course [e.g., aggregate untreated], subbase course [e.g., granular select backfill], and subgrade [cut and fill]) for the equipment operator. This process poses challenges in quality and efficiency because it is labor intensive and there is potential for error in setting the slope stakes and grade stakes and in the contracted operator's ability to match the grade that is staked during construction. There are also safety concerns because the survey team setting the grades and stakes need to occupy the same space as the heavy equipment. Survey layout and stakeout using traditional processes use 2D/3D CAD design models as available and manually input spatial coordinates in construction contract document plans, drawings, and tables to survey set and locate transportation assets—a process that is inefficient and prone to manual errors.

With BIM-enabled workflows, the contractor reviews the final design data model (DA.12) with updates to the model for survey layout, stakeout, and AMG and others. The final design data model at LOD 300 is checked for model conformance, completeness, consistency, and readiness before handing over to contractors for their use and to modify for machine control and AMG. AMG links BIM data models generated from advanced design software with sophisticated construction equipment to direct, guide, and control the operations of construction machinery using positioning devices such as GNSS and onboard computers. These positioning devices use extracted data from the design model with a high level of precision and accuracy. Survey layout and stakeout using BIM-enabled processes use 2D/3D CAD design models directly and can be linked to survey feature codes to survey set and locate transportation assets.

Using AMG and construction data models improves construction efficiency, quality, and safety while reducing schedule, cost, and environmental impacts. State DOTs are moving toward standardizing their construction contract documents, standard specifications, data model requirements, and final design model deliverables to leverage AMG and machine control-ready models from the roadway design data in providing 3D surface data, grades, breaklines, and avoidance zones (White et al., 2018). Additionally, the existing conditions survey model generated from high-accuracy LiDAR surveys can be provided to the contractor to use in conjunction with design models.

2.5.3.1 Data Modeling to Support Automated Machine Guidance

The final design disciplinary data models at LOD 300 are reviewed and updated to fully incorporate construction-ready AMG, layout, and stakeout data, which are typically sent as construction digital data exchange files (or AMG-ready model files) for the contractor to use, check, modify, and update with their specific construction machinery. At times, the construction densifies construction data models, adds transitions, or adds exclusion areas. Examples include densifying the final design data model exchange files for contractor dozers to eliminate blade equipment chatter; adding transitions to improve grader equipment passes; or adding exclusion areas to prevent grading into or near sensitive wetland areas, utility areas, or non-permitted areas.

Key data design data models to support this use case are discussed below:

- **Survey model:** 3D existing terrain features that were consolidated from aerial photogrammetry, LiDAR, and ground survey. Survey model elements need to be at LOD 300 and of sufficient spatial accuracy to support construction tolerances in locations where planned and existing surfaces tie together.
- **Roadway geometry model:** contains the horizontal alignment, vertical alignment, superelevation, and typical cross-sectional geometry of the roadway using an object-oriented approach to defining these geometric elements.
- **Pavement section model:** typical sections depict roadway pavement cross-sectional geometry and are used in combination with the cross-section template library to define the template drops needed by the roadway corridor model or use parametric components and subassemblies.
- **Roadway corridor model:** combines the elements from the roadway geometry model with surfaces or template drops to represent the roadway cross section and the survey model to create a 3D representation of the roadway. A 3D surface can be generated for the top or bottom of each layer in the roadway cross section template. Roadway corridor model elements need to be at LOD 300.
- **Drainage model:** an analytical model that contains information about catchment areas, runoff coefficients, and volume with drainage assets such as pipe size location and inverts, structure size and location, flume and ditch location, size, and shape.
- **Grading model:** a model that defines grading required by the drainage design, such as swales, ponds, pipe inlets and outlets, and slopes. This model can be created as a corridor model that represents a ditch, flume, or a series of feature (i.e., break lines). The final output from this grading model is a 3D surface of finished grade.
- **Bridge and wall grading model:** typically created as a series of break lines that represent grading at bridge abutments, piers, or retaining walls. Retaining walls are often modeled as corridors. The final output from this grading model is a 3D surface of finished grade.

The 3D surface generated from the roadway corridor model is combined with the 3D surfaces generated from the drainage grading model and bridge and wall grading model to create a single 3D surface. The frequency of elevation points along the roadway corridor model or grading features needs to be small enough to accurately represent the design surface and support construction tolerances. Closed boundaries are created for each 3D surface, honoring shared edges between 3D surfaces where they exist. These 3D surfaces are pasted onto the existing terrain 3D surface to create a composite 3D surface. This composite 3D surface is a detailed and accurate triangulated irregular network of the design and is commonly referred to as the AMG-ready model.

Table 2-15 presents the content that is included in the final design model, including the AMG-ready model. The table presents design data entities, property sets, and properties linked to LOD that are modeled in the BIM-enabled workflow to produce an object-based AMG-ready model for each data model.

Table 2-15. Example BIM-mature object-based data model for automated machine guidance.

Model	Element Property Set	Element Property Description
Final Design Models (AMG-Ready Models)	Roadway Top finished grade surface	**Geometric:** Top of finished grade surface for roadway centerline, pavement edge, lanes, shoulder, gore, median, access, curb and gutter, sidewalk, barrier, and clear zones **Non-Geometric**: roadway and pavement assets attribute data and final design roadway pavement analysis
Final Design Models (AMG-Ready Models)	Roadway Bottom subbase surface	**Geometric:** Bottom of subbase surface for roadway centerline, pavement edge, lanes, shoulder, gore, median, access, curb and gutter, sidewalk, barrier, and clear zones **Non-Geometric**: roadway and pavement assets attribute data and final design roadway pavement analysis
Final Design Models (AMG-Ready Models)	Existing terrain surface (Subgrade)	**Geometric:** Subgrade surface for roadway centerline, pavement edge, lanes, shoulder, gore, median, access, curb and gutter, sidewalk, barrier, and clear zones **Non-Geometric**: roadway and pavement assets attribute data and final design roadway pavement analysis
Final Design Models (AMG-Ready Models)	Structural	**Geometric:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects including superstructure, substructure, deck, bridge type, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall, wingwall, slope protection, wall bench, and abutment bench **Non-Geometric**: bridge and structures assets attribute data and final design bridge and structural analysis
Final Design Models (AMG-Ready Models)	Drainage	**Geometric:** drainage pipe inlets and outlets, storm sewers, culverts, outfalls, and ditches **Non-Geometric**: drainage assets attribute data and final design drainage analysis
Final Design Models (AMG-Ready Models)	Grading	**Geometric:** grading for roadway, ramp, median, gore, intersection, cut and fill slopes, and berms **Non-Geometric**: grading assets attribute data and final design grading analysis
Final Design Models (AMG-Ready Models)	Environmental	**Geometric:** grading, wetlands impacts, and ponds **Non-Geometric**: environmental impacts analysis
Final Design Models (AMG-Ready Models)	ROW, parcel, and easement	**Geometric:** ROW, parcels, and easements **Non-Geometric**: parcel, easement, and permit assets attribute data

Model	Element Property Set	Element Property Description
Existing Conditions Survey Model	Roadway geometry	**Geometric:** existing roadway centerline, pavement edge, grade, median, access, curb and gutter, sidewalk, shoulder, lane, clear zones, and railroad **Non-Geometric**: existing roadway assets attribute data and existing roadway section as-built PDFs
Existing Conditions Survey Model	Structural	**Geometric:** existing bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects including superstructure, substructure, deck, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall, wingwall, and slope protection **Non-Geometric**: existing structures assets attribute data and existing structures as-built PDFs
Existing Conditions Survey Model	Pavement	**Geometric:** existing roadway centerline, pavement edge, grade, median, access, curb and gutter, sidewalk, shoulder, lane, and railroad **Non-Geometric**: existing pavement section assets attribute data and centerline striping and lane marking pavement section as-built PDFs
Existing Conditions Survey Model	Drainage	**Geometric:** existing inlets, storm sewers, culverts, and outfalls **Non-Geometric**: existing drainage assets attribute data and existing drainage as-built PDFs
Existing Conditions Survey Model	Traffic and safety	**Geometric:** existing traffic control signal, traffic sign, ITS, FTMS, barrier, and lighting **Non-Geometric**: existing traffic and safety assets attribute data and existing traffic and safety as-built PDFs
Existing Conditions Survey Model	Utilities	**Geometric:** existing electric, telecommunications, utility poles, and other surface utilities (in and outside of ROW in surrounding area) **Non-Geometric**: existing utility as-built PDFs (in and outside of ROW in surrounding area)
Existing Conditions Survey Model	Grading	**Geometric:** existing grading for roadway, ramp, median, gore, intersection, erosion control, and surrounding topographic DTM survey fused with reality mesh imagery or LiDAR data collection **Non-Geometric**: existing grading, erosion control, and planting inventory data and existing spot-check elevations
Existing Conditions Survey Model	Environmental	**Geometric:** existing grading outside of roadway corridor section, delineated wetlands, and ponds **Non-Geometric**: existing environmental inventory data (soils, bedrock, hydrology, wetlands, waterways, other) and environmental documents
Existing Conditions Survey Model	ROW, parcel, and easement	**Geometric:** existing control, parcels, easements, and ROW **Non-Geometric**: existing parcel assets attribute data and existing property PDFs and photographs

2.5.3.2 Data Management for the AMG-Ready Model

The AMG-ready model from the final design model and associated roadway, drainage, and bridge structure models are made available through a CDE by federating the authoritative model authoring applications within the CDE. The iBIM-enabled data management process aspires to ensure AMG production and model quality assurance, referencing the most current version of all models and model outputs in the CDE. For larger projects such as multilevel interchanges, the AMG-ready model is partitioned into smaller sub-models that allow the project team to manage updates, QA/QC, and deliver the AMG-ready models more efficiently. A shared transfer space with the contractor is typically established within the CDE to store AMG models that are formally submitted.

Data sharing, exchanging, and provisioning processes; tools; and systems need interoperability between design software and AMG machinery. Opportunities for improving the data sharing, exchange, and provisioning process entail standardizing 3D surfaces that can be reliably produced by software and used AMG machinery and developing a certification process for software and AMG machinery.

The AMG-ready model can be checked by comparing DTM surfaces in models or detailed contour plans, surface profiles, and cross sections generated from the AMG-ready triangulated irregular network against the roadway design drawings. The AMG-ready model can be checked by comparing the 3D surface from the final design model with the 3D surface from the AMG-ready model. Both the roadway designer and contractor perform QA/QC on the AMG model from the final design model. Once vetted, the 3D AMG-ready model is transferred to the contractor who uses, updates, or modifies the model using survey-and-machine vendor AMG software. Table 2-16 summarizes some of the QA/QC checks for AMG-ready data models.

Table 2-16. QA/QC checks for final design models (AMG-ready models).

Properties	QA/QC Check Description
Horizontal and vertical alignment, super elevation, lane width, edge treatment, sidewalks	Compare surfaces or overlay contours from AMG-ready model with final design grading plans to verify horizontal alignment, vertical alignment, and superelevation match design. Overlay feature lines from AMG-ready model with final design plans to verify width and location of travel lanes, shoulders, edge treatment, and sidewalks.
Daylight slopes, drainage ditches, and swales	Overlay contours and slope intercepts and drainage-related feature lines with roadway grading and drainage grading plans to verify drainage grading model matches drainage design.
Bridge grading	Compare slope analysis of AMG-ready model with bridge and retaining wall plans and sections to verify slopes match design.

2.5.3.3 Uses of AMG Data Models

For iBIM, the business process activities that constitute this use case would use 3D design models and transition to use open standards. Furthermore, such models would be made available to contractors so that they can be used, modified, and updated as part of the construction process and imported or exported into specific construction machinery. All relevant grading would be modeled using AMG, where appropriate, for pavement and slope areas, and around bridge abutments, drainage outfalls, and barrier locations to the needed level of accuracy and detail. To attain BIM Level 2, recent advances in model-based connected construction, construction machinery through positioning devices with GNSS, advanced survey methods, and E-construction need to be incorporated in highway and bridge projects. Improvements in interoperability between connected design, construction, and survey software applications along with using a connected cloud-based CDE can be leveraged to reduce costs, schedules, and risks and to improve performance, quality, and safety. Mature standards for data exchanges, software integrations, LOD, and QA/QC need to exist before this use case can reach BIM Level 2. A shift in model-based tools used by transportation discipline engineers and contractors transitioning to full digital delivery could accelerate efficiencies in workflows. The following stakeholders could use the PS&Es, final design models, and existing conditions survey model for construction layout, stakeout, and AMG:

- Design project managers overseeing the design and survey teams and third-party consultant(s) who approve, sign, and seal the PS&Es, final design models, and existing conditions survey model for project bidding to be used by contractor.
- Construction project managers overseeing the construction team and the contractor who will be using the contract documents (including the AMG-ready model) for constructing and installing assets involving the project.
- Contractors with subcontractors bidding and using the construction contract documents (including AMG-ready model) and after award are involved in construction.
- Surveyors, survey technicians, and construction engineering inspectors who field verify and QA/QC the installed assets and oversee the contractor survey staff for layout.

2.5.4 Use Case DC.6 – Develop and Review Shop Drawings and Models

Shop drawings are detailed plans that translate the designer's intent and provide fabricators with the necessary information for manufacturing and erecting a building. The structural engineer (or representative of the owner) reviews and approves these shop drawings and envisions BIM-enabled fabrication models prior to release for fabrication.

2.5.4.1 Data Modeling for Shop Drawings or Models

The traditional process has often involved hard copy paper or PDFs from CAD drawings, which are produced based on information and specifications provided in the contract plans and shop preferences. The fabricator or an outside detailer would complete the drawings, which the owner (or representative) would send for review and approval using hand markups and ink stamps. These drawings are then provided to a fabricator's personnel on the shop floor. Other purposes may include final QA/QC by the designer or documentation for the owner.

The deliverable for the traditional business process is a set of drawings that are approved for fabrication. The following steps are usually involved:

- The fabricator creates shop drawings based on the interpretation of the contract plans and then submits them to the designer.
- The designer reviews the shop drawings and accepts, rejects, or accepts with red-line changes.
- The fabricator re-creates or modifies the shop drawings based on the designer's comments and resubmits them to the designer for review.

When the designer approves the shop drawings, fabrication is authorized. This exchange of data has been improved by using PDFs and electronic exchanges of data but is still a plans-based workflow and is archaic compared to other industries such as automobile manufacturing.

The envisioned BIM-enabled model-centric process involves a paradigm shift to storing data in a fabrication model instead of in drawings. These models would ideally start with the contract model and be modified based on the contractor's means and methods, along with the fabricator's process. There is an opportunity to incorporate the contractor's value engineering proposals at this time. It is important to note that model-based fabrication is already being used routinely in most manufacturing industries. This technology process does not need to be developed, but merely imported into bridge design and construction.

The deliverable for the envisioned model-centric process is a fabrication model from which drawings and a bill of materials can be extracted. The envisioned BIM-enabled fabrication model uses file formats that record not only the final configuration, but also the fabrication process itself. A BIM-based workflow would include shop drawings developed directly from data models produced in design, then updated by the fabricator to include more detailed information needed for fabrication and specific shop preferences. The model could then be used to produce drawings as needed for the shop floor, but the review and approval process would be through the model. Additionally, element fit could be assembled within a data model environment as a constructability review, which could be done as a virtual assembly where warranted.

The fabrication models for bridge structures are generated at LOD 400 from the PS&Es and final design models' construction contract documents and include the property sets and properties described in Table 2-17.

Though the current process of shop drawing approval is predominantly paper-based, many fabricators are creating 3D models and associated digital data to use in the fabrication process. The 2D plans may or may not be needed on the shop floor, but they are still needed for the review and approval processes.

Key components to achieve an iBIM workflow include improved interoperability between bridge model authoring software and software used in fabrication. In this context, mature data specifications for IFC data exchanges (e.g., design-to-fabrication IDM), LOD, and QA/QC are important to advance iBIM. A shift in tools used by structural engineers and fabricators to produce, use, and review digital data is also needed. A transition from shop floor staff using models instead of paper plans could accelerate full implementation. However, this is not universally necessary (internal means and methods flexibility should be preserved). Efficiencies gained through this transition include:

- Reduced waste because fabricators are creating some (or all) information in 2D shop drawings for owner's acceptance and not using the information at all.
- Reduced review efforts and times because design intent and fabrication details are more apparent in visual models.

Table 2-17. Example of BIM-mature object-based data model created with property sets and properties for final fabrication data models.

Elements	Properties Description (Examples)
Structural Elements	**Geometric:** bridge including superstructure, substructure, deck, bridge type, parapet, railing, and deck drainage **Non-Geometric**: bridge and structures assets attribute data
Drainage Elements	**Geometric:** inlets, outlets, and deck drains **Non-Geometric**: drainage assets attribute data

The major obstacles to implementing the BIM workflow would primarily be cultural around norms in CAD standards, roles and responsibilities, and project resourcing. The following steps could be taken to accelerate BIM workflows for this process:

- Standardize 3D models (e.g., using bSI IFC step-based) that can be produced by any software and used by every fabrication method.
- Develop a certification process for software and fabrication facilities.

2.5.4.2 Data Management for Creating Final Fabrication Models

In the iBIM-enabled workflow, this model handover would be time-stamped, versioned, and executed through the CDE. During the construction phase, the final fabrication models would be created with the content as described above and made available through the CDE by federation of the model authoring application(s) with the CDE. The construction schedule model would also be created (as part of process DC.5, as shown in Figure 2-17). The CDE would allow reviewers to align and synchronize the construction contract model, construction schedule model, and the final fabrication model. Using models through the CDE would enhance the quantity and the quality of the shared data. The scheduling and fabrication models would have a higher LOD at 400 and would incorporate the contractor's means and methods as well as the fabricator's best practices. The fabrication model would therefore not be the container of the information as in the paper-based workflow, but rather an extraction of the information contained in the model.

For each of the data models developed, model data quality reviews would be a key step in the data management process. This would be particularly important for ensuring that the models can be integrated in the CDE environment seamlessly once made available from the federated authoritative systems. Table 2-18 describes QA/QC checks used to validate all structural elements associated with the bridge as well as the connecting elements from the roadway, geotechnical, drainage, traffic and safety, and utilities data associated with the bridge elements from the structural model.

Table 2-18. Data model QA/QC checks.

Model	Properties	QA/QC Check Description
Structural Data Model	All structural elements associated with the bridge	Validation and conflict resolution
Roadway Geometry Data Model	Roadway elements associated with the bridge (e.g., centerline, bridge edge, grade, median, curb and gutter, sidewalk, shoulder, lane, and superelevation)	Validation and conflict resolution
Geotechnical Design Data Model	Geotechnical elements associated with the bridge (e.g., substructure support)	Validation and conflict resolution
Hydraulic Data Model	Drainage elements associated with the bridge (e.g., deck drains)	Validation and conflict resolution
Traffic and Safety Data Model	Traffic and safety Elements associated with the bridge (e.g., lighting, barrier, sign, etc.)	Validation and conflict resolution
Utilities Data Model	Utilities elements associated with the bridge (e.g., permitted use of utility on bridge)	Validation and conflict resolution

2.5.4.3 Uses of Final Fabrication Models

The following stakeholders could use the fabrication model:

- Design project managers overseeing the design team and third-party design consultants who would oversee structural discipline review and approve the fabrication models for the bridge structures.
- Construction project managers overseeing the construction team and third-party contractor overseeing construction of the bridge structures.
- Structural lead designers working with the structural design team and third-party design consultants who would review and QA/QC the fabrication models of the bridge structures.
- Fabricators and detailers who would deliver structural shop drawings and meet requirements and specifications from the PS&Es and final design model construction contract documents in fabricating, detailing, and supplying materials for the bridge structures.

2.5.5 Use Case DC.7 – Verify Construction Results and Record As-Built Data

As-builts record key information to document the location and detail of installed assets and capture deviations from the design during construction to SoRs involving new construction, reconstruction, rehabilitation, renovation, and other transportation project types. This information becomes a permanent as-constructed record that can be used in operation and maintenance and management of transportation assets conditions and performance. Additionally, digital as-builts are also updated as living records for lifecycle asset management. While as-builts for surface features may also be collected supplementally as part of the operation and maintenance phase (e.g., statewide mass LiDAR data collection), the focus of this section is on field-survey verification and recording of as-built data during construction, as shown in Table 2-2, which then become a record digital as-built of newly installed assets. Such as-built records may also be thought of as an updated existing conditions survey data model (like the one discussed in section 2.2.2). The digital as-built is the link between the PIM in data handover to the AIM. The goals of digital as-builts include improving construction management, operation and maintenance, asset management and project scoping, which complete the lifecycle digital delivery process.

The primary uses of digital as-builts include:

- Locate assets geospatially for lifecycle data management.
- Use advanced models for visual field inspection, E-construction and post-construction.
- Inspect, field verify, and enhance construction pay quantity processes.
- Document and archive as-built PDF and model data to SoRs.
- Link, integrate, and extract survey and CAD/BIM model data to GIS/AMS.

Secondary and future uses of digital as-builts include:

- Link post-construction statewide mass LiDAR data collection.
- Link asset data to hazards and emergency response and repair.
- Link machine data (e.g., AMG, Intelligent Compaction [IC], etc.).
- Link continuous real-time assets monitoring with sensors, internet of things, artificial intelligence, and machine learning.
- Visualize assets using augmented reality, virtual reality, mixed reality, and extended reality for lifecycle asset management.

The potential benefits of digital as-built models for transportation projects are readily accessible data, real-time data for timely decision-making, extractable data for reuse in enterprise asset management data systems, enhanced safety, and streamlined project delivery workflows. Both current and envisioned BIM-enabled workflows for field-survey verification and recording as-built data are presented, and the opportunities for improvement in current data creation and exchange processes are listed.

Traditionally, as-builts documenting the changes in construction after field-survey verification are marked up on hard copy paper plan prints or mylar plans, scanned, or recorded using static PDFs. These traditional methods of creating as-built plans during construction involve the construction manager, construction engineering inspector, or third-party contractor recording changes by red-lining the contract plans, which are then reviewed, approved, archived, and stored in PDF format for future use. The redlined markup plans are commonly edited using a PDF markup tool and may be replicated from paper plans and notes in the field back to 2D CAD drawing sheets in conjunction with adding data from inspector daily reports. The traditional deliverable for the current process is an as-built set of paper, mylar, or PDF markup plan documents that are archived into a hard copy file system or searchable on-premises document management system repository. The major shortcomings of these hard copy or electronic plans-based document processes are data accessibility, manual changes, and data recreation.

2.5.5.1 Data Modeling for As-Built Model Production

The record as-built data incorporates key discipline data into the as-built model during construction after field-survey verification from a new existing conditions survey model. These data are summarized below and listed in Table 2-19. Field verification during construction typically consists of using geospatial reality capture methods, which include UAS, LiDAR and GNSS RTK, and robotics total station technologies.

- **Roadway Geometry data:** roadway centerline, pavement edge, grade, median, curb and gutter, sidewalk, shoulder, lane, and railroad.
- **Structural data:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects including superstructure, substructure, deck, bearing, curb, sidewalk, median, deck drain, joint, haunch, girder, parapet, railing, abutment, pier, pier cap, pier column, pier wall (crash wall), wingwall, and slope protection.
- **Pavement data:** pavement layer types and thicknesses for surface, base and subbase courses and subgrade earthworks. Often, salvaged materials are used, including full-depth reclamation, recycle concrete aggregate, and recycle asphalt pavement. The pavement data may also include underdrain, geotextile (if needed), centerline striping, lane marking, rumble strips, safety edge (if needed), and other data types.
- **Drainage data:** inlets, storm sewers, culverts, vaults, outfalls, outlet control structure, and detention and retention ponds.
- **Geotechnical data:** deep and shallow foundations including drilled shaft, micropile, augercast pile, driven pile, spread footing, cofferdam, and other geotechnical data linked to structural and drainage data.
- **Traffic and Safety data:** traffic control signal, traffic sign, ITS, FTMS, barrier, and lighting.
- **Utilities data:** utilities and easements within the ROW.
- **Grading data:** grading for roadway, ramp, median, gore, and intersection.
- **ROW, Parcel, and Easement data:** 2D parcel, easement, and ROW.

Table 2-19. Example of BIM-mature object-based as-built data model created with property sets and properties.

Properties	Properties Description (Examples)
Roadway Geometry	**Non-Geometric**: roadway assets attribute data **Geometric:** roadway centerline, pavement edge, grade, median, access, curb and gutter, sidewalk, shoulder, lane, railroad, superelevation, etc.

Properties	Properties Description (Examples)
Structural	**Non-Geometric**: bridge and structure assets attribute data **Geometric:** bridge, retaining wall, sound wall, sign bridge, large culvert (greater than 20 feet in diameter), approach slab and other structural asset objects including superstructure, substructure, deck, bridge type, curb, sidewalk, median, deck drain, parapet, railing, abutment, pier cap, pier column, pier wall (crash wall), wingwall, slope protection, etc.
Pavement	**Non-Geometric**: pavement section, subgrade, earthworks, underdrain, geotextile (if needed), centerline striping, lane marking, rumble strips, safety edge (if needed) assets attribute data **Geometric:** surface, base and subbase courses, subgrade, etc.
Drainage	**Non-Geometric**: drainage assets attribute data **Geometric:** inlets, storm sewers, culverts, vaults, outfalls, outlet control structure, detention and retention ponds, etc.
Geotechnical	**Non-Geometric**: geotechnical assets and foundation attribute data **Geometric:** deep and shallow foundations including drilled shaft, micropile, augercast pile, driven pile, spread footing, cofferdam, etc.
Traffic and Safety	**Non-Geometric**: traffic and safety assets attribute data **Geometric:** field-verified traffic control signal, traffic sign, ITS, FTMS, barrier, lighting, etc.
Utilities	**Non-Geometric**: utility and easement attribute data **Geometric:** electric, telecommunications, utility poles, and other surface utilities within the State DOT ROW
Grading	**Non-Geometric**: grading attribute data **Geometric:** grading for roadway, ramp, median, gore, intersection, ditches, breaklines, etc.
Property ROW, Parcel, and Easement	**Non-Geometric**: parcel attribute data **Geometric:** 2D ROW, parcel, easement, etc.

2.5.5.2 Data Management for Producing an As-Built Data Model

With BIM-enabled workflows, transportation assets installed during construction would be field-survey verified, and changes would be made to key discipline data models including roadway geometry, pavement, structural, geotechnical, hydraulic, traffic and safety, utilities, and grading data models. The LOD for as-built data is 500 for field-verified data or to practical completion for the asset elements in the data models linked to phases for each data model. The as-built data would include geometric graphical data, attribute non-graphical data, and metadata.

The envisioned model-centric process is also referred to as digital as-builts. With the transformation in the industry to digital delivery, model-based design-construction, and digitalization of data, model-based digital as-builts provide a dynamic, data-rich, as-constructed record. Rather than recording changes on paper, mylar, or PDFs, changes can be made in real time directly on the 2D/3D geospatial CAD data models with multiple discipline data models overlaid. Field-survey verification results can also be added to the data models directly with acceptable tolerances confirmed. Advances in the following survey geospatial reality capture methods leverage geospatial data for digital as-builts:

- UAS, LiDAR, and GNSS RTK technologies.
- Subsurface location methods such as ground-penetrating radar, electromagnetic, and SPAR subsurface utility and utility pipeline mapping technologies.
- E-construction data collection methods such as mobile tablets, smartphone devices, and mobile applications.
- Visualization 3D/4D methods to view data such as augmented reality, virtual reality, and computer vision.

This is especially useful for subsurface utilities that are difficult to access after construction is completed. The digital as-builts from PIM become a part of the digital twin and an AIM with extractable data useful for operation, maintenance, and asset management.

A major challenge faced by State DOTs over the years in advancing as-builts using the traditional workflows is the convoluted project delivery and asset management workflows shown in Figure 2-19. Digital delivery and model-based workflows facilitated by iBIM methods as discussed in this chapter, improve the 2D/3D processes related to digital as-builts and data handover as shown in Figure 2-20.

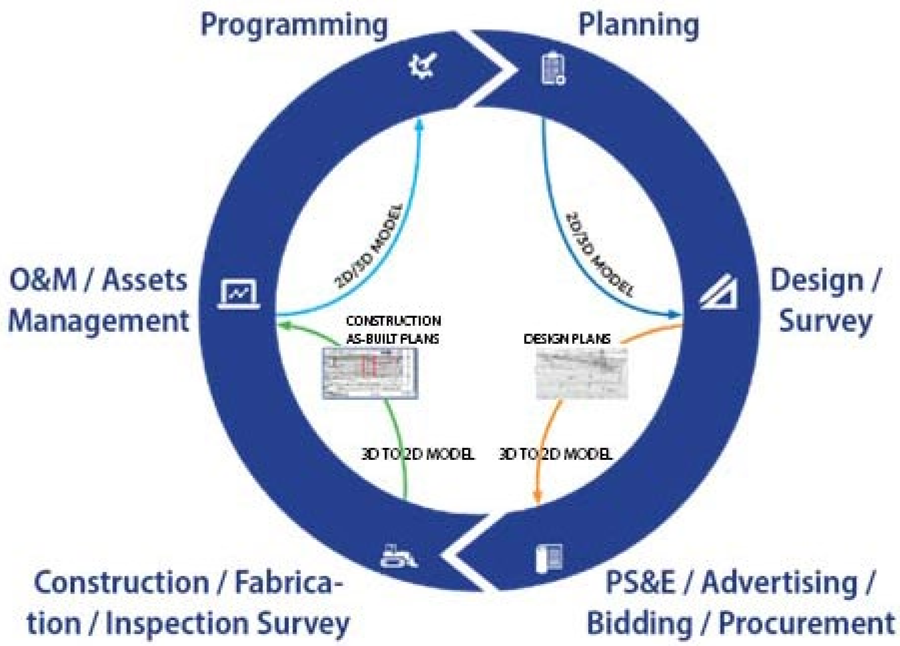


Figure 2-19. Graphic. Current traditional as-built plan information delivery process.

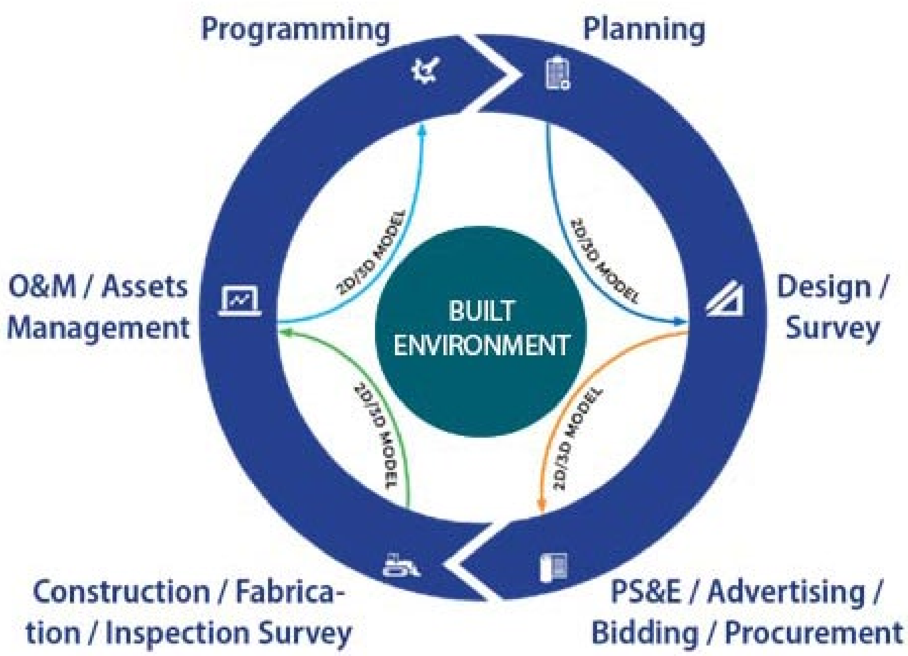


Figure 2-20. Graphic. Model-based digital as-built information delivery process.

Figure 2-21 and Figure 2-22 show traditional as-built processes (paper-based and electronic PDF document-based). Figure 2-23 shows digital model object-based processes.

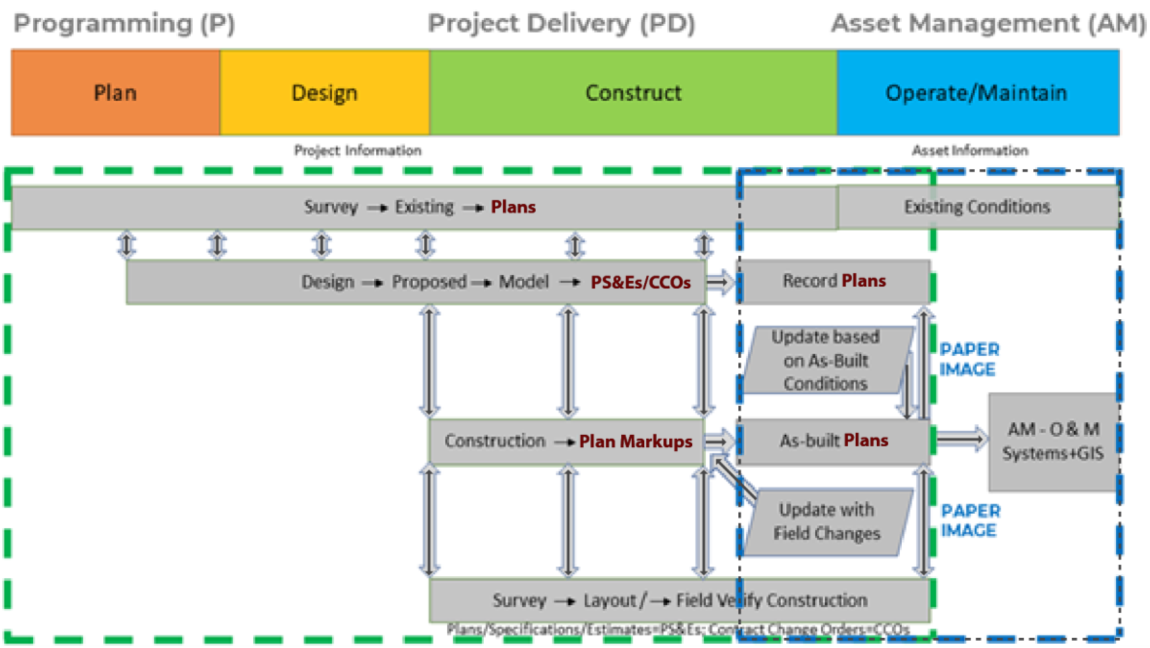


Figure 2-21. Graphic. Traditional paper -based as-built methods.

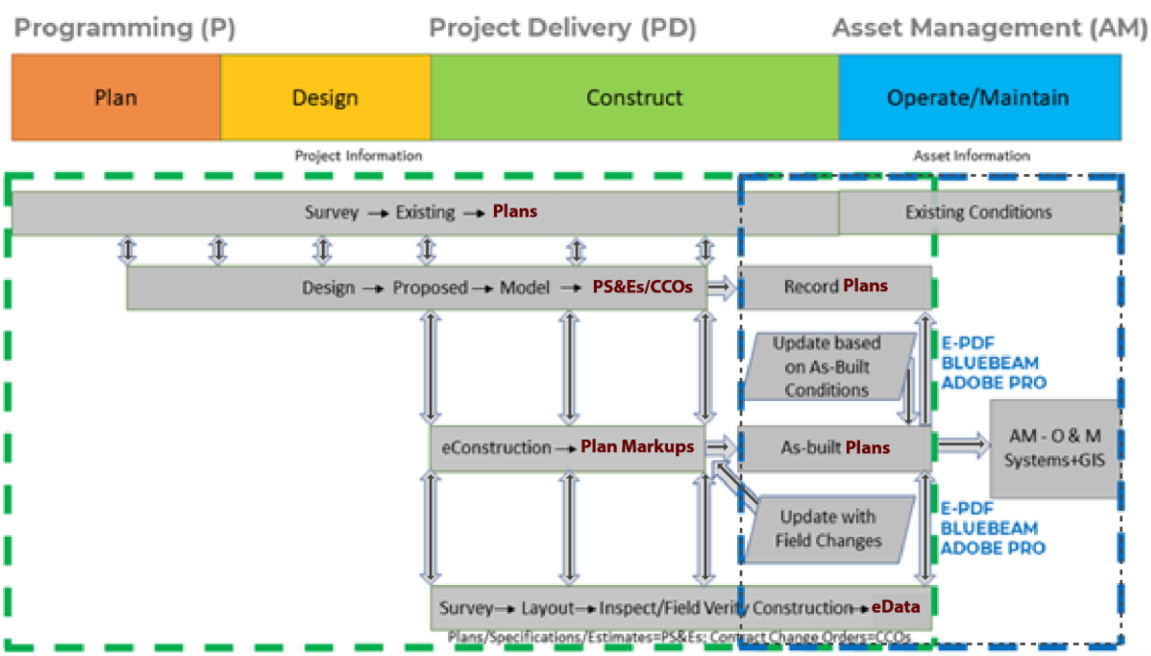


Figure 2-22. Graphic. Electronic PDF document-based as-built methods.

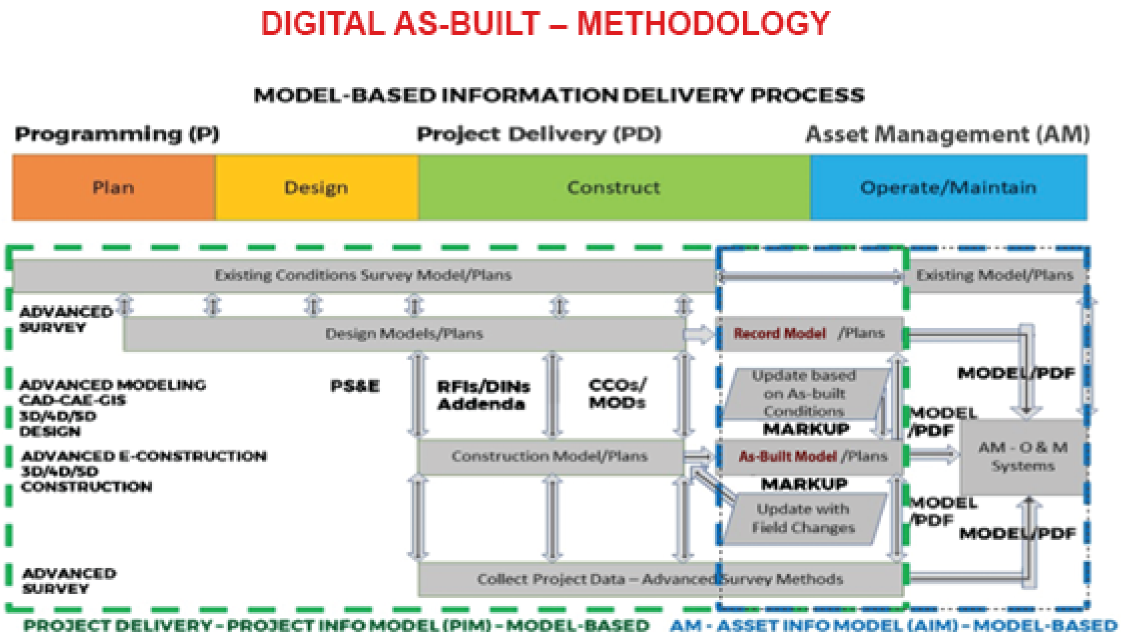


Figure 2-23. Graphic. Digital model object-based as-built methods.

For model-based digital as-built workflows, one of the key benefits is extractable asset object-based data useful for data handover and downstream uses as an AIM. The primary deliverables are the digital as-built data model, which can generate PDFs as needed. Owners requiring as-built digital twins as a deliverable on highway projects are key to the transition to BIM-enabled workflows. Standardization of the digital twin modeling processes, format, content, open platforms, and interoperable data exchanges are also keys to success.

Table 2-20 presents the data quality checks that could be implemented in each of the data models used in the as-built model.

Table 2-20. Example QA/QC checks in producing as-built data model.

Model	Elements	QA/QC Check Description
As-built Model	All Key Discipline Elements	Geometric geospatial coordinate system checks and visual QA/QC checks would be performed on all necessary disciplines.
Existing Conditions Survey Model (Field Verified After Construction)	All Survey Elements	Geometric geospatial coordinate system checks, QA/QC spot checks and visual QA/QC checks would be performed on all survey data elements involved in the existing conditions survey model (field verified after construction).

2.5.5.3 Uses of As-Built Data Model

The following stakeholders could use the as-built model:

- Construction project managers overseeing the construction team and third-party contractor who approve the record as-built model to document as-constructed installed assets.
- Construction team that compiles the record as-built model and generates punch list items to be completed during construction.
- Surveyors, survey technicians, and construction engineering inspectors who provide the existing conditions survey model (field verified after construction) and associated as-built geometric data, attribute data and metadata typically using geospatial reality capture methods including navigation satellite system (GNSS) RTK rover and robotics total station technologies; and E-construction data collection methods such as mobile tablets, handheld survey data collectors, smartphone devices and mobile applications, and inspection daily reports to generate the record as-built model.
- Planning, design, construction, and asset management staffs who use the record as-built model provisioned through the CDE for lifecycle asset management use.

2.6 BIM WORKFLOW 4: DATA AND PROCESSES ACROSS DESIGN, CONSTRUCTION, AND ASSET MANAGEMENT

This section describes the data and process standards that could be used to create an iBIM workflow across the business processes in design, construction, and asset management. Figure 2-24 presents the data and processes that could be integrated to create an iBIM workflow. This iBIM workflow is initiated after construction is complete and ends with handoff of as-built asset information and construction inspection data to an asset information management system. The objective of integrating the data and processes shown in Figure 2-24 is to enable development of an AIM that can be handed off to asset management (more precisely to asset management systems and processes) after construction. The AIM would meet the AIRs created by asset managers for project delivery and the EIRs created by owners or their delegates for contractors based on the AIRs.

Although the practice is changing, such AIRs and EIRs may not always be widely communicated to construction contractors at letting, which may hinder contractors from incorporating as-built data, asset inventory data, and post-construction inspection data in an as-built data model in a manner that is ready for downstream use.

As discussed in Section 2.5.4, the development of the digital as-built data model itself is yet to become a standardized and object-based data model development practice in the industry. At most agencies, an object-based as-built construction data model with asset properties is not created at the end of construction. Information about the built asset is provided either in the form of 2D/3D drawings (either on paper or as electronic PDFs) or in the form of a geometric model with limited non-geometric or non-graphical information about the built asset. However, in the iBIM-based workflow, as shown in Figure 2-24**,** data from the construction contract model (created at the end of design), as-built data and asset inventory data (documented after construction), and the construction inspection model would be integrated to create the AIM for asset management handoff.

In bridge repair, rehabilitation, and replacement projects, the bridge rating information would also be modeled and included in the AIM for delivery to asset managers to allow the rating data to be used for truck routing and permitting during the operation phase. In the next section, the BIM data and process standards that could be introduced in the "Post-Construction Bridge Inspection" business process are discussed in detail as an example of an iBIM workflow (Figure 2-24**)**. This example process is flagged as BIM Use Case DCA.3 in Figure 2-24**.**

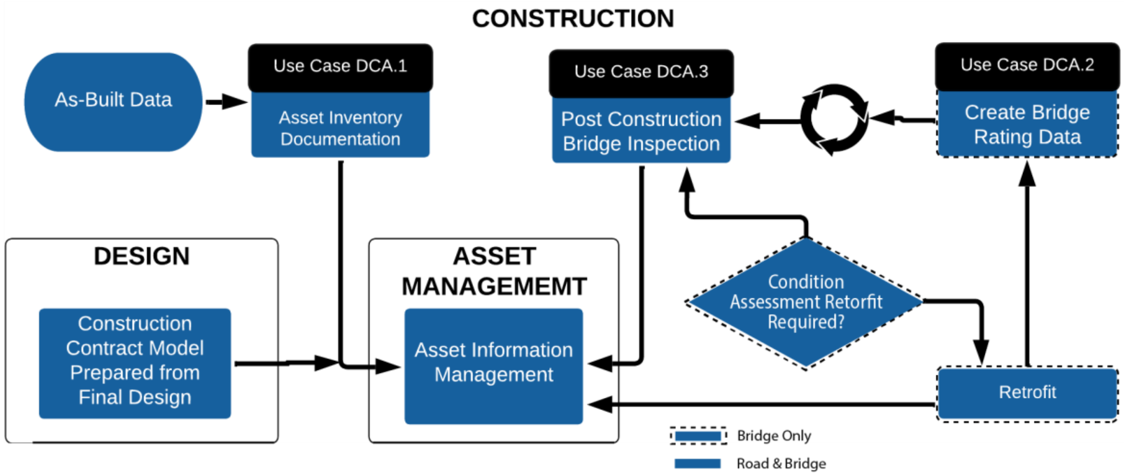


Figure 2-24. Diagram. Integrated BIM Workflow 4 depicting data and process flow across business processes in design, construction, and asset management phases.

2.6.2 Use Case DCA.3 - Provide In-Service Bridge Safety Inspection Data for Asset Management

Transportation infrastructure requires asset management by the owner, which involves capturing in-service bridge safety inspection data at regular intervals and reporting it to the FHWA. Bridge safety inspection is a critical aspect of a State DOT's asset management program. Approximately 620,000 bridges are listed in the FHWA's National Bridge Inventory (NBI), which requires reporting every year. Most of these structures need to be inspected at least every two years during the operation and maintenance phase in accordance with National Bridge Inspection Standards regulation (23 Code of Federal Regulations 650, Subpart C).

Additionally, when a structure is first constructed or when it undergoes a major rehabilitation, repair, or replacement, a post-construction initial safety inspection needs to be completed to capture information about the impact of the work on the condition of the structure. This business process involves conducting an initial safety inspection after the construction and adding that information into the asset information management system, so that the post-construction initial safety inspection data can be integrated with the routine inspection data from the operation and maintenance phase and used in bridge lifecycle analysis.

2.6.2.1 Data Modeling in Support of Creating a In-service Bridge Safety Inspection Model

In-service bridge safety inspection data are typically collected in one of the following three ways:

- Traditional paper-based forms that are either filed with the post-construction as-built plans in a document management system or digitized after inspection and made available in an information management system. Typically, such paper-based forms lack any ability to locate bridge elements geospatially.
- Mobile applications that locate a structure on a 2D map and record information about the condition of structural elements, including National Bridge Elements (NBE) and Bridge Management Elements (BME), as described in the AASHTO Manual for Bridge Element Inspection.
- UAS that collect LiDAR data, photographs, and imagery data for the structure and for the overall project site. Modern mass geospatial data collection systems like LiDAR (either terrestrially mounted or mounted on UAS) collect a large quantity of information that can be processed and structured to support iBIM workflows.

The opportunity for improvement lies in how the data collected from these sources is modeled. If the data are modeled using an object-based, geospatial data model, the data can be seamlessly provisioned to the enterprise asset information management system and to other stakeholders in the organization. However, if data are modeled in paper-based forms, in an unstructured format (e.g., text, or report), then the inspection data extraction and dissemination to structured and geospatial bridge asset information systems can become more difficult. The data collection technology, the availability of the captured data in an object-based data model, and the provisioning of this object-based data model through a web-based CDE or enterprise BIM hub are the three key factors that dictate the maturity of the BIM process in post-construction bridge inspection.

Current information modeling workflow has the following limitations:

- Lack of information in asset inventory data models about asset construction methods, environment, asset maintenance and warranty guidance, asset rehabilitation, and replacement work description (including timeline of work).
- Lack of interoperability from model authoring software and inspection recording software (e.g., mobile inspection tools).
- Linking GIS (geospatially defined data) and BIM platforms (bridge model data) to geolocated photos.
- Linking bridge management and other asset management databases to GIS/BIM platforms.
- Change in process from manual and paper-based to automatic and model-centric, including widespread use of new hardware and software for field activities.
    - Tablets as the primary field data tool (visibility of data, etc.).

- New programs centered around 3D models rather than paper plans.
- Effort needed for individual customization based on exact information agencies collect for bridge inventory.

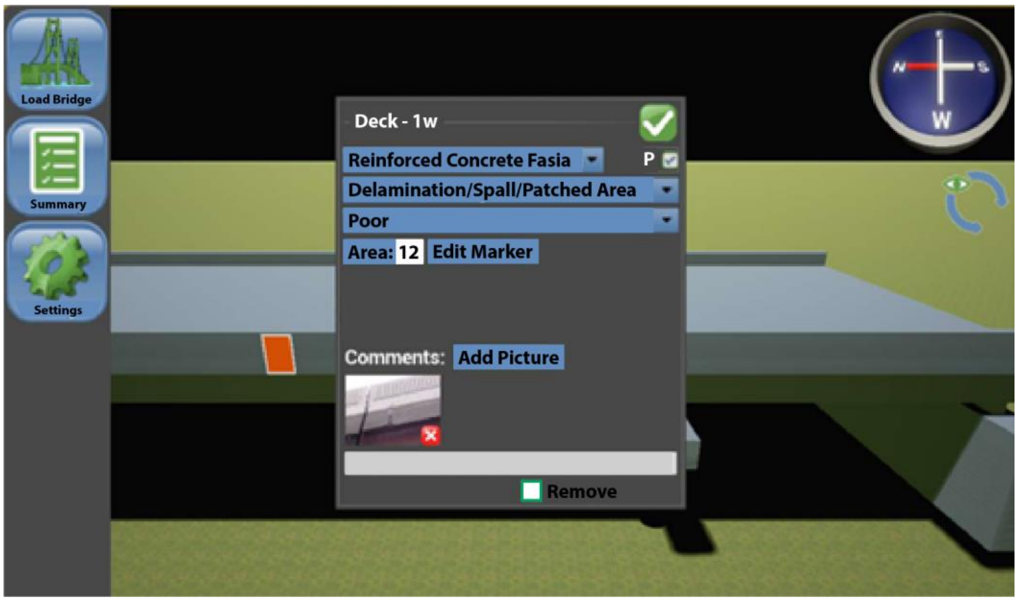
An object-based data model that is also open-standards-compliant can be created using IFC, which allows bridge elements to be modeled using IFC classes and the properties of these objects to be defined. IFC provides agency administrators with the ability to define property sets and identify properties that should be part of each set. The onus is on the State DOTs to define these property sets and properties consistently and to develop a statewide or potentially a national standard for how properties will be modeled and associated with infrastructure objects. Table 2-21 presents an example of the types of property sets and properties that State DOTs can define to develop data standards for creating the bridge inspection data model. An object-based bridge inspection data model that contains geometric and non-geometric information associated with bridge inspection can be used to enhance the BIM maturity of the post-construction inspection.

Table 2-21. BIM-mature object-based data model with property sets and properties for in-service bridge safety inspection data model.

Model	Properties	Properties Description
In-service Bridge Safety Inspection Data Model	NBI Properties	**Geometric**: Bridge location (start/end mile point or station/offset, or latitude-longitude) **Non-Geometric**: Bridge inventory and inspection attributes that have been identified in the NBI manual (FHWA, 2022)
In-service Bridge Safety Inspection Data Model	NBE and BME Properties	**Geometric:** Bridge element location, element object geometry (e.g., deck, pier) **Non-Geometric:** Element, environment, defect, severity, quantity in Condition States 1–4, damage extent
In-service Bridge Safety Inspection Data Model	Imagery (e.g., thermal imagery, point cloud or photographs)	**Geometric**: Georeferenced images, LiDAR point cloud data files **Non-Geometric information**: Bridge identification number, project number, element identification number

In a more mature BIM process, bridge inspectors would use a 3D-data model of the bridge to visualize and populate more detailed and complete information about current bridge conditions. Inspectors would use tablets in the field to document the location and extent of distress on a 3D model of the structure. This is an aspect of the digital twin concept that the vertical construction industry currently uses. The models link to the structure information available in the asset management databases, including any data from non-destructive evaluation or structural health monitoring. Data will also update rating models for re-analysis if conditions change based on inspection. Bridge inspectors would collect the necessary data for the structure elements and add this information to the asset management model. These data would be spatially and temporally attributed, meaning, they will contain the 3D X, Y, and Z coordinates plus the time the data were collected. The data would be organized using a geospatial model that is capable of spatiotemporal modeling and could be queried in many ways.

Use of 3D models in the field with digital data provides opportunities to connect and populate bridge management systems and other asset management portals. Many State DOTs are moving toward full electronic collection of data using tablets in the field for this purpose. However, these workflows still rely on paper-based workflows using forms and require identifying bridge elements by visually representing the location and extent of defects noted in the field using text-only inputs and referencing inspection photos. With a BIM-based workflow, inspectors can take advantage of the efficiency and effectiveness of being able to use a model to visually isolate specific objects during inspection and then include the findings in tagged documentation. Figure 2-25 shows the testing of the Michigan DOT 3D Bridge application tool with the visual placement and documentation of a defect on a bridge abutment (Michigan Tech Research Institute, 2017).



Source: Michigan Tech Research Institute (2017).

Figure 2-25. Screenshot. Deck defect documentation using Michigan DOT 3D bridge application.

The transition to iBIM data management architecture would involve:

- Automating data extraction from a functional bridge model from bridge management systems.
- Using existing data inputs, many of which are standardized for reporting to FHWA, to employ routines that create visual model representations of structures. These models will not be of a high level of detail but will be sufficient to create solids models with approximate geometry of all primary structural elements for inspection reporting and photo geolocation. The routines can be created by bridge type to further refine the model implementation.
- Additional customization for a certain percentage of the existing inventories, but most workhorse typical bridges should benefit from automation.

2.6.2.2 Data Management to Produce a In-service Bridge Safety Inspection Data Model

As part of the asset management process, bridge safety inspectors collect the necessary data for the structure elements for reporting to FHWA. Traditional paper forms are used in the field to populate the owners' electronic software applications.

The transition to a more mature BIM data management architecture would involve performing QA/QC checks on the data that are in the model. For example, Table 2-22 presents examples of some data quality checks that can be performed on data associated with bridge inventory and condition.

- Development of IFC bridge exchanges (e.g., Design-to-Bridge Inspection IDM) that can be critical to ensuring interoperability between model authoring software and inspection recording software.
    - Standardization of the data transferred from the design to asset management and bridge inspection allows the opportunity to transfer data from one software to the next automatically to use tools for their intended purpose without manual re-entry.
    - If needed, these values can be updated from the construction process, although the revision of items for this exchange would be rare.
- Development of data platforms that could facilitate integration and analysis of data. For example:
    - Platform that allows for integration of bridge safety inspection data from inspection applications with bridge inventory data from asset management systems and bridge design data from design and construction as-builts.
    - Platform that hosts streaming data from sensors in a big data store and enables analysis of this sensor data for predicting bridge performance data.

Table 2-22. Example QA/QC checks during the production of a post-construction bridge inspection data model.

Property Set	QA/QC Check Description
NBI Properties	**Non-Geometric Property Checks:** NBI data checks (FHWA, 2021)
National Bridge Management Element Condition	**Non-Geometric Property Checks:** (a) The quantity of element in each condition states adds up to total quantity of element (b) The elements inspected are part of the NBE inventory
National Bridge Management Element Condition	**Non-Geometric Property Checks:** The defects recorded in each element are from the authorized list of events

2.6.2.3 Uses of Post-Construction Initial Bridge Safety Inspection

The initial bridge safety inspection data that are collected after construction are integrated into the bridge management systems so that bridge owners can use them to make informed and effective decisions. The goal is to assess the performance and needs of bridges, evaluate alternative strategies for addressing needs, and prioritize projects that maintain safety in a cost-effective manner. The post-construction initial bridge safety inspection links lifecycle planning and development of bridge management action plans during the asset management, operation, and maintenance phases of the asset lifecycle.

2.7 SUMMARY

Chapter 2 describes how various business processes across survey, design, construction, and asset management could be matured further by building data models, federating data models organizing data in authoritative data model authoring applications, and deploying data-use processes and standards to provision data to multiple stakeholders across the enterprise. The chapter illustrates that BIM implementation would involve establishing data and process standards, policies, tools and technology, people, and organizational structure. The chapter identifies and analyzes existing data and process workflows that could be transitioned from traditional workflows to BIM-based workflows using 10 business processes from across various asset lifecycle phases and establishing how these processes could mature in terms of data modeling, data management, and data use. Corresponding to all the use cases and each of the following three data and process standard development areas, the following questions are discussed:

- Data Model Structure
  - What content should be included as properties and property sets in the envisioned iBIM data model?
  - How would these data be obtained from another data model or business process?
- Data Management
  - What QA/QC checks are done after the model is created?
  - Where is the model stored and how is it federated and made available in the CDE?
- Data Use
  - Who is the user of the model?
  - How do the users access the model in the CDE and extract data from the model for their use?

The improvement opportunities that are identified involve developing object-based data models with property sets and properties; enabling data modeling and exchange using open standards such as IFC; federating the data modeled in model authoring applications; deploying a CDE; and enabling use of data models created in multiple downstream business processes.

CHAPTER 3. BIM ARTIFACTS FOR ENABLING BIM-BASED WORKFLOWS

3.1 INTRODUCTION

For enabling BIM-based workflows in planning, survey, design, construction, operation, and maintenance business processes, State DOTs need to deploy and manage BIM libraries. These libraries manage the following content that is used to enable BIM-based processes:

- Information needs.
- OTL and data dictionary.
- IDMs.
- ILS.
- MVDs.

Each transportation agency could create these artifacts based on open standards. For example, at the international level, organizations such as bSI, Open Space Consortium (OGC), and the World Wide Web Consortium (W3C) have created OTLs, data dictionaries, IDMs, and ILS that are managed and provisioned through API services and websites of these respective organizations.

At the national level, FHWA has created data dictionaries associated with the following:

- All Roads Network of Linearly Referenced Roads (ARNOLD).
- Highway Performance Monitoring System (HPMS).
- Model Inventory of Roadway Elements (MIRE).
- NBI.
- NBE.
- BME.

Some State DOTs (e.g., Minnesota, Florida) have created libraries for holding their enterprise data dictionaries, terms and definitions, and ILS. States have also created asset and project information requirement documents and provisioned websites for consumption by stakeholders through their enterprise file repositories. Some transportation organizations have even created enterprise data libraries as part of their data governance efforts. Such libraries are typically being used to store and maintain information modeling standards (e.g., CAD design and survey manuals), enterprise data dictionaries, data requirements and terms associated with key business processes, lists of applications, and associated system architecture documents. As State DOTs deploy BIM workflows, many of these existing BIM artifacts will have to be updated to ensure that they are compliant with standards and reference each other. For example, agencies that have captured information requirements may need to update them to ensure that they have been captured from the perspective of all business users, are ISO 19650[5] standard-compliant, and use the standard terms and definitions. Agencies may also need to ensure that the information requirement artifacts are set up as the foundation for developing other BIM artifacts such as the OTLs, data dictionaries, IDMs, ILSs, and MVDs. This chapter describes the current state-of-the-practice to understand how State and National transportation agencies manage these documents. A thorough understanding of the state-of-the-practice is essential to understanding how an CBTL (repository) and a SBTL may be relevant.

This chapter recognizes such BIM artifacts and libraries to establish the current state of BIM libraries and artifacts and the work being done by SDOs for storing, integrating, harmonizing, and standardizing existing libraries into a usable repository for practitioners.

3.2 INFORMATION NEEDS

ISO 19650[5] establishes a standard for managing information over the whole lifecycle of an infrastructure asset using BIM. The standard is divided into five parts, and two of the five parts are dedicated to information management during the delivery and operational phases of the asset lifecycle (ISO 19650). ISO 19650[5] emerged as a standard from BS-1192 and PAS-1192 UK Standard for information management. In 2018, the ISO Technical Committee (ISO/TC 59) and European Standards Committee (CEN/TC 442) coordinated to extend the ISO 19650[5] standard and develop a national standard document that outlines the approach for capturing the organization, asset, project, and EIRs (OIR, AIR, PIR, and EIR, respectively). Such documents and the U.S. versions of ISO 19650[5] if created could be managed in an CBTL. In addition, information requirements created by State DOTs in the United States using the ISO 19650[5] guidelines could be stored and managed in an CBTL. State transportation agencies in the United States have been creating such information requirement documents. For example, MnDOT has created PIRs and AIRs for creating the as-built data model (MnDOT, n.d.). Utah DOT has also established information requirements as part of the digital delivery initiative and captured information in the model-based design and construction guidelines document (Utah DOT, 2019). As the practice of BIM evolves, such efforts for capturing OIRs, AIRs, PIRs, and EIRs based on open standards and guidelines such as ISO 19650[5] are likely to gain momentum, both at the national and State levels. State DOTs have started publishing such information requirements on their websites and in the form of BIM artifacts.

3.3 OBJECT-TYPE LIBRARY AND DATA DICTIONARY

International SDOs have created OTLs and data dictionaries by considering the vocabulary of terms and definitions associated with transportation data and information requirements as part of their open BIM data exchange standards work (e,g., bSI's IFC and OGC's LandInfra/InfraGML, CityGML). These OTLs and dictionaries should be related to the work of national transportation entities in the US to develop a connection between existing US transportation industry subject matter knowledge and national and international data modeling and linking standards. For example, considerable roads and bridge industry knowledge is encoded in FHWA's reporting standards such as ARNOLD, HPMS, and NBI or in AASHTO's Bridge Element Inspection Standard (AASHTO, 2019) and in AASHTO JTCEES' Model Element Breakdown and Level of Development (MALD) document. Private actors have also made progress in this area and have standards that should be considered as part of the open BIM discussions. Table 3-1 briefly describes some of these OTLs and data dictionaries and categorizes them based on whether they are definition standards (i.e., those that introduce objects, terms and meaning) or content standards (i.e., those that provide a portal or a software to store and manage the libraries of objects, terms, and definitions).

While all of these OTLs and dictionaries are available through the publication portals of the developer, a centralized national repository could serve as a guide to transportation agencies and inform them about the artifacts that could be adopted. An CBTL could serve as a one-stop location where libraries and data dictionaries that are relevant for BIM deployment could be found.

For example, among all the libraries listed in Table 3-1, the bSI IFC OTL is developing as a potential transportation industry standard. ISO 12006-3 (International Framework for Dictionaries) has also recognized bSI's buildingSMART Data Dictionary (bSDD) API for accessing standard terms, processes, and object definitions. Data definitions for geometry and building object classifications have been standardized as ISO 16739 (IFC). To date, IFC has been the primary output adopted in the design and construction industry.

Additional examples of online libraries exist in other related industries. Irrespective of the specific libraries that are recognized in any industry, at any given point in time, an CBTL should serve as the repository that could host any of these OTLs from the SDOs. An CBTL should also serve as the repository for all derived OTLs created by merging two or more of these SDO libraries to ensure that a comprehensive set of object types (classifications) are available for representing all of the transportation features across all stages of the asset lifecycle.

Table 3-1. Examples of BIM object-type libraries and data dictionaries.

Resource	Categories	Description
bSI IFC	Definitions	Industry Foundation Classes is a data standard, recognized as ISO 16739 that describes geometry and classifications of objects, which are used for communicating building data for purposes of construction and management of facilities. To date, it has been adopted by 200+ software applications, all major BIM authoring tools that serve commercial building construction markets, and in Europe in particular.
bSI BCF	Definitions	BIM Collaboration Format is a data specification used to describe issues found during design or construction. To date, it has been adopted by 10-plus design and construction review applications.
bSI bSDD[a h]	Software Definitions Languages	bSDD is an online service hosting classes (terms) and properties, allowed values, units, translations, relations between those and more. It provides a standardized workflow to enable data quality, information consistency and interoperability.
OGC InfraGML[b h]	Definitions	InfraGML presents the Geography Markup Language encoding of concepts supporting land and civil engineering infrastructure facilities specified in the OGC Land and Infrastructure Conceptual Model Standard (LandInfra), OGC 15-111r1. Conceptual model subject areas include land features, facilities, projects, alignment, road, railway, survey (including equipment, observations, and survey results), land division, and condominiums. OGC and buildingSMART have aligned the object definitions in InfraGML and IFC.

Resource	Categories	Description
OGC CityGML[c h]	Definitions	CityGML is used to describe infrastructure elements such as buildings, roads, rivers, bridges, vegetation and city furniture. The Netherlands has extended the CityGML library to create a national BIM library (called IMGeo). This library is also used for modeling assets outside of cities.
FHWA NBI	Content Definitions	The FHWA NBI defines a set of fields for reporting the condition of bridges and contains data for all bridges in the U.S. that meet minimal criteria.
NBS National BIM Library[d h]	Content Library	This online portal in the United Kingdom is approved by governmental authority as being the only portal that meets stated requirements. All data are provided in documented formats (e.g., Industry Foundation Classes). It is community-driven in that users may upload content subject to curating. The service precludes distribution of content by other software.
AASHTOWare Bridge Design/Rating	Software Content Definitions	AASHTOWare Bridge Design and Rating encompasses software as authoring tool, content from libraries (within database for respective organization), and definitions of components for bridge information, primarily for structural analysis purposes. Because licensing restricts usage, only publicly available information about this software is used as a basis for this report. However. it is listed here, based on the assumption that many States (via AASHTO) have made substantial investments in the software and data based on this software, and are in position to make such content and definitions open for public use and standardization if they choose to do so. While this software has not provided a public content library per se, the software provides a library capability, where libraries of bridge components are stored in databases for each State DOT – if such library data were to be shared across DOTs, that would form a national content library.
Microsoft Github[e h]	Content Library	GitHub is a website that allows software developers and others to store documents (mainly programming language code). It is free to join and offers an example of crowd-sourcing to collaborate on software development projects.
BIMobject[f h]	Content Library	This online portal provides 3D BIM objects with geometry and attributes that anyone can contribute to and use for private purposes. The portal offers some formats that are open (e.g., Industry Foundation Classes) and some that are not (e.g., Revit); some content is community-driven (with curation), some are paid for and provided by respective product manufacturers, and some are authored by employees of the portal. The service precludes distribution of content by other software.
openBrIM[g h]	Library Content Definitions Languages	The term "openBrIM" has been used in past FHWA research (Bartholomew, et. al, 2015) to refer to a comprehensive model of what can be achieved with standardized components and storage of data definitions. It has also provided valuable representative components typical for bridges such as cross frames.

[a] buildingSMART Data Dictionary. https://bsdd.buildingsmart.org/

[b] OGC InfraGML. https://www.opengeospatial.org/standards/infragml

[c] OGC CityGML. https://www.opengeospatial.org/standards/citygml

[d] National BIM Library. https://www.nationalbimlibrary.com/[b] GitHub. https://github.com

[e] GitHub. https://github.com

[f] BIMobject. http://bimobject.com/; https://accounts.bimobject.com/termsofservice

[g] OpenBrIM. https://openbrim.org/www/brim/

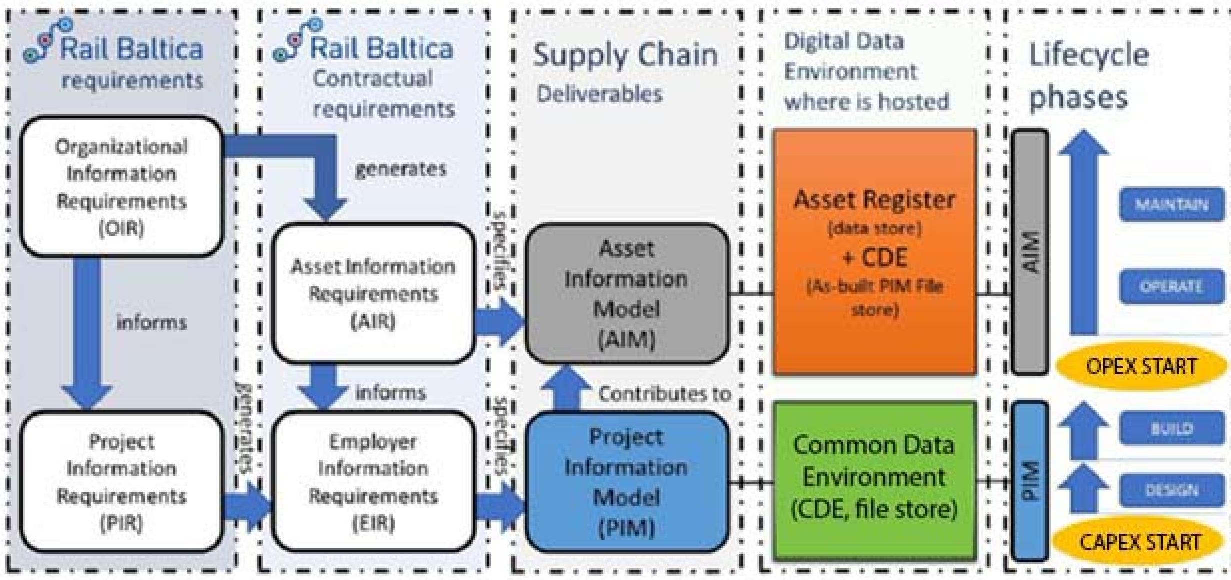
[h] Trademarks or product names are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

3.4 INFORMATION DELIVERY MANUALS

The bSI organization has coordinated with ISO to get the ISO 29481-1:2010 "Building Information Modelling - Information Delivery Manual - Part 1: Methodology and Format" standard developed. The objective of this standard is to describe a standard methodology for capturing and specifying processes and detailed user-defined specifications on the information that is exchanged as part of the processes (bSI, 2021). The assumption of the bSI organization is that national stakeholders in charge of advancing BIM will follow this standard to develop IDMs. For example, the BIM for Bridges and Structures under the Transportation Pooled Fund Program is developing an IDM to describe data delivery requirements, business use cases, and data exchanges involved in the survey, design, and construction processes of the bridge lifecycle. IDM creation is considered a formal method by bSI to establish the MVDs, which is a BIM artifact that enables the data exchange.

3.5 INFORMATION EXCHANGE SPECIFICATIONS

Development and management of ILS requires an understanding of various digital infrastructure elements associated with information exchange. The goal would be to have these digital infrastructure system elements operate as a cohesive unit to facilitate the extraction of data from authoritative systems and the consequent provisioning of data from autonomous and authoritative data models to other enterprise data models and stakeholders in the organization. The information lifecycle is the story of how project data are developed during design and construction (generating the PIM) in response to the requirements set out in the EIR. After migrating according to the AIR to comply with the OIR, the project data becomes built asset data, which are used during the operational phase of an infrastructure (generating the collated set of information of the AIM).



Source: Rail Baltica BIM Manual p. 48.

Figure 3-1. Flowchart. Lifecycle project information model and asset information model.

The PIM consists of a file-based federated BIM (models), a set of BIM extraction (drawings, data drops), and project-related documentation (reports and forms).

During the development of the PIM, the LOD increases gradually. At a certain point, the PIM becomes a virtual pre-construction model composed of objects and defined in a way that could be constructed, manufactured, or installed. The final output is the complete set of as-built BIM (models) and non-graphical information generated in the PIM.

Once the handover takes place, the AIM is generated with a mapping process that uses the as-built data from the PIM as the base (thus disregarding any non-constructed design intent) and generates a dual-information ecosystem: an asset register collating all the information from the PIM and any new data during the operation phase in a data-based structure, and a new CDE with a file-based structure hosting both the PIM as-built data and any new documentation generated during the operation of the AIM.

The structure of the AIM relies on the OIR and the AIR, which are developed jointly between the owner and the infrastructure manager. It should be correctly defined before developing the PIM so that design and the construction generate the BIM's data set that focuses on the operation needs and uses.

At State DOTs, ILSs are typically created as part of the development of interfaces between enterprise applications. For example, the New York State DOT has created information exchange specification documents for each of the interfaces shown in Figure 3-2. Similar specification documents have been developed by State DOTs in West Virginia, Ohio, and Texas. Some of these State DOTs inventory such information exchange specification documents in their system implementation repositories to be used during upgrades and enhancements to these implementations.

Such BIM data exchanges are being managed differently.

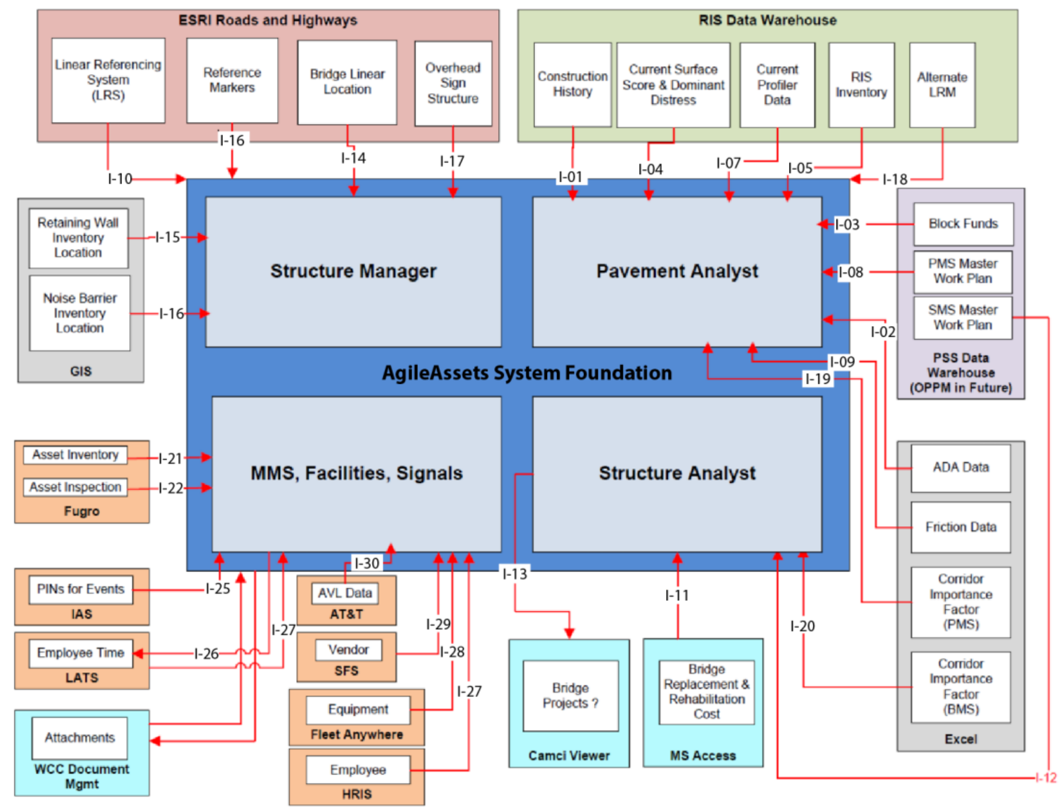


Figure 3-2. Flowchart. Lifecycle project information model and asset information model.

3.6 MODEL VIEW DEFINITIONS

Model views are created to extract and provision a subset of information modeled in authoritative SoRs to stakeholders for meeting their business use cases. For example, Construction Operations Building Information Exchange has been developed as a standard for packaging information captured in a construction data model and delivering to asset management for use during the operation and maintenance phase (NIBS, 2022). Corresponding to each of the data exchanges identified in Figure 3-1 and Figure 3-2, model views can be created corresponding to the subset of information that is delivered from source to target systems. Currently, such model views are managed as part of software systems, interface configuration systems, and API implementations.

3.7 MODEL CONTRUCTION DOCUMENTS

Model construction documents can be a key element of the contract-letting process for ensuring that models are used as documents for capturing pay items against each of the design and construction items. Client agencies could use the following documents to communicate with the contractors:

- AIRs.
- PIRs.
- EIRs.
- Information delivery guidelines as defined in the IDM.

Most early BIM adopters such as Utah DOT start by creating standards and specific State requirements related to the content and accuracy of the design elements to be created when authoring models for roadway and bridge projects (Utah DOT, 2023) regardless of whether such models are legal contract documents or not. AASHTO's JTCEES is also working to develop information on standard data deliverables that can be referenced when working with 3D engineered models on projects[6], a CBTL and SBTL could serve as platforms to manage such standards, processes, and policies associated with these data models and related IDMs.

3.8 SUMMARY

This chapter presents the current state of development of BIM artifacts and their management practices at the national and State levels to show that agencies are starting to investigate the development and administration of BIM artifacts to align with standards and customized to the business needs of the agency business units. The chapter establishes the following:

- BIM processes and the data workflows for these processes (as well as for data exchanges between these processes) are being documented in the industry and can be inventoried to ensure that stakeholders use a consistent set of IDMs, ILSs and MVDs. A standard version of these BIM artifacts can be developed and maintained.
- Agencies such as MnDOT are starting to capture post-construction asset information requirements as part of their digital as-builts (MnDOT, n.d.).
- SDOs and transportation agencies that are creating OTLs and data dictionaries are discovering the need to inventory these BIM artifacts and aligning them with each other. Such alignment allows for data standardization and the development of standard information requirements, terms, and definitions.

In summary, a library platform could be deployed for national and State organizations, including SDOs and public- and private-sector stakeholders, to manage and administer all the BIM artifacts being created in the industry, so that they could be better aligned with each other and with the standards.

[6] https://transportation.org/design/wp-content/uploads/sites/31/2023/04/AASHTO-JTCEES-MALD-Maturity-Model-3-2023.pdf

CHAPTER 4. CENTRALIZED BIM TRANSPORTATION LIBRARY FOR MANAGEMENT OF BIM ARTIFACTS

4.1 INTRODUCTION

Chapter 3 established that BIM artifacts—such as process documents, data workflow diagrams, information requirements, OTLs, data dictionaries, IDMs, ILSs, and MVDs are being developed as BIM implementation gains momentum in the industry. A CBTL would be helpful to align these artifacts with each other and with the open standards, as well to administer and manage different versions of these documents.

Chapter 4 introduces the recommendations, concept, and vision for a CBTL. It also presents examples of some centralized libraries that have been created and deployed in Europe and the United States to manage one or more of the BIM artifacts listed above. A high-level conceptual architecture for CBTL is presented to demonstrate how the library could host BIM artifacts created from various SDOs and national and international transportation agencies, and at the same time provide a platform for administrators to integrate and engineer new BIM artifacts based on the alignment of the BIM artifacts published by stakeholders in the industry.

4.2 RECOMMENDATIONS FOR THE CENTRALIZED BIM TRANSPORTATION LIBRARY

A CBTL should potentially meet the following:

- Serve as a centralized repository of BIM artifacts.
- Serve as a repository where stakeholders can publish their content.
- Allow stakeholders to access the standardized and engineered national BIM artifacts that have been created by CBTL administrators based on the integration and alignment of BIM artifacts published by various organizations.
- Make available BIM artifacts for use across all asset lifecycle phases: planning, survey, design, construction, and operation and maintenance (i.e., asset management).
- Serve as a single, centralized platform that provides autonomy to multiple authorized contributors in a secure, workflow-based environment that is governed through enterprise architecture and metadata management standards.
- Leverage commonalities in objects, properties, and standards that are specific to the U.S. market.
- Enable community-driven (e.g., State DOTs) and customizable content creation and governance.
- Facilitate integration of multiple resources and stakeholders including other standards and SDOs
- Serve as the centralized location of information updates.

- Able to be version-controlled so that changes to artifacts stored can be tracked, reviewed, and approved through various governance processes.

4.3 CENTRALIZED BIM TRANSPORTATION LIBRARY IMPLEMENTATIONS: STATE OF PRACTICE

This section describes the centralized transportation libraries created by SDOs, national transportation agencies, and private entities in other countries. While there are many web portals that capture libraries of BIM components, the focus is on portals that support collaborative authoring of components in addition to the ability to view or use. Some examples are presented to illustrate what the CBTL could look like. Not all the portals presented allow for collaborative editing, but are they presented as examples for content presentation. To author and consume content, data need to be made available to external applications. While this can be done by underlying version control systems, it can also be handled at a higher level by BIM portals that can translate content into various 3D modeling formats. Thus, rather than using such portals directly, they may also use familiar applications to author 3D components and to upload the resulting content. While many such formats are proprietary, at a minimum it may be possible to store parameters used along with a link to the underlying parametric model that may reside at the portal of a BIM authoring tool.

4.3.2 Dutch Concept Library of the Built Environment

In the Netherlands, the Building Information Council is a private organization that has created various online portals, including the Dutch Concept Library of the Built Environment, which organizes a taxonomy of object definitions and relationships. It provides a SPARQL (the standard query language and protocol for linked open data) endpoint as a means for linking to information from software.

4.3.3 Norwegian Roads Authority Database

The Norwegian Public Roads Administration has provided a web portal (vegdata.no, as shown in Figure 4-3) for viewing ontologies of transportation data, which are generated by definitions on a GitHub[7] repository. The web portal provides data in various electronic formats. The V440 classification provides bridge definitions similar in scope to the FHWA's NBI. Such portals typically provide information to technical data architects about the object types and attributes.

4.3.4 Other Centralized BIM Transportation Library Web Portal Examples

In addition to the transportation agency web portals and open portals, proprietary web portals are also available for hosting libraries of definitions from construction industry associations, and capturing parameters, geometry, available configurations, and standardized identifiers for referencing.

[7] Trademarks or product names are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

Figure 4-1 through Figure 4-4 present an example of one web portal that allows agencies to build their own OTL and map their OTLs to the open-standard OTLs from SDOs. In addition to collaborative editing, such custom portals can be integrated with open platforms and cloud-based services for software development and can allow for storing and presenting a lot of technical information about CBTL entities.

Figure 4-1 shows the contents of a library of steel shapes for the American Institute of Steel Construction (AISC). Some libraries have references to other libraries for dependent data, version history for released specifications as well as those in development, and files that may be downloaded in various formats. File formats include spreadsheets, data formats (e.g., XML, JSON), model formats (e.g., IFC), and programming languages (e.g., C#, GO, Java, Swift).

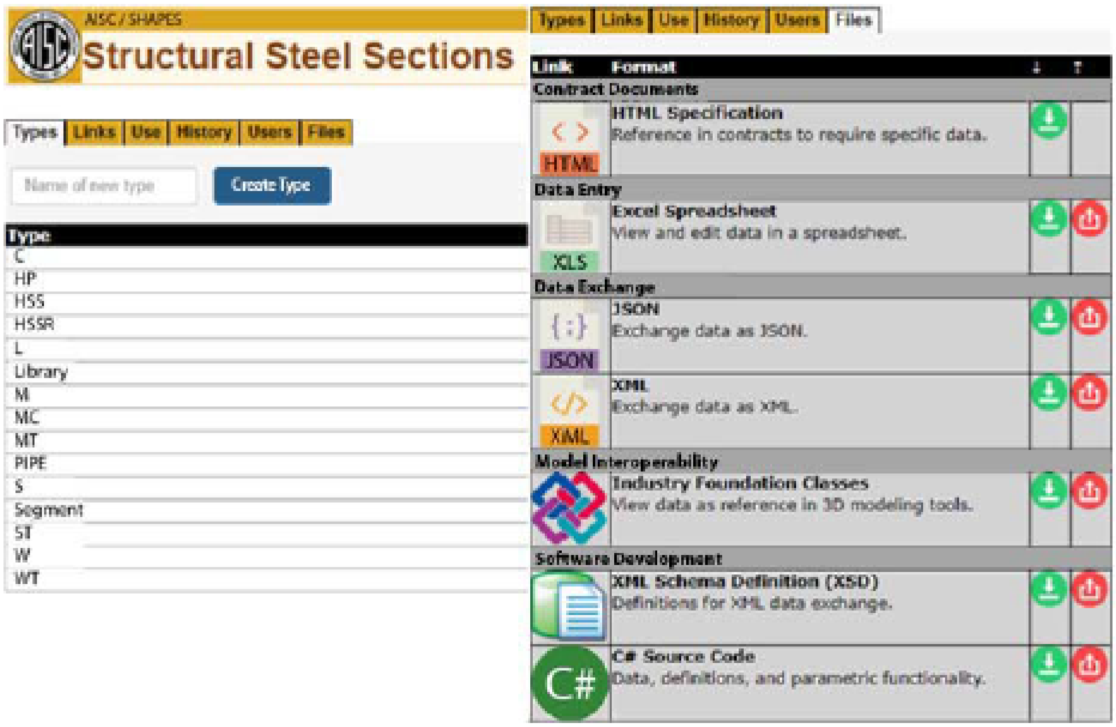
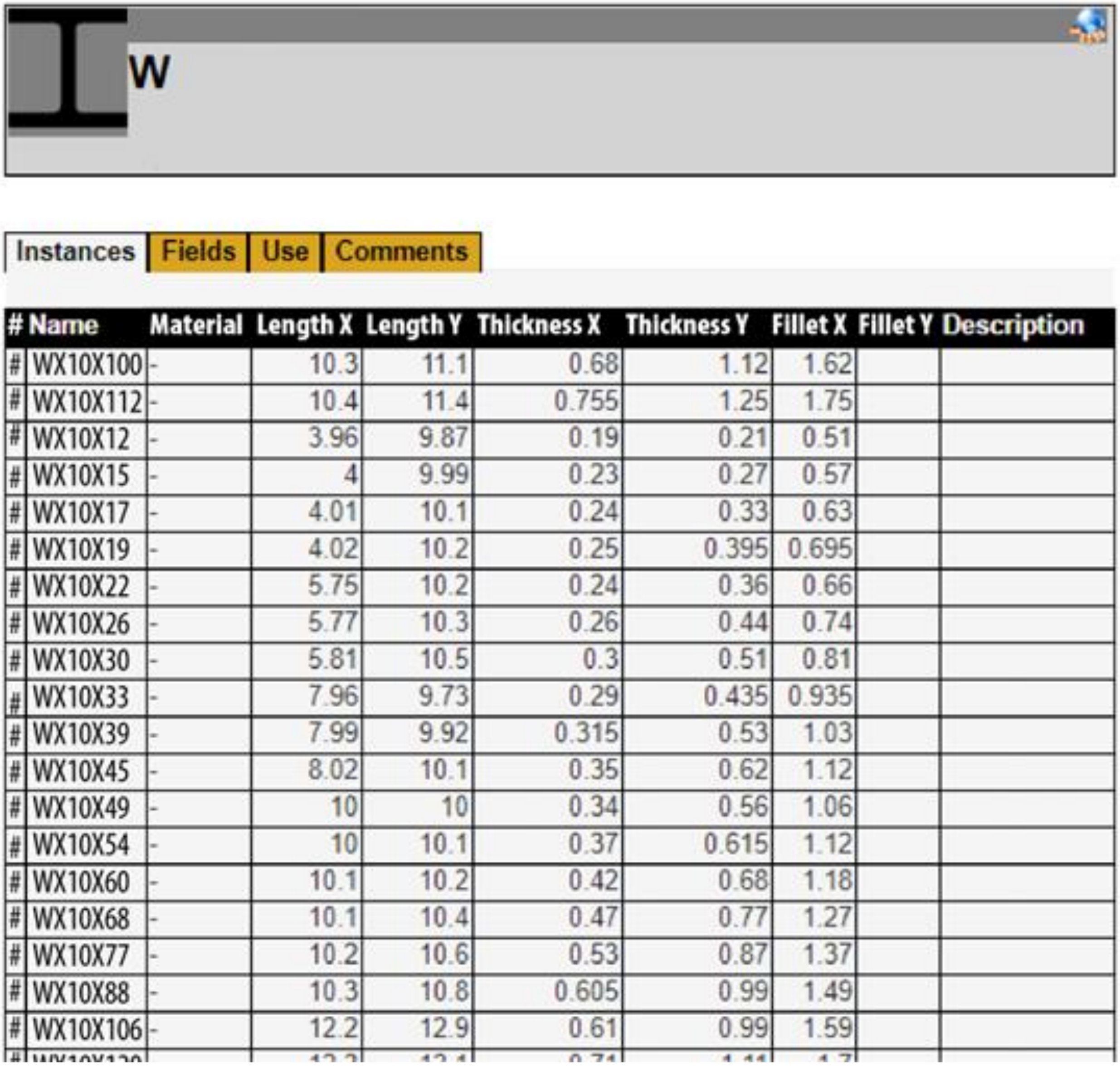


Figure 4-1. Screenshot. American Institute of Steel Construction library of steel shapes.

Figure 4-2 shows instances of an object type for AISC wide-flange members.



#	Name	Material	Length X	Length Y	Thickness X	Thickness Y	Fillet X	Fillet Y	Description
#	WX10X100	-	10.3	11.1	0.68	1.12	1.62		
#	WX10X112	-	10.4	11.4	0.755	1.25	1.75		
#	WX10X12	-	3.96	9.87	0.19	0.21	0.51		
#	WX10X15	-	4	9.99	0.23	0.27	0.57		
#	WX10X17	-	4.01	10.1	0.24	0.33	0.63		
#	WX10X19	-	4.02	10.2	0.25	0.395	0.695		
#	WX10X22	-	5.75	10.2	0.24	0.36	0.66		
#	WX10X26	-	5.77	10.3	0.26	0.44	0.74		
#	WX10X30	-	5.81	10.5	0.3	0.51	0.81		
#	WX10X33	-	7.96	9.73	0.29	0.435	0.935		
#	WX10X39	-	7.99	9.92	0.315	0.53	1.03		
#	WX10X45	-	8.02	10.1	0.35	0.62	1.12		
#	WX10X49	-	10	10	0.34	0.56	1.06		
#	WX10X54	-	10	10.1	0.37	0.615	1.12		
#	WX10X60	-	10.1	10.2	0.42	0.68	1.18		
#	WX10X68	-	10.1	10.4	0.47	0.77	1.27		
#	WX10X77	-	10.2	10.6	0.53	0.87	1.37		
#	WX10X88	-	10.3	10.8	0.605	0.99	1.49		
#	WX10X106	-	12.2	12.9	0.61	0.99	1.59		

Figure 4-2. Screenshot. Instances of an object type for American Institute of Steel Construction wide-flange members.

Figure 4-3 shows fields of an object type for AISC wide-flange members and the configuration of a field.

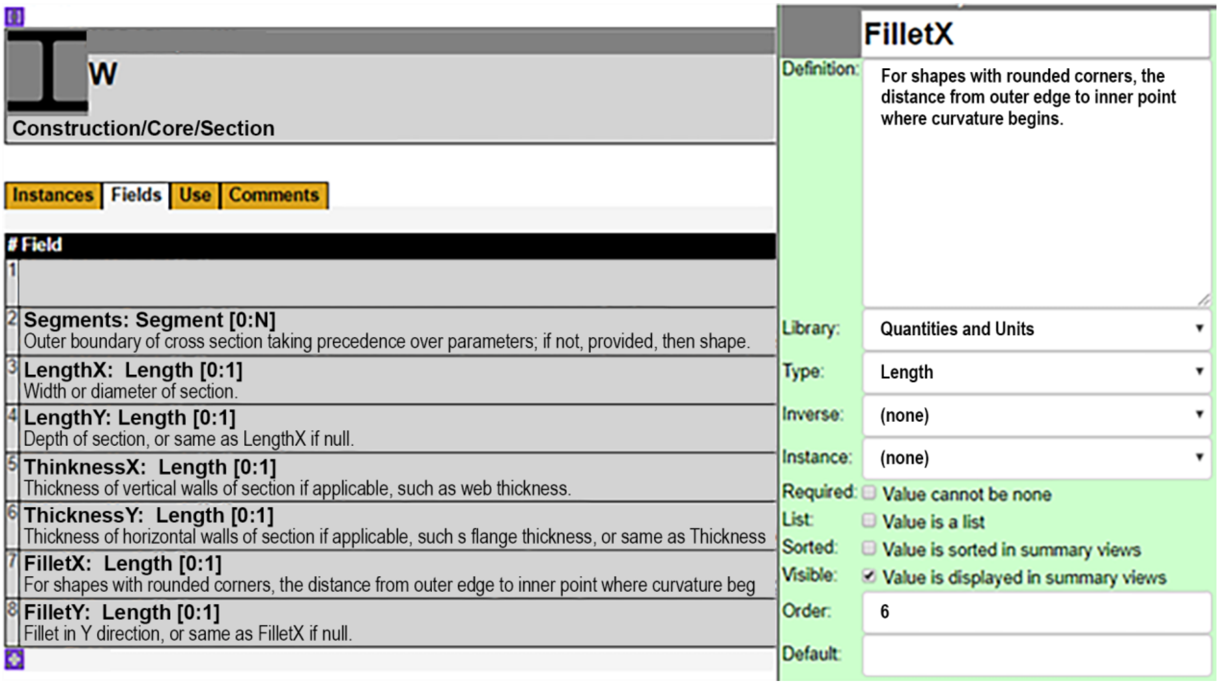
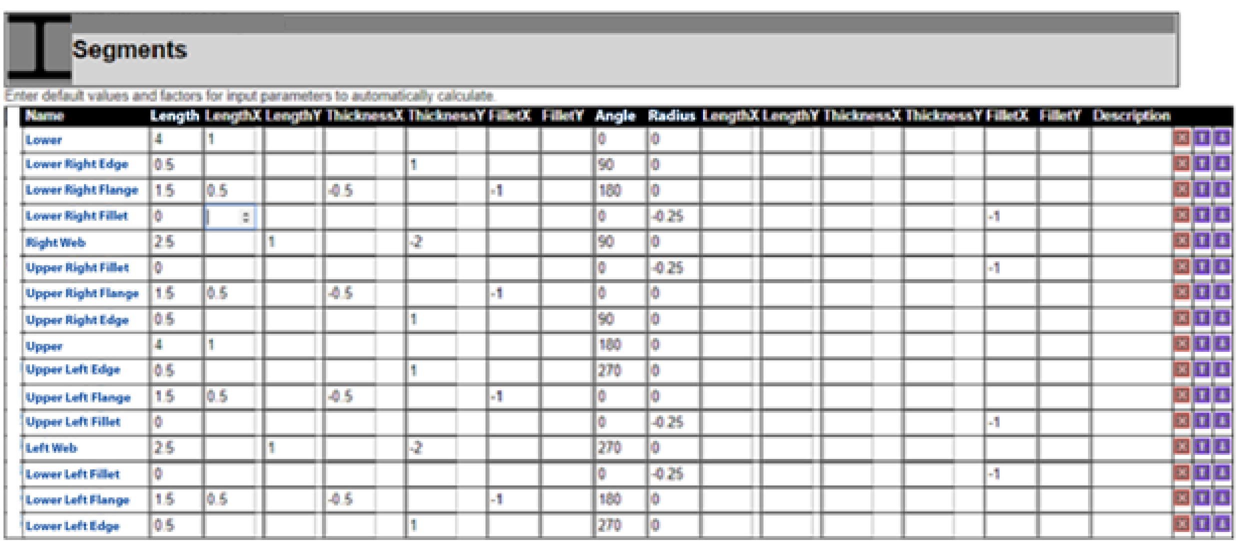


Figure 4-3. Screenshot. Fields (attributes) associated with object type for American Institute of Steel Construction wide-flange members.

Figure 4-4 shows the definition of a parametric field, where the cross section of a wide-flange section is defined as factors of input parameters.



Segments

Enter default values and factors for input parameters to automatically calculate.

Name	Length	LengthX	LengthY	ThicknessX	ThicknessY	FilletX	FilletY	Angle	Radius	LengthX	LengthY	ThicknessX	ThicknessY	FilletX	FilletY	Description
Lower	4	1						0	0							
Lower Right Edge	0.5				1			90	0							
Lower Right Flange	1.5	0.5		-0.5		-1		180	0							
Lower Right Fillet	0							0	-0.25					-1		
Right Web	2.5		1		-2			90	0							
Upper Right Fillet	0							0	-0.25					-1		
Upper Right Flange	1.5	0.5		-0.5		-1		0	0							
Upper Right Edge	0.5				1			90	0							
Upper	4	1						180	0							
Upper Left Edge	0.5				1			270	0							
Upper Left Flange	1.5	0.5		-0.5		-1		0	0							
Upper Left Fillet	0							0	-0.25					-1		
Left Web	2.5		1		-2			270	0							
Lower Left Fillet	0							0	-0.25					-1		
Lower Left Flange	1.5	0.5		-0.5		-1		180	0							
Lower Left Edge	0.5				1			270	0							

Figure 4-4. Screenshot. Defining parameters associated with cross section of a wide-flange section.

4.4 CENTRALIZED BIM TRANSPORTATION LIBRARY ARCHITECTURE

Figure 4-5 shows how a CBTL could be architected. International SDOs such as bSI and OGC provision BIM artifacts using APIs, web portals, and version control systems such as GitHub[7] or GitLab[7]. The U.S. CBTL could follow the same approach to provision the BIM artifacts to its stakeholders. The overall architectural framework would involve a back-end, which is a database that stores the BIM artifact, and a front-end, which could be one or more web portals designed specifically for the stakeholders. For example, front-ends such as the version control systems and API portals are typically created for data architects and software developers. Community portals such as the one deployed by the Dutch or the one deployed by the buildingSMART International (bSI) for the bsDD are created for business users and vendors alike who want a less technical interface to extract usable information for their data systems and business processes.

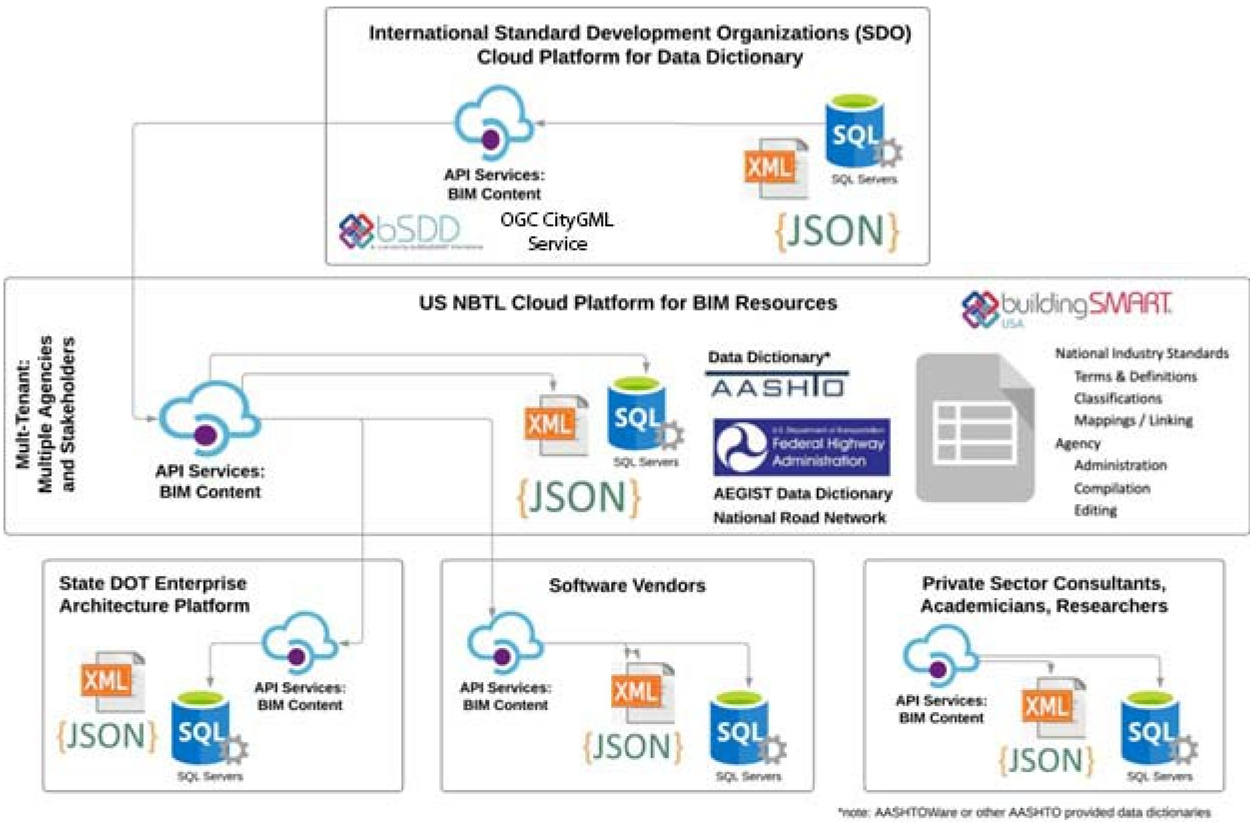


Figure 4-5. Illustration. One approach to Centralized BIM Transportation Library architecture.

A CBTL back-end could be established as a multi-tenant CBTL database to store information about BIM artifacts, such as the list of business processes, data workflow steps, list of information requirements, object types (classifications), attributes, data dictionary, IDM, ILS, and model views.

A CBTL front-end could be used to access, interact with, and provision these BIM artifacts using version control systems, community collaboration portals, and the APIs. A front-end could be created for the stakeholders in a manner such that they could be used to query information such as:

- Standard information requirements (OIR, AIR, PIR, EIR) by business process that are suggested for adoption and have been aligned with ISO-19650 by CBTL administrators.
- Standard OTL and data dictionary that have been provisioned by SDOs or engineered by CBTL administrators after integrating various OTLs and data dictionaries from SDOs.

Figure 4-6 presents a detailed view of a CBTL API services portal that could be used to provision the BIM artifacts engineered by CBTL administrators or created by SDOs.

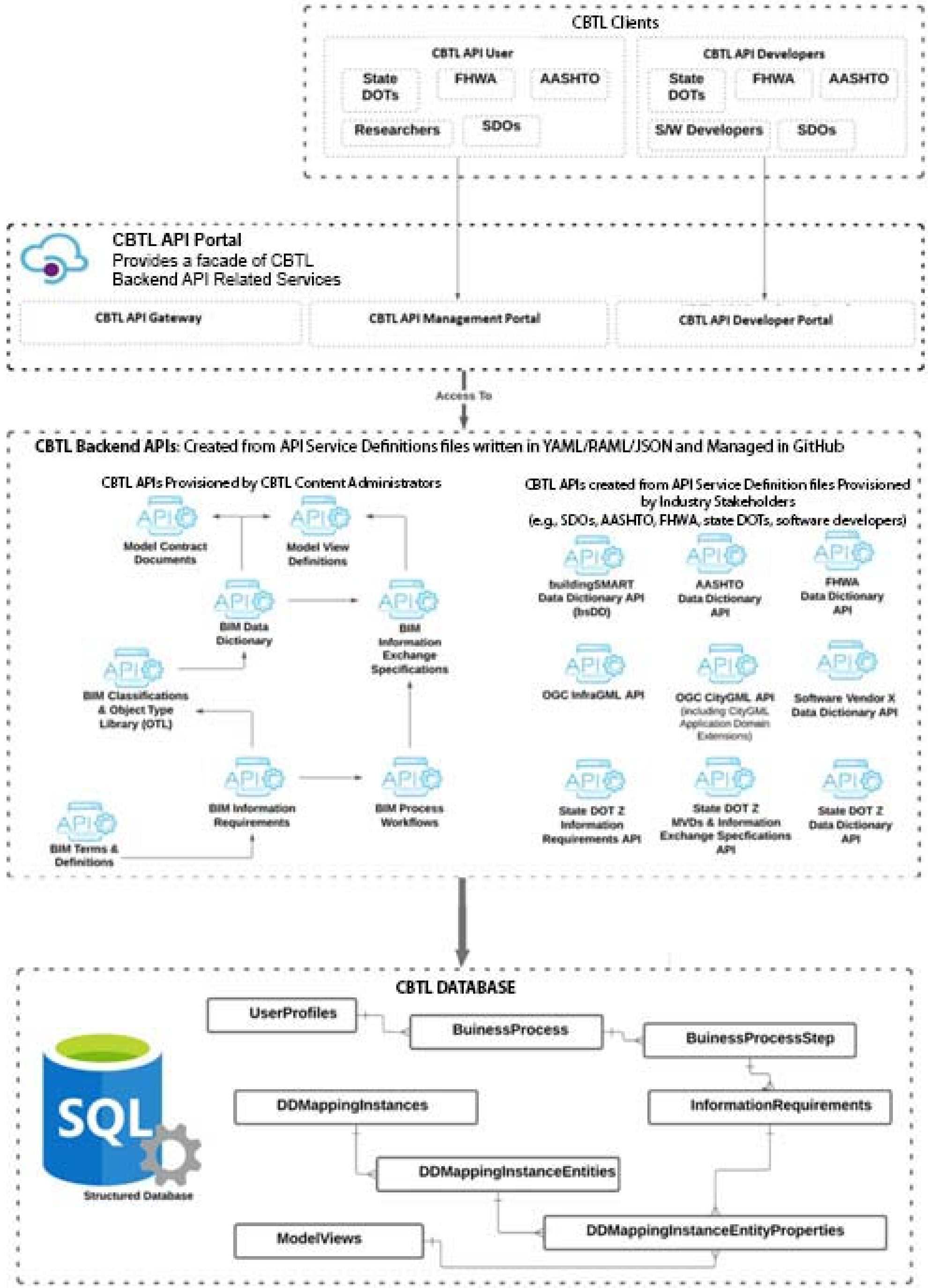


Figure 4-6. Illustration. Centralized BIM transportation library (CBTL) application programming interface (API) services portal with API gateway, management, and development portals, and CBTL back-end database.

Figure 4-7 illustrates how a CBTL administrator who is a data architect may engineer a national OTL and data dictionary using the OTLs and data dictionaries available from various SDOs, national transportation agencies, and cooperative software providers. The BIM OTLs and data dictionaries from these sources need not be published in a CBTL for them to be used in engineering of national OTLs and data dictionaries by CBTL architects. However, if such SDO artifacts are made available in a CBTL (as shown in Figure 4-6), a CBTL version control system could be used to track the versions of these SDO artifacts (as published by the SDOs) and the different versions of the SDO BIM artifacts used to engineer and provision a particular version of the integrated, harmonized, and standardized national BIM artifact. For example, the example presented in Figure 4-7 illustrates that IFC Version 4.3 is integrated with OGC CityGML Version 3.0 and HPMS Version 9.0 to create version 2.0 of an CBTL OTL and data dictionary BIM artifact. OTL and data dictionary architecture development tools could have been used to integrate and align the database schemas of these individual data libraries.

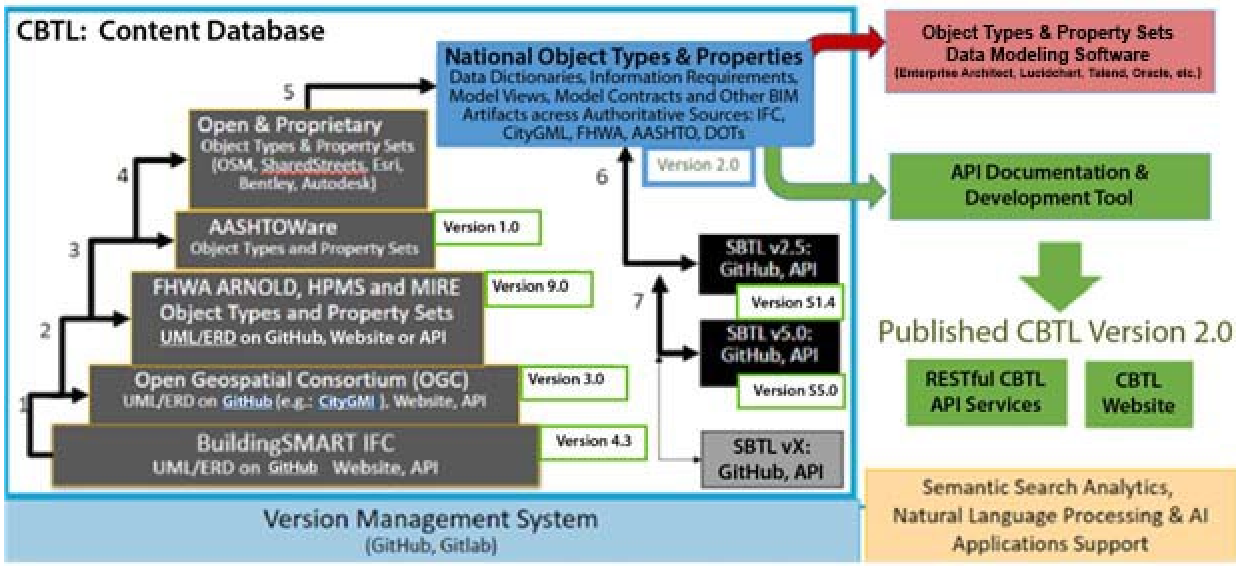


Figure 4-7. Illustration. Administrator(s) of centralized BIM transportation library.

Identifying object types would be a key feature in creating a national OTL and data dictionary. CBTL content would ideally be founded on the OTLs published and being developed by SDOs as well as the national OTLs. To identify the object types, object-type relationships, attributes, terms, and definitions, as shown in Figure 4-8, a CBTL administrator would likely end up examining multiple international, national, State, and local agency OTLs and determining which objects and attributes could be mapped and which ones need to be extracted from the individual standards to create a comprehensive BIM for Infrastructure OTL and data dictionary.

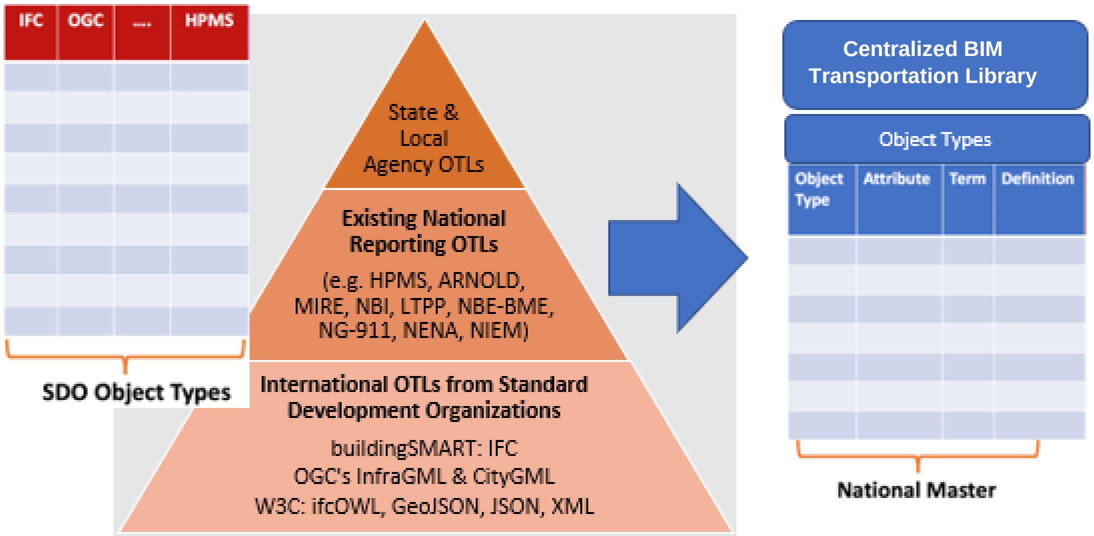


Figure 4-8. Illustration. Identifying centralized BIM transportation library object types, relationships, and attributes from open standards.

The users of CBTL resources could retrieve information from a CBTL and engineer their own BIM artifacts specific to their business use (e.g., State-specific BIM workflows). Figure 4-9 presents an example of how a CBTL could be used as a foundational platform by State DOTs to develop State-specific BIM artifacts and administer them using an SBTL. States could use CBTL resources and a CBTL content repository metamodel as the starting point to deploy a library with the similar architectural standard as a CBTL. The State DOT BIM library administrator(s) could use software tools and technology available to them to download content from CBTL APIs and cloud-based repositories and keep the content in the SBTL synchronized with CBTL content.

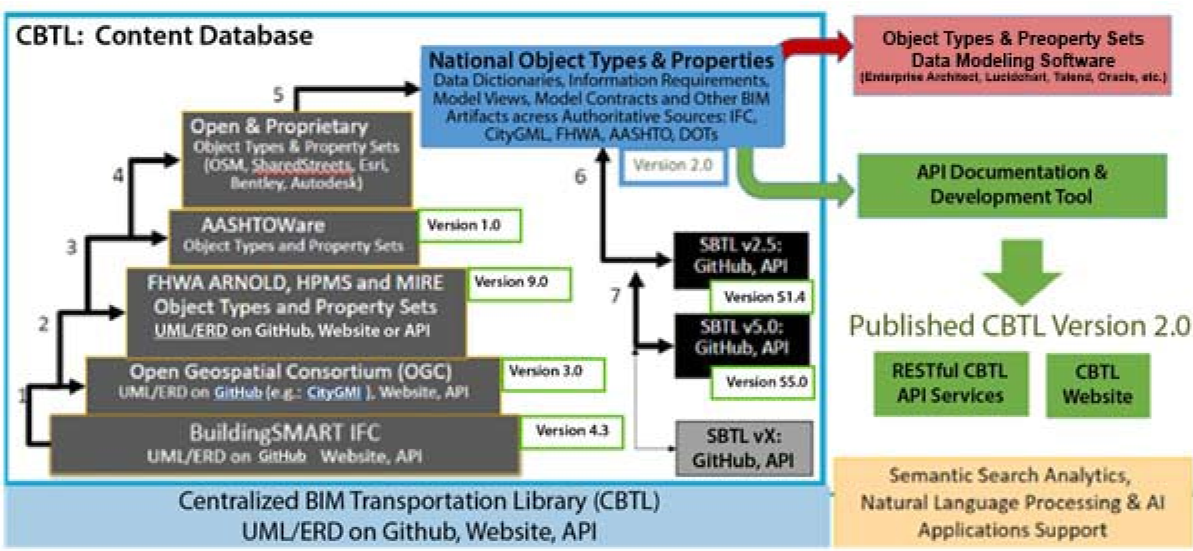


Figure 4-9. Illustration. State administrator(s) use centralized BIM transportation library to create State-specific BIM artifacts and store them in a State BIM transportation library.

4.5 SUMMARY

This chapter presents the concept, vision, and recommendations associated with a possible CBTL. Example CBTLs from other countries are discussed to share how CBTLs have been implemented in the past. A high-level architecture of a CBTL is presented to illustrate how CBTL artifacts would be stored in the back-end database and then provisioned using a front-end. The chapter describes how the front-end that provisions access to CBTL content may be a version control system or a community collaboration web portal or an API portal that developers could use to query CBTL data. The chapter accomplishes the objective of building on the information presented in Chapter 2 on the current state of practice and developing a vision for future CBTL deployment and management. The next chapter presents specific details about the type of information that could be managed in an CBTL. Chapter 5 demonstrates using the OTL and data dictionary BIM artifacts as an example and continues to build on some of the information presented in Chapter 4. In general, throughout this document, the OTL and data dictionary are used as examples to demonstrate CBTL content, architecture, vision, and scope.

CHAPTER 5. PROTOYPING CENTRALIZED BIM TRANSPORTATION LIBRARY USING NATIONAL OBJECT-TYPE LIBRARIES AND DATA DICTIONARY

5.1 INTRODUCTION

In Chapter 3, Table 3-1 presents some of the OTLs and data dictionaries created by international and national SDOs and describes how such BIM artifacts could be extracted from the BIM website or APIs of the organization that developed them and provisioned through an CBTL's version control system. Chapter 3 presents an example for a high-level CBTL architecture and illustrates how CBTL data architects could use such OTLs and data dictionaries to engineer and provision the U.S. CBTL OTL and data dictionary.

Chapter 5 dives deeper into the type of content and associated metadata that could be stored in an CBTL. The objective of this report is to use examples to illustrate how an CBTL could be set up and used. Therefore, this chapter builds on the OTL and data dictionary information and examples presented in Chapters 2 and 3 to show how CBTL data architects could store and manage versions of various OTLs and data dictionaries, and how such content could later be used to develop a consolidated OTL and data dictionary that covers all information requirements associated with asset lifecycle.

Irrespective of where the OTLs and data dictionaries published by SDOs and other such national and international transportation organizations are stored, CBTL data architects could use these artifacts to engineer OTLs and data dictionaries. A key characteristic for the use of a standard based OTL and data dictionary to be used as the foundation is its scalability and extensibility. SDOs such as bSI and OGC have set up the IFC, InfraGML, and CityGML schemas to be scalable such that additional property sets and application domain extensions can be defined by stakeholders in the industry who wish to adopt these international standards to add terms, definitions, objects, and business data attributes. The engineering of such a BIM OTL and data dictionary would occur incrementally over time, and therefore would require management of various versions that are created (as shown in chapter 4, Figure 4-7).

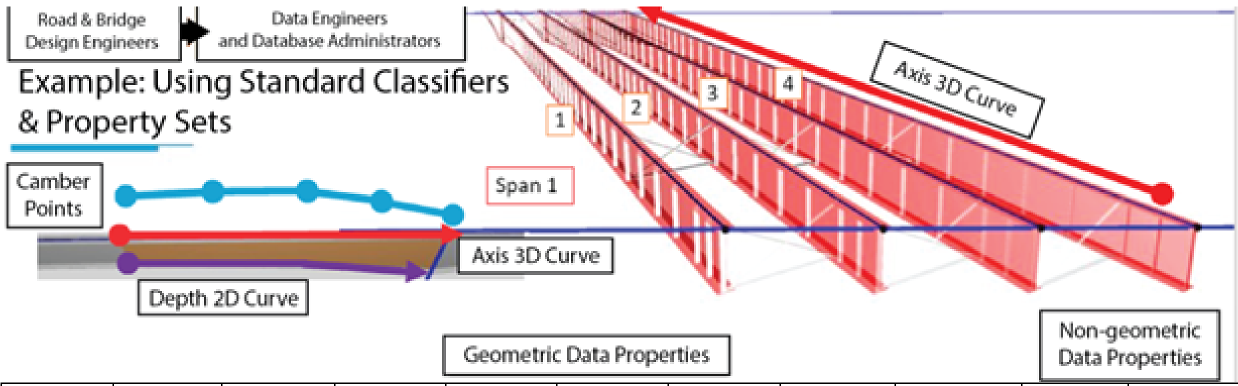
This chapter describes the motivation for engineering a national OTL and data dictionary. The chapter then presents the steps and key artifacts that data architects would need (and would ideally want to find through resources such as an CBTL). These resources, if provisioned through a CBTL, would need to be organized using a scientific approach, so that they could be easily found in the library. Therefore, a section on understanding the content and how it can be categorized in a CBTL is presented. Finally, the chapter discusses the functions that a CBTL needs to provision to support interoperability between the provisioned OTLs and data dictionaries, irrespective of whether those are from the SDOs, another U.S. entity appropriate, or engineered by CBTL data architects.

5.2 MOTIVATION FOR ENGINEERED OBJECT-TYPE LIBRARIES AND DATA DICTIONARIES

Transportation agencies in the United States create digital data models at all stages of the asset lifecycle for use in various business processes. As highlighted in FHWA's BIM NSR (Mallela and Bhargava, 2021), a goal over the next 10 years should be to break through the siloed and limited vision data models that are created in each of the phases. For example, in Chapter 2, the example from MnDOT is presented to illustrate how MnDOT is breaking the siloed data modeling that happens during the design and construction phases by defining as-built data model information requirements based on the requirements of asset managers during the operation and maintenance phase. Like many State DOTs, MnDOT realized that the data models being created during the design and construction phases do not capture asset data attributes in an object-based data model. Most transportation agencies have realized the following issues associated with models created in the design and construction phases:

- Focus is on using 2D/3D model geometry to represent the digital asset.
- Limited to no asset information is included in the model from the asset managers' perspective.
- Limited to no information about asset components lifecycle, manufacturing specifications, or construction environment is provided.
- Business user requirements outside design and construction are not factored.

Figure 5-1 illustrates how design and construction data models are created today with a focus on geometric properties. Non-geometric properties, such as pay items, quantities, and item types, are also captured, but such information is captured primarily in the model for use in construction engineering and management. Additional business data that are typically used during the operation and maintenance phase of the asset lifecycle could be captured. For this information to be captured, the form, format, and content associated with this information needs to be provided in consistent manner, so that the information can be communicated to designers and construction engineers for development of design and construction data models.



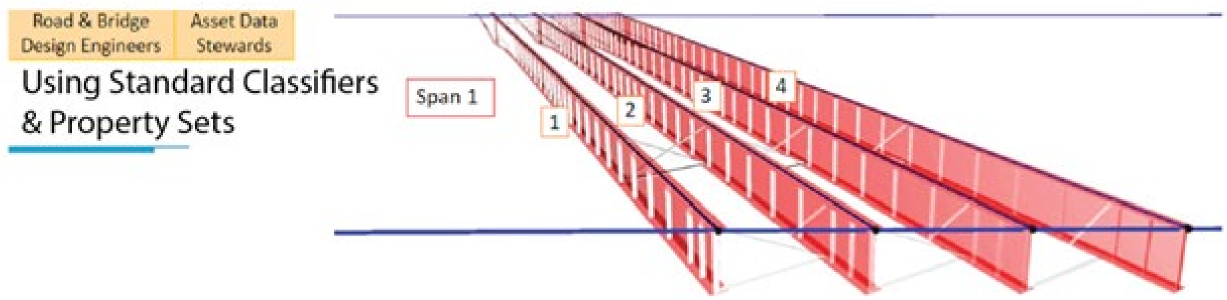
Girder ID	Span	Axis 3D Curve	Depth at Start	Depth at End	Start Offset	End Offset	Length	Spatial Geometry (CL, start)	Pay Item	Specification
G4	1	Offset 18' from Alignment	56"	84"	-9"	0" (Cont.)	134.25'	X, Y, Z	51067	18225

Plate ID	Profile	Positioning at Start	Positioning at End	Depth at Start	Depth at End	Start Offset	Length	Thickness	Spatial Geometry (CL, start)	Material	Fy
G4, Web Section 2	Camber pts., Varying, Depth, Parabolic	100+30.50	100+56.50	53"	80"	-9"	26.0"	0.50"	X, Y, Z	AASHTO M270 Grade 50W	50 ksi

Figure 5-1. Illustration. An example of using standard classifiers and property sets.

Using a bridge data model as an example, Figure 5-2 illustrates how object-based digital design data models could be created to capture information about asset data attributes in a more systematic, structured, and standardized manner. As shown in this example, the NBI attributes can be captured for the structure, and the NBI bridge elements and attributes can be set up and used as item types during the design and construction phases so that information such as pay items; quantities; and post-construction condition, material, manufacturing, and installation data can be associated with bridge data entities that are used during the asset operation and maintenance phase.

The NBI data and NBI bridge element information can be attached and associated with 2D and 3D objects. In addition to providing this information to asset management, asset managers can provide it to designers and construction engineers when the built structure needs rehabilitation or reconstruction. Therefore, there is potential for a two-way data exchange using a consistent content standard, content form, and format.



National Bridge Inventory (NBI) and National Bridge Elements (NBE) and Bridge Management Elements (BME)

Bridge Data Property Set								
Structure Number (NBI-8)	Number of Spans: Main (NBI-45)	Number of Spans: Approach (NBI-46)	Structure Length (NBI-49)	Structure Type – Main (NBI-43)	Structure Type – Approach (NBI-44)	Bridge Median (NBI-33)	Design Load (NBI-31)	Inspection Date (NBI-90)
14277	5	2	..	..	..	..	..	..

NBE Data Property Set							
Bridge ID	Element Number (EN)	Element Parent Number (EPN)	Total QTY	Condition State 1 QTY (CS-1)	Condition State 2 QTY (CS-2)	Condition State 3 QTY (CS-3)	Condition State 4 QTY (CS-4)
14277	107	n/a	1,064	700	319	45	0

Figure 5-2. Illustration. Using standard classifiers and property sets.

In general, the key needs for any such data models that are created during the design, construction, and operation and maintenance phases could be as follows:

- Models need to be object-based and comply with BIM standards. Example standards include bSI, IFC, OGC, InfraGML, and CityGML.
- Focus should be on developing a cohesive AIM for enterprise use with data about the road network, assets, condition, and work history information, i.e., the digital twin.
- Effort should be made to add information about assets and roadway characteristics during design, construction, and after construction (as-builts).
- Models should use terms, definitions, objects, and attributes from a centralized data dictionary, if possible, for ease of interoperability and data exchange between authoritative and autonomous systems and data models used within and outside the organization.

Figure 5-3 and Figure 5-4 illustrate how realization of such requirements could result in use of open standards such as IFC to classify design and construction elements and use standards-based attributes for capturing and exchanging information such as condition, work history, and construction year for asset components.

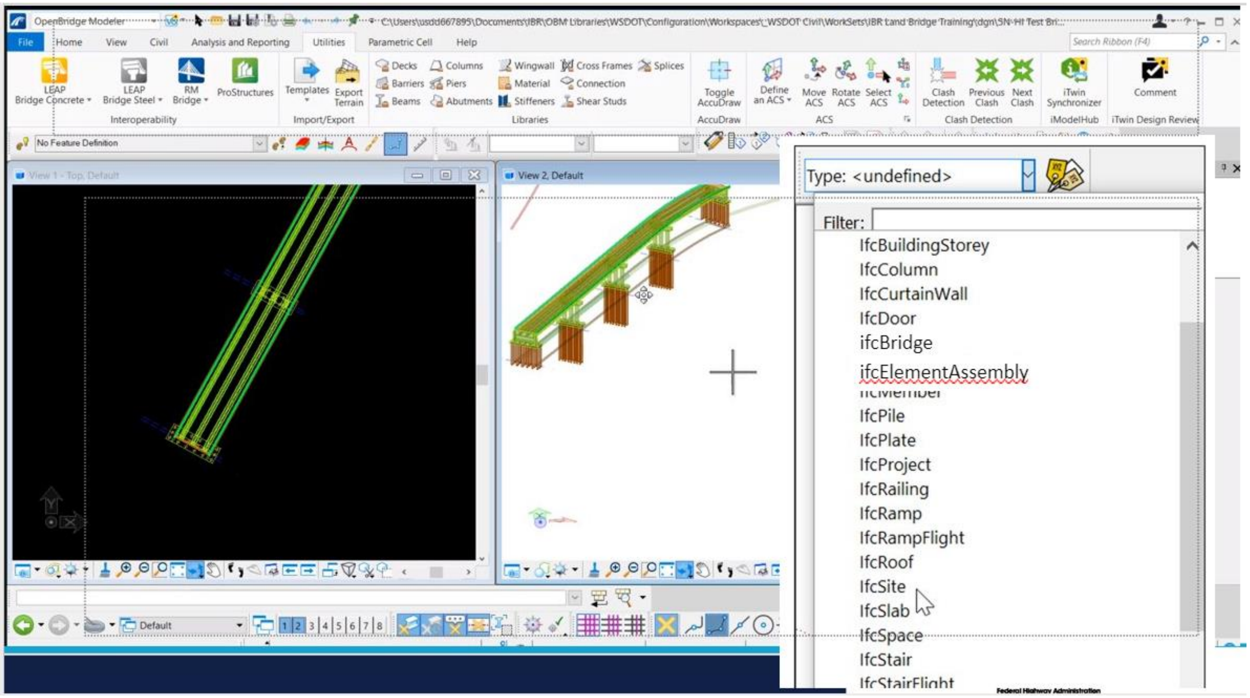


Figure 5-3. Screenshot. Envisioned BIM data model with centralized object-type library objects (classes).

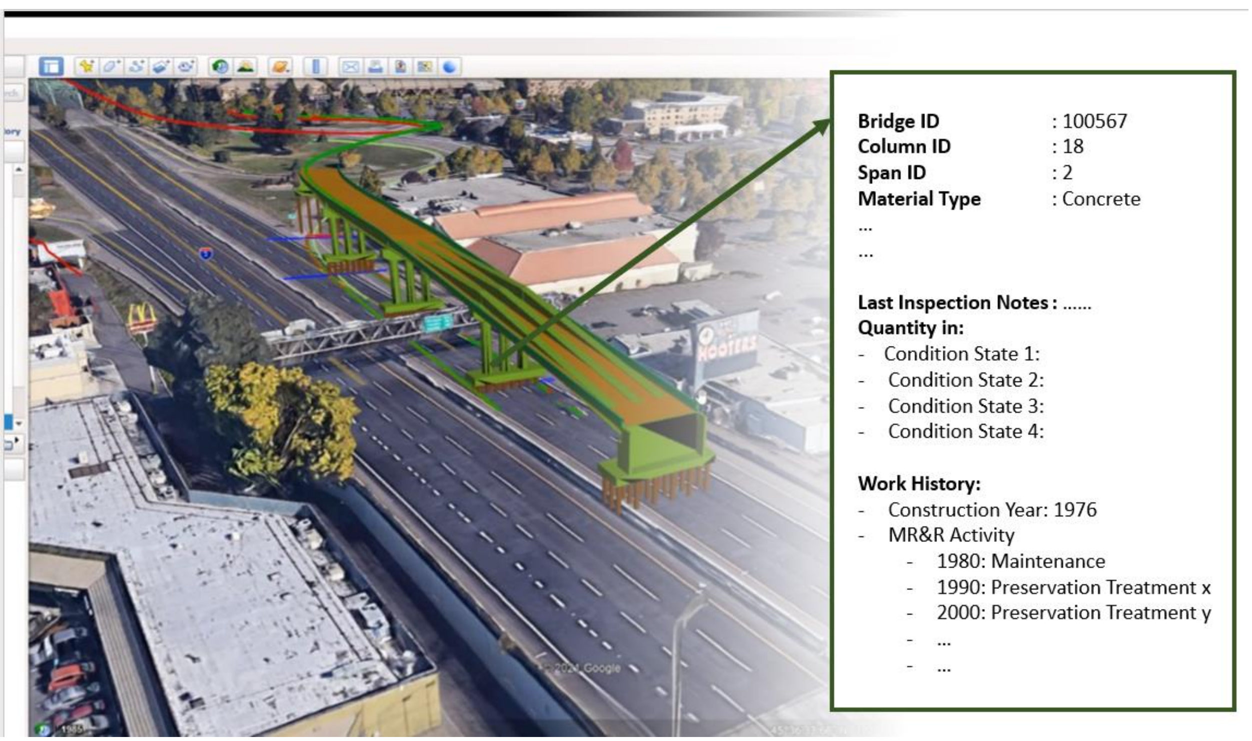


Figure 5-4. Illustration. Envisioned BIM data model with centralized data dictionary attributes.

Figure 5-5 and Figure 5-6 illustrate how IFC classes could be used to standardize the object types that are used to represent each of the infrastructure elements starting with the project and site, and then identifying the road, alignment, and bridge. Other open standards could also be used to classify infrastructure elements using object types. Properties could then be associated with these standard object types as shown in Figure 5-6.

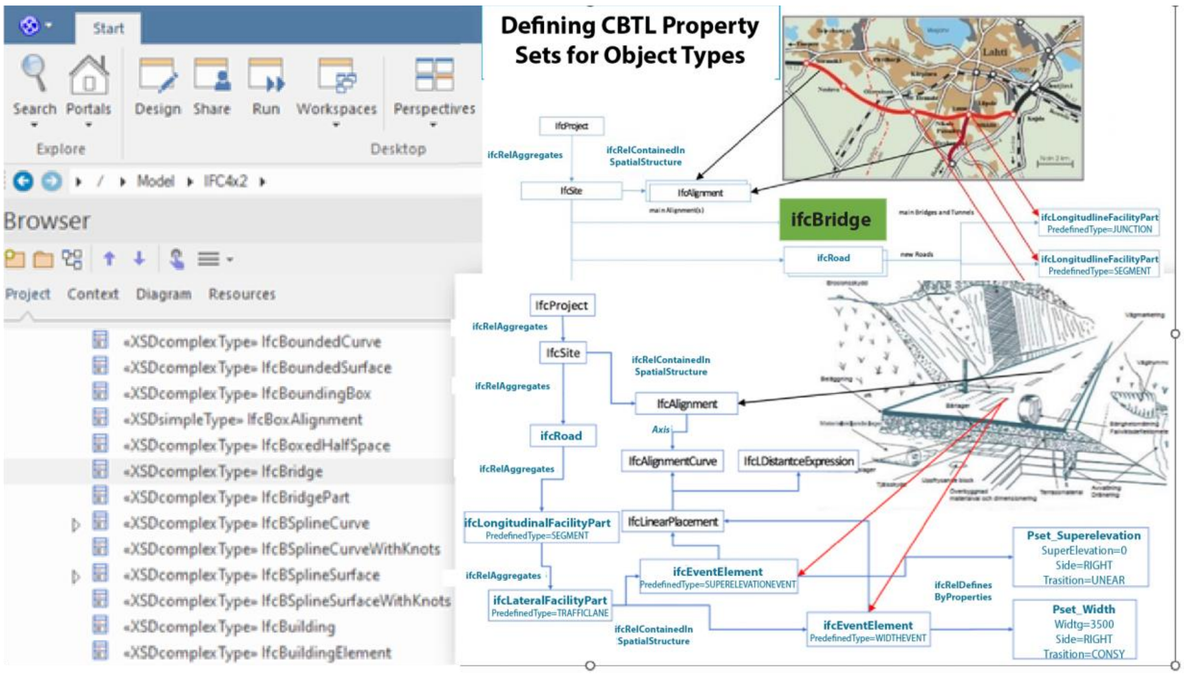


Figure 5-5. Screenshot. Defining centralized BIM transportation library property sets for object types.

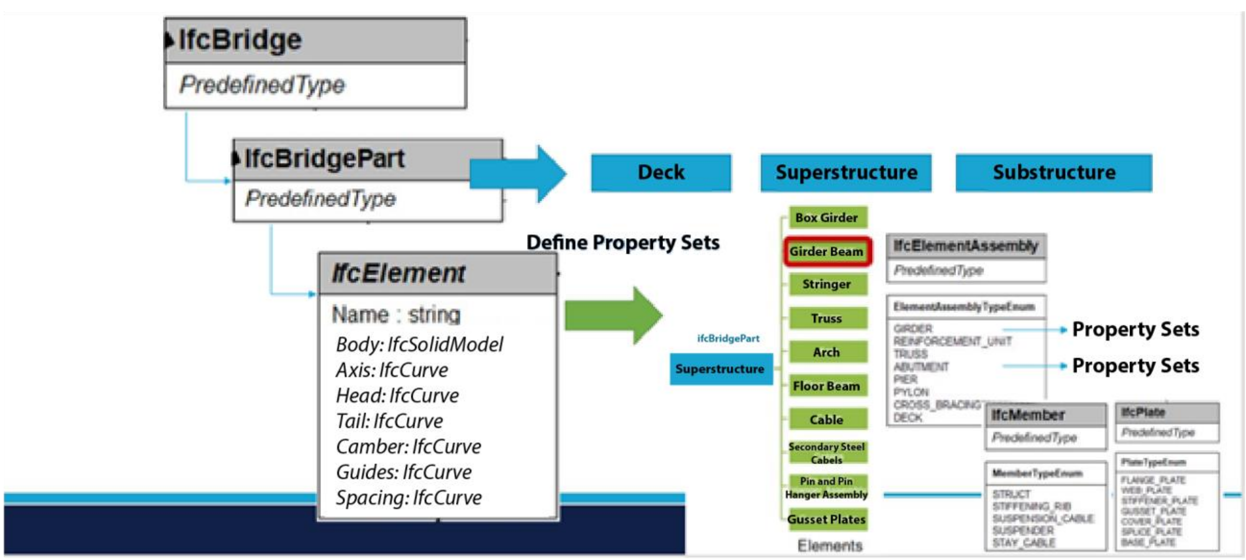


Figure 5-6. Screenshot. Adding non-geometric National Bridge Inventory, National Bridge Elements-bridge management elements properties.

Such standardization of digital data models would rely on holding different types of content in a CBTL. Figure 5-7 summarizes the type of content, i.e., the object types, properties, geometry, parameters, and enumerations—corresponding to which standards information could be aggregated, consolidated, engineered, and provisioned through a CBTL.

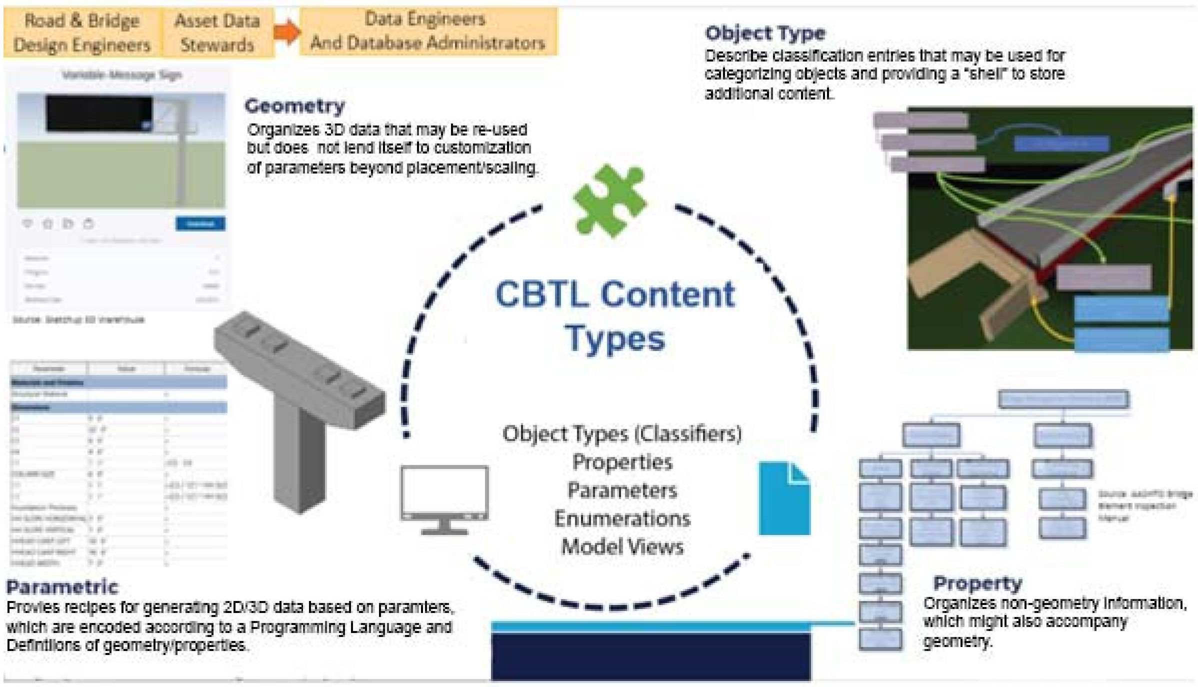


Figure 5-7. Illustration. Centralized BIM transportation library content types.

5.3 ENGINEERING CENTRALIZED BRIDGE OBJECT-TYPE LIBRARIES AND DATA DICTIONARY

5.3.2 Examining Existing Centralized Object-Type Libraries

While there are multiple national OTLs (e.g., HPMS, ARNOLD, MIRE) that could be used to identify the physical infrastructure object types, terms, and definitions, the research team selected AASHTO's library of NBE as a starting point. The NBE is an element classification system used for bridge inspection to provide consistency for element identification, quantity measurement, and condition state assessment for element level inspection.

Additional elements such as BME, which are elements typically managed in agency bridge management systems, appear in the AASHTO *Manual for Bridge Element Inspection* (AASHTO, 2019). The BME supplements the NBE with additional elements such as approach slabs and expansion joints. Figure 5-8 and Figure 5-9 show the NBE and BME categories and elements, respectively. These elements could be directly translated as object types; however, considering the objective to map across open standards (such as IFC) and custom agency OTL, this may not be the most effective organization (as discussed later in this report). Several other ongoing efforts have created bridge ontologies, including an active NSBA research project to create an IDM for steel-bridge girder fabrication. This effort could be investigated further to leverage the parallel efforts completed in this area.

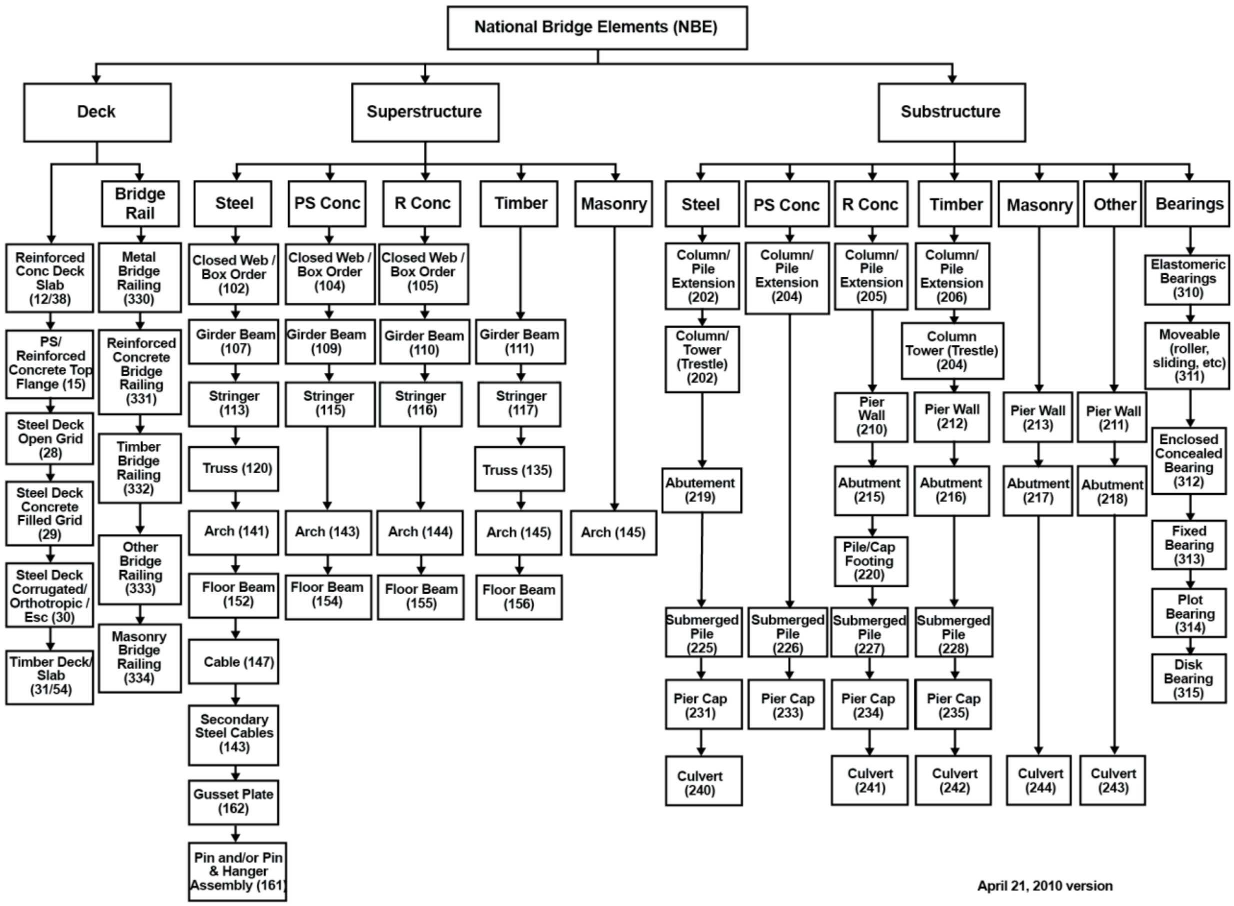
The NBE and BME can serve as a starting point for the bridge OTL for multiple reasons. First, they are familiar to all State DOTs because they are national specifications, and the element data are required to be submitted annually to FHWA by the States and Federal agencies for all bridges on the National Highway System.

The NBE is designed to be consistent across all State DOTs to facilitate collection of the required data. In addition, the NBE is a fairly comprehensive list of elements because it is used to document detailed element condition data for asset management. However, there are also limitations. Because the NBE is for collecting information on primary elements during bridge inspections, some of the elements and even categories necessary for other phases and applications are not included.

An example of this is the lack of secondary structural members (e.g., diaphragms, cross frames) and the omission of roadway geometry data for the bridge. Additionally, many State DOTs have their own nomenclature and common bridge types that require more customized items. Recognizing this, the AASHTO *Manual for Bridge Element Inspection (AASHTO, 2019)* has a provision for State DOTs to add agency-developed elements to provide flexibility to develop sub-elements to the NBE and BME or completely new elements.

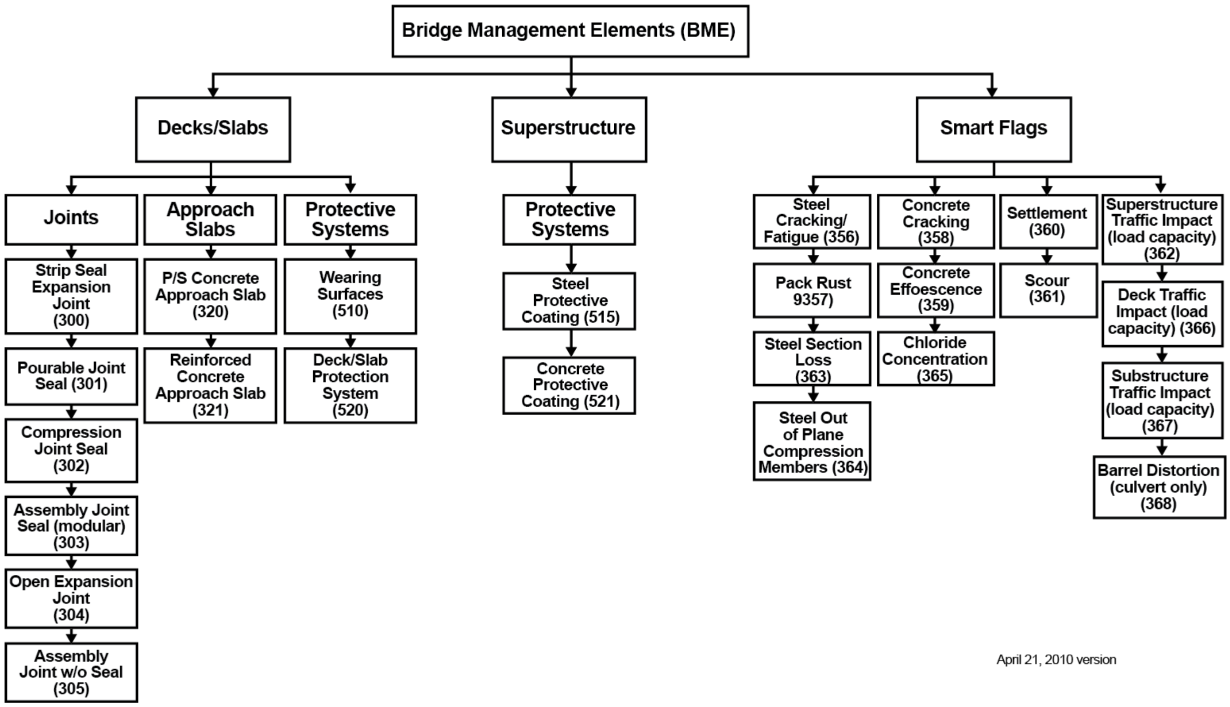
Finally, there are elements required for design and other applications or that are beneficial for digital data modeling that are not necessary for bridge inspections or management purposes and are therefore not included in the NBE or BME. For example, a girder system element allows for grouping of specific attributes that are re-used by multiple girders, therefore reducing redundancy and simplifying data structures for machine readability, but such a concept is not necessary for bridge inspection purposes.

The discussion in this section illustrates that an existing off-the-shelf classification system is not currently available. The elements and, ultimately the object types, would need to be determined for the national master OTL in a comprehensive yet flexible way that all State DOT participants could use and modify.



Source: AASHTO.

Figure 5-8. Illustration. National Bridge Elements categories and element naming and numbers in parenthesis.



Source: AASHTO.

Figure 5-9. Illustration. Bridge management elements categories and element naming and numbers in parenthesis.

5.3.3 Examining State Department of Transportation Object-Type Libraries

In addition to analyzing open national specifications, an examination of State DOT data models, databases, and data management systems can reveal an object-type classification system, ontology, and the object types, as shown in Figure 5-10.

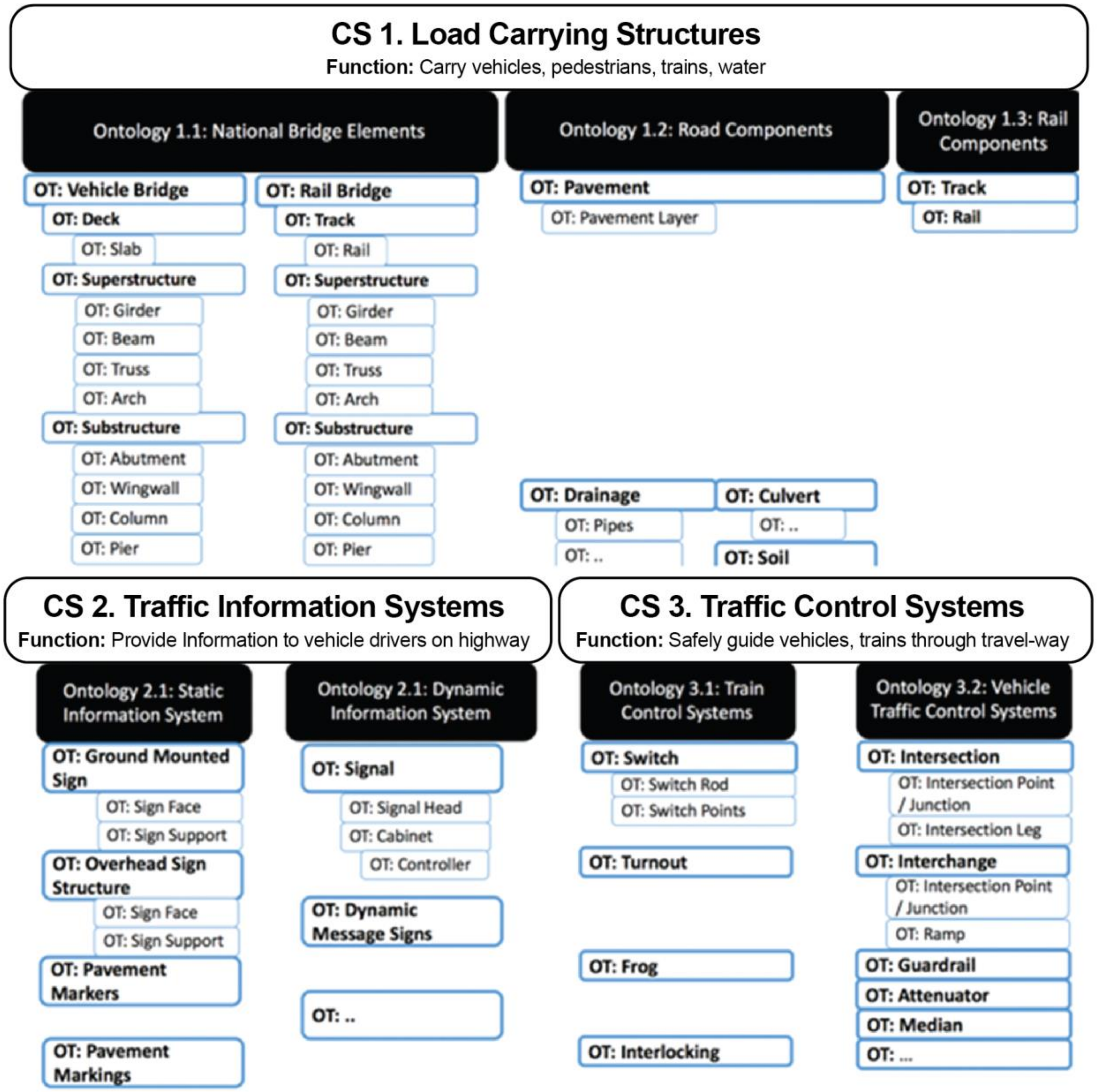


Figure 5-10. Illustration. A sample classification system.

In addition to the object types, information about object-type attributes would be an important feature of a CBTL. In fact, it is the object-type attributes that vary significantly across State DOTs, SDOs, and national and international data modeling libraries. Object-type attributes allow key data to be added to or associated with objects. The attributes are type-specific, and all objects of that particular type can be defined by using the type attributes. At this point, the NBE/BME classification system is reaching the end of its usefulness for the OTL. The NBE/BME attributes are limited to condition, state, and quantity for the listed elements because the purpose is to document these elements for the severity and extent of bridge condition deficiencies. However, this information is not sufficient for other use cases and applications of these elements.

The attributes are grouped into attribute sets, which define functional categories for the attributes. These set designations include groupings such as properties, layout, and dimensions. The attribute sets provide organization to the attributes and consistency among bridge elements.

These collections of data can be large, depending on the element and the use case being described. For example, the object-type attributes needed to fabricate a steel girder would be much larger than those for visualization at a public meeting for the same girder element. Object-type attributes vary not only for the intended use case but also from agency to agency. Many of these variations can be considered nomenclature differences, but there are also differences in the amount and specific attributes captured across State DOTs. Even within the same organization, attributes could be different based on what is in standard drawings and what is included in individual bridge data models to take advantage of commercial software OTLs and default naming conventions.

Table 5-1 shows several steel superstructure attributes for both rolled beams and built up plate girders and their mapping to two sample State DOT organizations’ standard element designations and how they are represented in sample bridge models.

Table 5-1. Attributes associated with steel beam element (NBE #107) mapped to IFC as IFC element assembly with predefined type set to girder.

Attribute Set	Attribute	Term	Definition	State DOT 1 Attribute	State DOT 2 Attribute
Properties	Girder Name	Name	Girder name most often referred to by a letter and number (i.e., G3 as Girder 3)	G#	G#
	Beam Section	Beam section (closed section)	Girder section as an enclosed shape for rolled sections	Rolled Beam Size	Rolled Shape Size
	Girder Material Designation	Material	Reference to ASTM or other steel material specification for rolled sections	Structural Steel Designation (design manual), Material (data model)	(F_y, F_u, and Coating defined in model, specification number for full material designations)
	Top flange plate material	TF material	Reference to ASTM or other steel material specification for the top flange	Structural Steel Designation (top flange)	(F_y, F_u, and Coating defined in data model, specification number for full material designations)

Attribute Set	Attribute	Term	Definition	State DOT 1 Attribute	State DOT 2 Attribute
	Bottom flange plate material	BF material	Reference to ASTM or other steel material specification for the bottom flange	Structural Steel Designation (bottom flange)	(F_y, F_u, and Coating defined in model, specification number for full material designations)
	Web plate material	Web material	Reference to ASTM or other steel material specification for the web	Structural Steel Designation (web)	(F_y, F_u, and Coating defined in model, specification number for full material designations)
	Weld size	Weld size	The top flange to web weld size	Web to flange welds	Web to flange welds
	Weld size	Weld size	The bottom flange to web weld size	Web to flange welds	Web to flange welds
Layout	Alignment Positioning	Alignment Positioning	Defining placement and offset from a reference alignment (additional layout attributes in Girder System object)	(Dimension on framing layout)	(Dimension on framing layout)
Dimensions	Girder Length	Length	Length of girder	Overall beam length	Beam Segment Length
	Top flange plate thickness	TF thickness	The thickness of the top flange of a welded plate girder	Top Flange Thickness	Top Flange Thickness
	Top flange plate width	TF width	The width of the top flange of a welded plate girder	Top Flange Width	Top Flange Width
	Bottom flange plate thickness	BF thickness	The thickness of the bottom flange of a welded plate girder	Bottom Flange Thickness	Bottom Flange Thickness
	Bottom flange plate width	BF width	The width of the bottom flange of a welded plate girder	Bottom Flange Width	Bottom Flange Width
	Web plate thickness	Web thickness	The thickness of the web of a welded plate girder	Web Thickness	Web Thickness

Attribute Set	**Attribute**	**Term**	**Definition**	**State DOT 1 Attribute**	**State DOT 2 Attribute**
	Web plate depth	Web width	The width of the web of a welded plate girder	Web Width	StartValue (web), EndValue (web)
	Girder Quantity Volume	Volume	Volume of girder	Volume	Volume
	Girder Quantity Weight	Weight	Weight of girder	Unit Weight	Unit Weight

To further illustrate the differences between State DOT elements and attributes, Figure 5-11 and Figure 5-12 show images of diagonals from a cross-frame in two models created for contract documentation by separate State DOTs. A few differences are obvious and expected between organizations with different standards and specifications. First, the shape of the diaphragms are different. Figure 5-11 is a X-type cross-frame, and Figure 5-12 is an inverted K-type. Note that Figure 5-11 uses the term “Diaphragm” instead of “Cross-Frame” for the element name. Also, different pay or bid items are State DOT-specific. Figure 5-11 has its information located under the “General Items” attribute designation, while Figure 5-12 uses specific naming “Pay Item1” and “Pay Item2” attributes attached.

Some attribute designations are similar, such as the geometry attributes, including volume, surface area, offsets, and length. However, this consistency can be traced to the internal mapping of the model authoring software, which was the same for both models. Many of these values would likely be named slightly differently in standard drawings or design manuals. Also note that the values provided for common attribute designations such as “Material” vary and could not be assigned a single value.

Figure 5-11. Screenshot. Model example #1 of a cross-frame diagonal element (highlighted in blue) and its attributes.

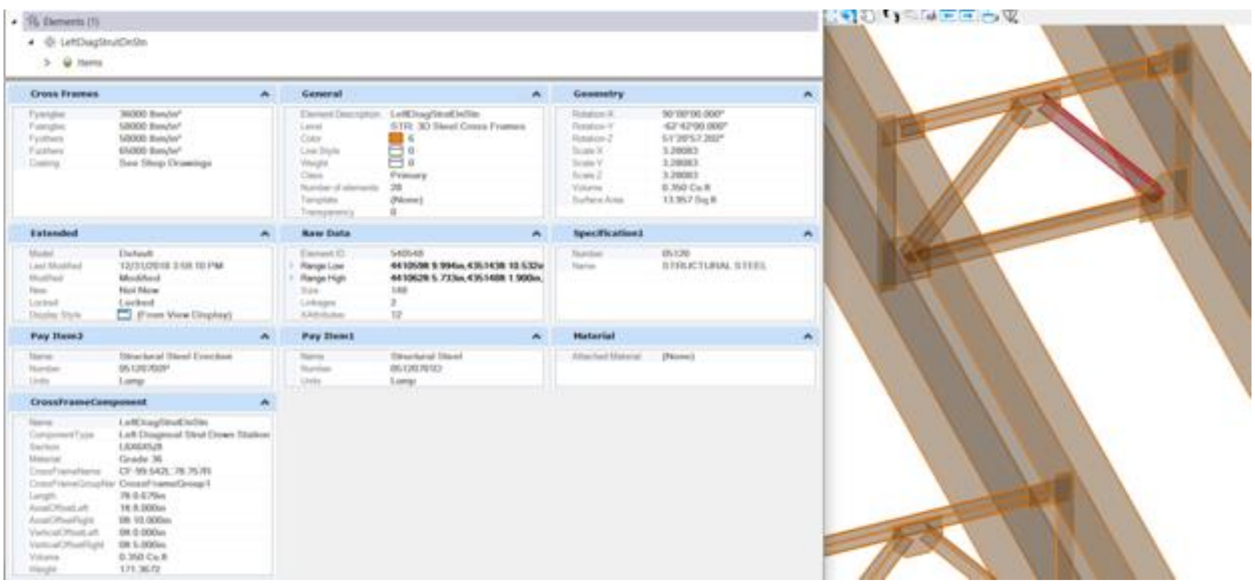


Figure 5-12. Screenshot. Model example #2 of a cross-frame diagonal element (highlighted in red) and its attributes.

These differences are justified and important in many instances, and others are insignificant differences in the current processes because the industry understands many alternate naming schemes for similar elements. However, the differences introduce complexity when mapping elements and attributes to an open standard such as IFC, for example. This is the one of the top motivating factors for a CBTL and specifically to establish a national master that is flexible enough for individual organizations and particularly by State DOTs to update.

5.3.4 Examining IFC Object-Type Libraries

Aligning the findings from the examination of national and State DOT data dictionaries with open-standard OTLs and data dictionaries would be a key step in engineering a centralized BIM OTL and data dictionary. In this research, for illustration, IFC 4.2 standard is used, and IFC data structures are defined to use for applicable bridge components. Initial outreach to State DOTs was carried out to identify the need for additional data requirements from a U.S. perspective for bridges (i.e., the templates of bridge components that can be mapped to IFC classes, defined from U.S. perspective). Bridge data administrators could then use this CBTL to update and maintain the bridge object types or recommendations for IFC data structures and usage.

Table 5-2 shows a sample of elements and their NBE or BME designation (if applicable). This table offers a general illustration of how the framework of the OTL may be structured. Also included is the category and host element showing a representative taxonomy and relationship between elements. Finally, the equivalent IFC 4.2 object or class and classification is shown to provide an example of mapping of elements to an open standard. While similar mappings can be developed for physical infrastructure objects with other open standards, an CBTL would allow stakeholders to determine which open-standard object type could be used to model the different infrastructure asset elements (i.e., the physical objects).

Table 5-2. National Bridge Element/Bridge Management Element designations and Industry Foundation Classes object type or classification for common bridge elements.

Category	Element	NBE/BME Element #	Element Parent #1	IFC Object Type and Subtype
Deck	Cast-In-Place Concrete Deck	12/38	--	IfcElementAssembly:DECK
	Reinforced Concrete Bridge Railing	331	--	IfcWall:Parapet
Superstructure	Girder System	NONE	--	IfcBridgePart: SUPERSTRUCTURE
	Steel Girder/Beam	107	--	IfcElementAssembly:GIRDE R
	Prestressed Concrete Girder/Beam	109	--	IfcBeam
Superstructure (secondary elements)	Concrete Diaphragm	NONE	107/109	IfcBeam:DIAPHRAGM
	Steel Cross-Frame/Diaphragm	NONE	107/109	IfcElementAssembly: CROSS_FRAME
	Stiffener	NONE	107	IfcPlate:STIFFENER
	Connection Plate	NONE	107	IfcPlate:SPLICE
	Shear Connector	NONE	107	IfcMechanicalFastener: SHEAR_CONNECTOR
Substructure	Pier Assembly	NONE	--	IfcElementAssembly:PIER
	Concrete Pier Cap	234	--	IfcBeam:PIERCAP

Category	Element	NBE/BME Element #	Element Parent #1	IFC Object Type and Subtype
	Concrete Column	109	--	IfcColumn
	Concrete Pier Wall	210	--	IfcWall
	Concrete Pile Cap or Footing	220	--	IfcFooting
	Abutment	215	--	IfcElementAssembly: ABUTMENT
Roadway	Alignment	NONE	--	IfcAlignment

The IFC object types are defined from the overall data structure introduced in IFC 4.2 for bridges. Once the object types have been identified, classes are defined for each object type. Figure 5-13 illustrates this structure, indicating common bridge elements. The enclosing IfcProject describes overall context and is decomposed into an IfcSite that describes the surrounding land. This IfcSite is then decomposed into an IfcBridge for the bridge structure, and then further decomposed into IfcSpace for the deck, superstructure, and substructure categories. The site may contain IfcAlignment objects (introduced in IFC 4.1). IfcAlignment objects describe the main reference line that governs the layout of the bridge in 3D space (both roadway alignment and profile). Each of the main structures may be decomposed into physical assemblies or elements, where the class IfcElementAssembly has several predefined classifications, including GIRDER, BRACED_FRAME, and SLAB_FIELD. IFC 4.2 has expanded these to include PIER, ABUTMENT, CROSS_FRAME, and DECK.

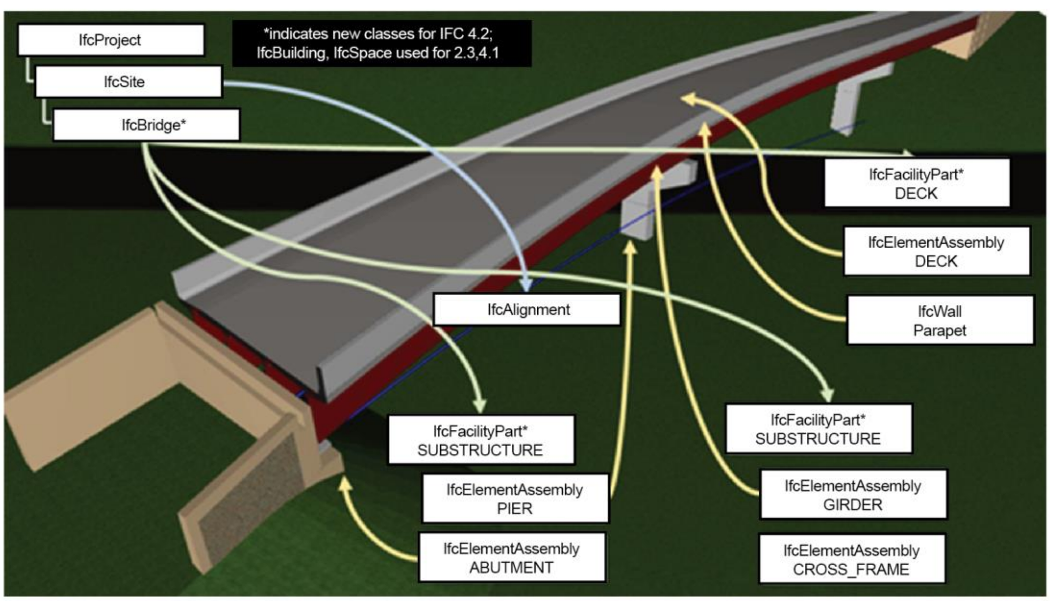
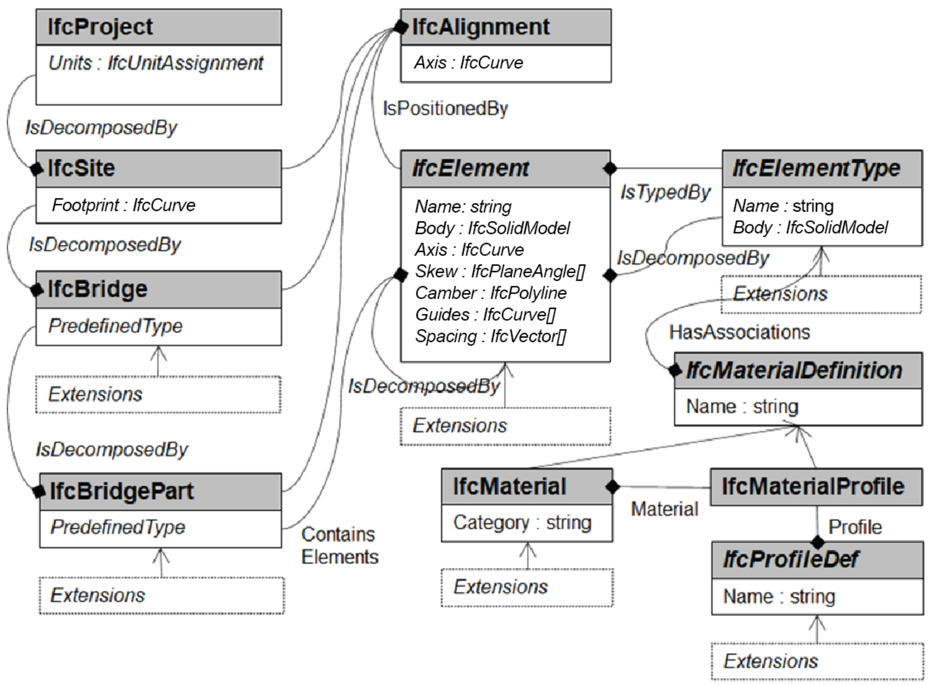


Figure 5-13. Diagram. IFC 4.2 data structures for bridge systems.

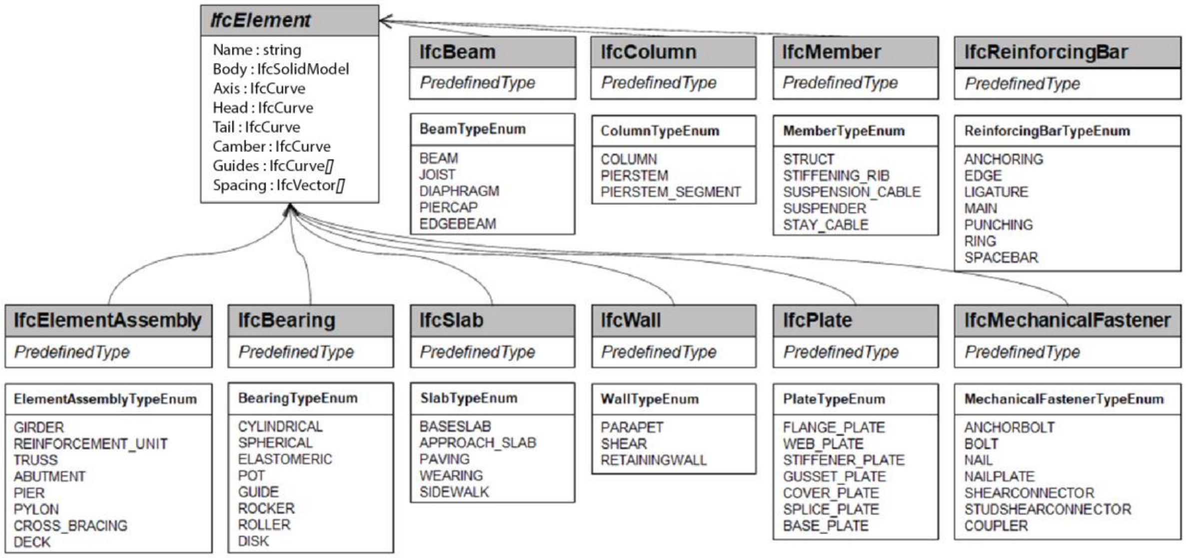
Figure 5-14 illustrates the primary data structures for capturing a bridge model in the form of a Unified Modeling Language (UML) diagram, where referencing relationships have a diamond at the end, inheritance relationships have an open arrow at the end, abstract classes use italics, and optional attributes and relationships use italics. The data structures shown have been abbreviated to only show attributes relevant to bridge modeling, omitting IFC objectified relationship classes and inherited classes, and showing layout geometry inline in blue text. Classes intended for extension are shown within extensions boxes, where such extensions take the form of derived classes and additional attributes (using property sets in IFC).



Source: bSI.

Figure 5-14. Illustration. Unified Modeling Language diagram for the primary data structures for capturing a bridge model.

Figure 5-15 illustrates data structures for physical elements (deriving from IfcElement) in the form of a UML diagram. The PredefinedType for each class refers to a functional category of an element, which is conceptually the same as a subclass. There are other subclasses relevant to bridges such as IfcFooting, IfcPile, IfcTendon, as well as additional PredefinedTypes for classes shown; however, they are omitted for brevity.



Source: bSI.

Figure 5-15. Illustration. Unified Modeling Language diagram illustrating data structure for physical elements.

For library type objects to be used within bridge models, such type objects may be defined with variable lengths, widths, or other parameters. To accommodate this usage, the specific values and curvature of such parameters typically vary for specific spans, alignments, and layouts based on the unique dimensional parameters for every bridge.

In general, layout of bridge elements can be described using the following concepts:

- **Host (Object Containment)**. To define components of assemblies (e.g., girder segments, cross-frame members, rebar), elements may have a breakdown structure where sub-elements are positioned relative to the containing component, commonly referred to as the host in design software.
- **Type.** To define types of objects that can be re-used repeatedly, an element may have a corresponding type, which is the basis for such an OTL.
- **Material**. Physical material of an element may be referenced by known identity, or elaborated into physical attributes such as density, strength, and modulus of elasticity.
- **Profile (Cross Section)**. To define the cross section of a linear component—a bridge deck, member of a cross-frame, or pier—a profile may be used that is based on a 2D closed curve.
- **Axis Curve.** To define the span of a linear component—whether a bridge deck, girder segment, cross-frame, or pier—any physical element may define an axis that refers to a 3D closed curve that indicates the path of an element.
- **Skew Angles.** To define linear elements with edges that are laterally skewed, skew angles may be defined at the start and end of an element span.

- **Guide Curves.** To define a cross section that varies with exact curvature (e.g., parabolic), 3D curves may also be defined to associate a point or edge of profile with a curve.
- **Camber Curves**. To define the layout of components as fabricated, 2D curves may be defined relative to the axis curve. These are not illustrated for visualization but are used for fabrication.
- **Spacing**. To define elements that repeat at periodic spacing intervals (e.g., rebar, shear studs), elements may define pattern placement.

Examples that follow illustrate specific usage of each of these concepts. Figure 5-16 illustrates how these concepts corresponds to data structures in IFC.

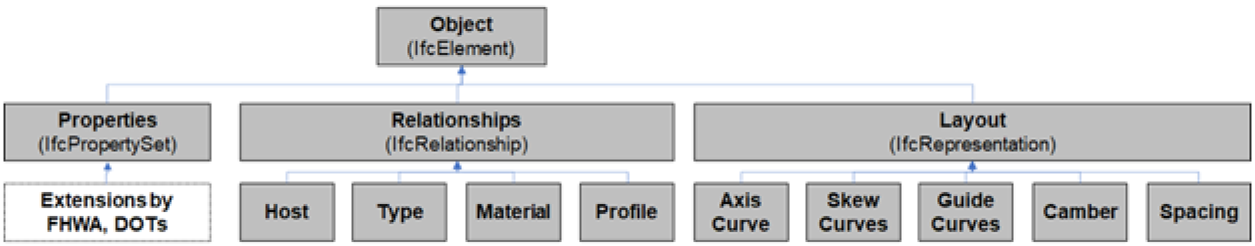


Figure 5-16. Illustration. Example of hierarchy of object, attribute sets, and example attributes in industry foundation classes.

Appendix A provides detailed mappings of each of these attributes to IFC data structures. Extensions developed by transportation agencies on a State or national level may take the form of property sets in IFC. While IFC defines thousands of properties, most of these relate to plumbing, electrical, and mechanical systems and would have limited applicability to bridges. Table 5-3 lists a sample set of IFC properties that would likely need to be further elaborated for use by specific agencies.

Table 5-3. Example Industry Foundation Classes property set and description.

Class	Property Set	Property	Description
IFcElement	Pset Condition	Assessment Date	Date on which the overall condition is assessed.
		Assessment Condition	The overall condition of a product based on an assessment of the contributions to the overall condition made by the various criteria considered. The meanings given to the values of assessed condition should be agreed and documented by local agreements. For instance, is overall condition measured on a scale of 1–10 or by assigning names such as Good, OK, Poor.
		Assessment Description	Qualitative description of the condition.

Class	Property Set	Property	Description
IFcBeam	Pset_Beam Common	Span	Clear span for this object. The shape information is provided in addition to the shape representation and the geometric parameters used within. In cases of inconsistency between the geometric parameters and the shape properties provided in the attached property, the geometric parameters take precedence. For geometry editing applications, like CAD, this value should be write-only.

Examples for common bridge elements are further elaborated. Figure 5-17 illustrates a bridge deck following the above concepts, where the alignment stationing defines the span of the deck segment, the deck profile defines the starting cross section, optional guide curves define variation of the deck profile, and optional skew angles are at the start and end. Rebar is defined as two components for longitudinal and lateral, respectively, with initial position and spacing defined. Rebar for connecting parapets (while shown in Figure 5-17) is not defined as part of the deck but rather as part of the parapet walls because the layout is specific to this shape even though such rebar is placed in the deck during construction.

Bridge element objects could be captured with a standard template or series of templates that would be used to enter geometric and other attributes into the OTL. This tool, described as a BIM object definition template, would provide a structured approach to providing input to define and expand digital descriptions and associated software standards. A template would also provide a consistent form for a user, including State DOTs, to enter customized elements and attributes for their use. A future extension of this research could combine this concept with the library content and provide examples of how the template could be introduced in the OTL.

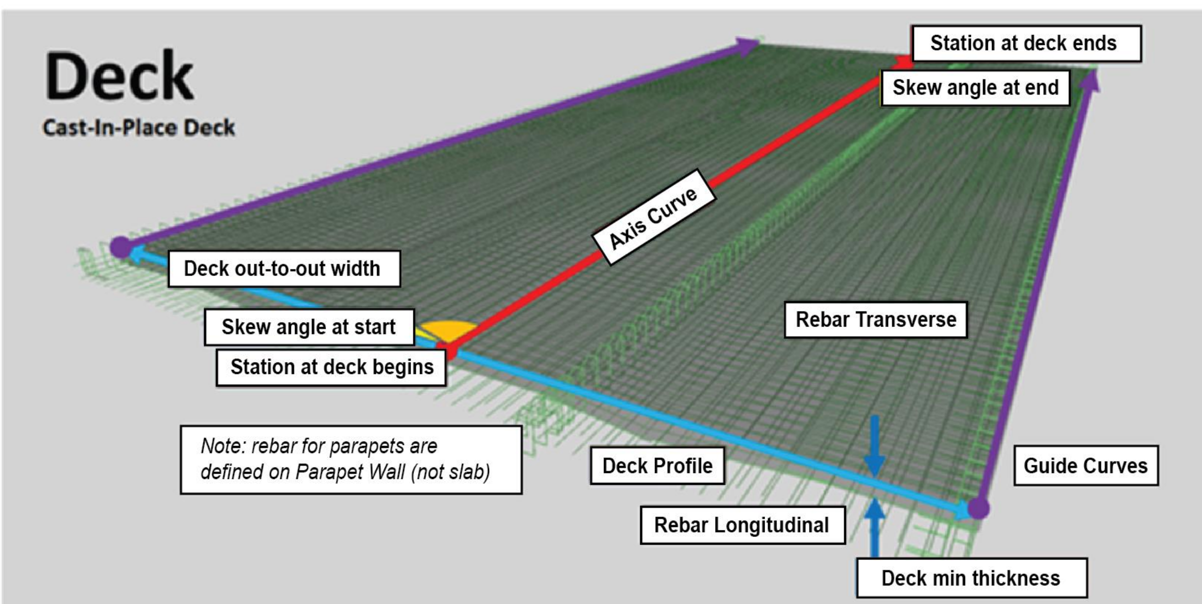


Figure 5-17. Illustration. Deck element with sample attributes illustrated.

Example data may be structured as provided in Table 5-4, which shows an example of what the user of a CBTL would view as input content for deck geometry attributes, and Table 5-5, which shows an example of how the data could be mapped internally for open standards and other OTLs.

Table 5-4. Example of deck geometry attribute inputs for a centralized BIM transportation library user.

Element	Deck Profile	Station at Deck Begins	Station at Deck Ends	Skew at Start	Skew at End	Deck Out-to-out Width
Cast-In-Place Deck	Normal Crown	100+00	101+50	15 deg	15 deg	40.0’

Table 5-5. Example of deck geometry attribute inputs mapped internally for open standards.

Element	Deck Profile	Station at Deck Begins	Station at Deck Ends	Skew at Start	Skew at End	Deck Out-to-out Width
IfcElementAssembly/DECK	{points}	{X: 100+00}	{X: 101+50}	{RZ: 15 deg}	{RZ: 15 deg}	{Y: -20', +20'}

Hosted elements or sub-elements, such as reinforcement, could also be mapped. Table 5-6 shows an example of what the user of a CBTL would view as input content for deck sub-element rebar attributes.

Table 5-6. Example of deck rebar attribute inputs for a CBTL user.

Object	Host	Type/Profile	Axis Curve	Spacing
IfcReinforcingBar	IfcElementAssembly/DECK	#6 {circle 0.75"}	{X: +2"… span-2"}	{Y: 9"}
IfcReinforcingBar	IfcElementAssembly/DECK	#6 {circle 0.75"}	{Y: -19'10"…+19'10"}	{X: 4"}

Figure 5-18 illustrates a web plate within a steel girder bridge. The bridge superstructure is decomposed into girder lines, each with its own axis curve, and such girder lines are further decomposed into plates. As illustrated, the web plate has an initial rectangular profile, is swept along the axis curve, and the depth of the web plate varies according to a guide curve. Camber is also illustrated separately using a list of points along the span with vertical offsets.

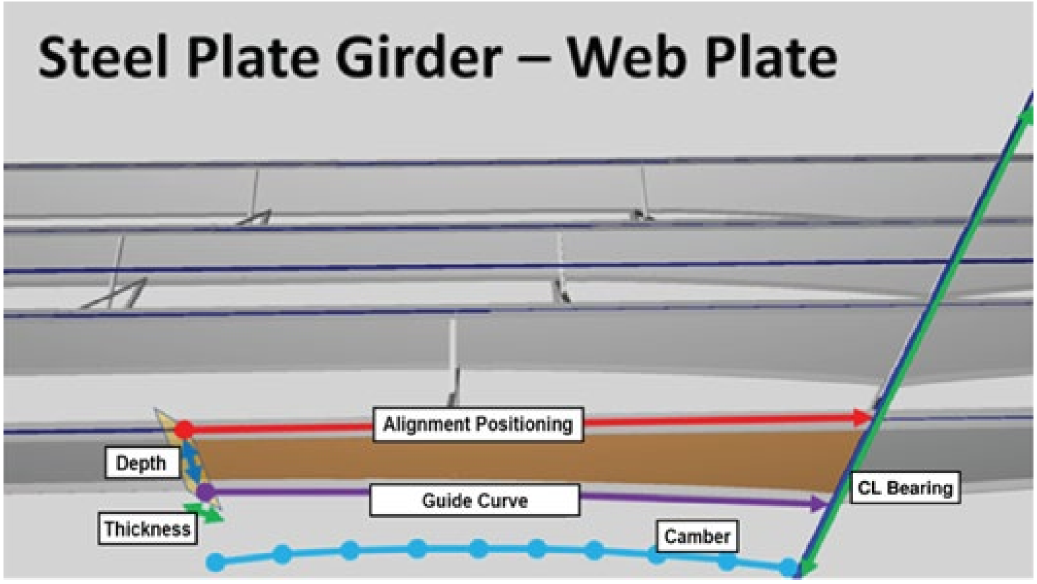


Figure 5-18. Illustration. Steel girder element with sample attributes.

Table 5-7 provides an example of what the user of a CBTL would view as input content for steel girder geometry attributes, and Table 5-8 shows an example of how the data could be mapped internally for open standards and other OTLs.

Table 5-7. Example of steel girder and web plate geometry attribute inputs for centralized BIM transportation library user.

Element or Sub-Element	Parent Element	Type/ Profile	Alignment Positioning (Offset or Start/end sta.)	Depth at Start	Depth at End	Thickness	Guide Curve
Girder 4	n/a	n/a	Offset: 12’	33”	54”	n/a	Camber ordinates
Girder 4, Web Section 2	Girder 4	Varying depth	Start: 100+30, End: 100+50	30”	50”	0.75”	Parabolic

Table 5-8. Example of steel girder and web plate geometry attribute inputs mapped internally for open standards.

Object	Host	Type/ Profile	Alignment Positioning (Offset)	Depth at Start	Depth at End	Thickness	Guide Curve
GirderLine 4	Superstructure	n/a	{Y: +12'}	{Z: 2'9”}	{Z: 4'6”}	n/a	{Z: 1.23”…0.00”}
GirderLine 4-Web2	GirderLine4	{rectangle 1"x2'6"}	{X: 100+30…100+50}	{Z: 2'6”}	{Z: 4'2”}	{Y: 0.75”}	{Z: 2'6"…2'}

As illustrated, the data structures defined within IFC 4.2 or other open standards could support the basic structure for supporting arbitrary library objects; however, software vendors could also implement specific usage of these data structures to support parametric design. Once such generic requirements are supported, then arbitrary assemblies may be defined that leverage these parameters. The parameters outlined are designed to support the most common data structures and can go only so far. Specific shapes may have other parameters used for driving specific geometry, which would need to be elaborated specifically for each shape, and part of the definition of such objects incorporated into a library.

5.4 UNDERSTANDING CONTENT CATEGORIZATION

To organize the content in an CBTL and engineer a centralized OTL and data dictionary from various open-source and standards-based OTLs and data dictionaries, it is important to understand the architecture of these artifacts. Broadly, the architecture has three levels, each of which reflects its functionality and use. At each level, the content can be categorized using multiple categories. These levels and their associated categories are presented in the subsequent sections.

5.4.2 Level 1 Categories: Languages, Definitions, Content, and Software

At the highest level, OTL and data dictionary categories include languages, definitions, content, and software. This terminology is used as a compromise between terms often used by software developers and those used by practicing engineers; aliases for equivalent terms are also listed for clarity.

Table 5-9. Digital information exchange system resource categories at level 1.

Resource	Aliases	Description
Languages	Syntax	Languages define syntax for describing information in a persistent form. Standards organizations have adopted various languages. Major technology companies have historically been the creators of such languages. As languages have become relatively settled and commoditized, it is typically advantageous for definitions and content not to invent new languages and to leverage what already exists and ideally independently such that any language can be used by any software as best fits.
Definitions	Metadata schemas	Definitions define data structures (e.g., classes, fields, functions) for how information can be described. Standards organizations have adopted various sets of definitions (or schemas) as international standards.
Content	Data instances	Content defines information structured according to definitions. Industry associations have focused on standardizing content for member manufacturers.
Software	Applications	Software consumes or produces content, based on definitions and languages. Software might support content and definitions from external sources or provide a closed ecosystem.

Offerings can span a blend of these, and this blending often poses a barrier to an interoperable market:

- Software that works only with its own definitions cannot share data with other software using different definitions.
- Content that is based on definitions for a particular software cannot be used by other software that does not recognize such definitions.
- Software that supports parametric component design based on specific languages and definitions for functions cannot share such parametric operations with other software.

To the extent that logical layers among software resources can be further identified and standardized, greater integration becomes possible.

5.4.3 Level 2 Categories: Language

Each of the Level 1 categories can be further broken down. For example:

- Languages are subdivided into categories according to what they support and how they are used in practice as shown in Table 5-10. Because languages are well established where a small set are used by the majority of the software market, there is little benefit for definitions, content, or software to introduce any dependencies on new or obscure languages because they can present a barrier to adoption. Languages are elaborated and listed herein primarily for clarity in relating other concepts.

Table 5-10. Categorization of language information exchange system resources at level 2.

Category	Example	Description
Encoding Language	JSON STEP (P21) XML	An encoding language defines how data are translated to bits sent over communications networks or stored on persistent media, independent of the content or definitions used.
Schema Language	EXPRESS SQL UML XSD	A schema language defines object classes and fields, forming the structure for data instances. Examples of schema languages listed are those that are primarily used to describe object classes and fields, however some of them also support full functionality of programming languages but are not used as such in practice. A schema language may be built upon an encoding language (e.g., XSD/XML)

Category	Example	Description
Programming Language	C++ C# Go Java Swift	A programming language defines functions and logical operations that operate on instances of object classes defined from a schema language. Most programming languages are also schema languages and are often used for such purpose. While programming languages are used as a basis for creating software, they can also be used as a basis for defining dynamic functionality as software plug-ins. When used for 3D models, objects with programming functionality can adapt according to parameters based on dynamically defined instructions that can be exchanged between software. For such plug-in system to support specific functionality, a baseline set of object classes, fields, and functions used should exist. For a programming language to support any potential behavior, the term "Turing-complete" is used. In the context of parametric BIM models, some standards meet this level, while others support a subset (such as providing only formula expressions with arithmetic operations).

Note: Trademarks or product names are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

- Definitions are subdivided into categories according to the nature of data described as shown in Table 5-11. The distinction of categories becomes meaningful for determining the feasibility of combining disparate information. For example, geometry by itself is generally interchangeable (though potentially with loss of parameterization), while functions defining particular logic require software platforms to support common functionality to be compatible.

Table 5-11. Categorization of definition information exchange system resources at level 2.

Category	Example	Description
Geometry Definitions	CityGML Collada IFC GeoJSON LandXML	Geometry definitions refer to object classes and fields for representing 2D or 3D geometry, without respect to classification, non-geometry properties, or dynamic programming behavior. A geometry language may describe merely tessellated surfaces (triangles) or higher-level constructs based on fixed parameters such as swept cross sections or Boolean subtractions. A geometry language may prescribe one or more encoding languages. Such geometry definitions can further be categorized according to data structures.
Property Definitions	NBI	Property definitions refer to object fields that describe functional aspects of an object (as opposed to form-based aspects such as geometry or classification aspects). Examples would include parameters such as structural strengths, thermal expansion coefficients, and fire ratings.
Classification Definitions	CSI OmniClass NBI	Classification definitions refers to object fields and formatting conventions for distinguishing objects based on defined criteria, forming a taxonomy.

Category	Example	Description
Function Definitions	APIs made available by major software vendors to developers to interconnect with their software and extend their functionality.	Function definitions define logic for calculating output parameters or operating on data structures given a set of input parameters. For software to interoperate, a set of functions may be defined, which is often referred to as an API.

Note: Trademarks or product names are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

- Content is also subdivided into categories correlating to definition categories as shown in Table 5-12. Distinction is made between content libraries themselves and software web portals that may be used to host such content because the same content could be hosted on multiple portals.

Table 5-12. Categorization of content information exchange system resources at level 2.

Category	Description
Geometry Content	A geometry content library organizes 3D data that may be re-used across construction projects of similar nature. A geometry content library by itself does not lend itself to customization of parameters beyond placement and raw scaling.
Property Content	A property content library organizes non-geometry information, which might also accompany geometry information. For example, a library of steel cross sections might define shape dimensions along with other parameters such as unit mass and moment of inertia for each axis. As another example, a library of partition wall types might define layers of stud framing and drywall sheets used along with resulting performance ratings for fire, sound, and limiting length.
Classification Content	A classification content library defines classification entries that may be used for categorizing objects.
Parametric Content	A parametric content library provides recipes for generating 3D data based on parameters. Data are encoded according to a programming language and definitions of geometry and properties. The distinction that makes a library parametric (as opposed to just geometry content) is if programming logic is captured in the library itself, rather than just parameters applied to existing definitions.

- Finally, as shown Table 5-13, software is subdivided into categories of market segments within scope of this report.

Table 5-13. Categorization of software information exchange system resources at level 2.

Category	Description
BIM Authoring Software	An authoring tool enables creation of content in a manner familiar to its target audience. Such tool may be online or run on a local computer. It may have its own version control, content libraries, and data formats, and support third-party libraries and formats.

Category	Description
Content Portal Software	A content portal organizes libraries of re-usable 3D components such as manufactured products and general product configurations based on established dimensions. A content portal may contain geometry libraries and parametric libraries. Various stand-alone content portals exist, as well as those built-in to BIM authoring tools.
Version Control Software	A version control service provides an online location for storing digital content that may be shared with multiple parties or the public at large and authored by multiple parties. Information stored may be arbitrary documents, structured data, or software source code, where different platforms may focus on functionality tailored accordingly.

In reviewing various online resources, distinction is made to indicate categories of resources for each offering and how each fits within the ecosystem of the U.S. construction software market.

Such distinction is most relevant in a business context. Given customer demand, dominant players in a market segment are generally more receptive to interfacing with software and standards in other segments in which they do not compete and are less receptive to interfacing with software or standards within the same category. Market players spanning multiple categories where vertical integration provides competitive advantage are less receptive to any standards that cut through their multiple categories of focus.

It is important to make a distinction between what is open and what is proprietary. This report defines open as anything that can be copied freely without restriction. Any resource having terms that do not allow for redistribution of content is not considered open for purposes of this report in achieving the stated goals.

Commercially available bridge design software applications—can also provide substantial functionality for authoring, publishing, and versioning components for bridge models. To visualize where existing resources fit and how they may complement each other and where integration may occur, Table 5-14 illustrates a matrix for what each resource provides.

- Triangles indicate that a resource is published for use and can be used without any license restrictions.
- Squares indicate that a resource exists, but licensing terms restrict use.
- Circles indicate the reuse of external resource(s) (e.g., GeoJSON builds on top of JSON).

Table 5-14. Existing resources.

	Languages			Definitions				Content				Software		
	Encoding	Schema	Programming	Geometry	Classification	Property	Function	Geometry	Classification	Properties	Parametric	Authoring Tool	Content Portal	Version Control
AASHTOWare Bridge D/R	●	-	-	■	■	■	-	■	■	■	-	■	■	-
BIMObject	-	-	-	●	●	●	●	■	■	■	■	-	■	-
buildingSmart Dictionary	●	▲	-	-	▲	▲	-	■	▲	-	-	-	-	-
buildingSmart IFC	●	-	-	▲	▲	▲	-	-	-	-	-	-	-	-
FHWA N. Bridge Inventory	▲	-	-	-	▲	▲	-	-	▲	▲	-	-	▲	-
GeoJSON (IETF)	-	-	-	▲	-	-	-	-	-	-	-	-	-	-
Google Poly	-	-	-	●	-	-	-	■	-	-	-	-	■	-
ISO 10303-11 (EXPRESS)	-	▲	-	-	-	-	-	-	-	-	-	-	-	-
ISO 10303-21 (STEP)	▲	-	-	-	-	-	-	-	-	-	-	-	-	-
Java {or C#, C++, Go, etc.}	-	-	▲	-	-	-	-	-	-	-	-	-	-	-
JSON	▲	-	-	-	-	-	-	-	-	-	-	-	-	-
Microsoft GitHub	-	-	-	-	-	-	-	-	-	-	-	-	-	▲
NBS National BIM Library	-	-	-	●	-	-	-	■	■	■	-	-	■	-
OpenBrIM	●	■	■	■	■	■	■	■	■	■	■	■	■	-
OGC CityGML	●	-	-	▲	▲	-	-	-	-	-	-	-	-	-
OGC InfraGML	●	-	-	▲	▲	-	-	-	-	-	-	-	-	-
XML (W3C)	▲	-	-	-	-	-	-	-	-	-	-	-	-	-
XSD (W3C)	●	▲	-	-	-	-	-	-	-	-	-	-	-	-

Note: Trademarks or product names are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

This matrix illustrates what can feasibly be integrated and where conflicts may emerge. While a particular resource filling multiple categories may offer more of a complete solution on its own, resources that are more specific to a single purpose are more easily integrated compared to resources that combine multiple purposes that cannot easily be separated—both technically and economically.

Multiple resources may be leveraged for each category. Vendor-specific software applications are not mentioned in Table 5-14 under the Software category, but this category is organized into three broad groups—design authoring tools, content portals, and version control systems—leaving the specific choices to the user.

To provide a neutral location of content libraries accessible by multiple software vendors, dedicated version control services may be used as a means to capture all data. The use of version control services (as opposed to arbitrary online storage) is recommended because such services have become the de facto standard for most software companies. Well known commercial services exist in this regard which leverage existing tool infrastructure for comparing, versioning, and branching derivative definitions.

While basic content portals that simply reference select GitHub repositories and provide higher-level user interfaces could be produced easily, there is room for innovation where a competitive market of software companies could provide added value for browsing objects of interest, viewing details, and possibly editing content on such portals. For interoperability with content between portals and authoring tools, either data definitions need to be uniform throughout (a daunting undertaking), or an approach is needed that enables content from multiple authoring tools to co-exist within the same data set.

If the containerization of data is well-defined and simple enough to allow embedding of 3D objects, then existing simple conventions could be leveraged as a basic means of editing stand-alone parametric content from other authoring tools. To support such interoperability, a basic approach using established conventions is described later in this document.

5.4.4 Level 3 Categories

The third level of analysis breaks down each of the general categories. Geometry definitions are subdivided as shown in Table 5-15.

Table 5-15. Subdivided definitions.

Category	Description	Required
2D Polygons	2D polygons (including convex and concave) – any 2D curve can be reduced to this	Yes
2D Arcs	2D circular arcs	Yes
2D Splines	3D spline curves	--
3D Triangles	3D triangle meshes with vertex and normal vectors	--
3D Polygons	3D polygonal representations (a.k.a. B-Reps, polyhedrons)	Yes
3D Cylinders	3D cylinders and derivative surfaces	Yes
3D Splines	3D spline surfaces (NURBS)	--
3D Sweeps	3D swept solids are supported by sweeping any 2D geometry along any 3D curve	Yes
3D Booleans	3D constructive solid geometry for Boolean differences, unions, intersections	--
Color	Flat diffuse color	--

Category	Description	Required
Reflection	Colors for light reflectivity	--
Transparency	Transparency such as for windows	--
Textures	Textures for detailed appearance and texture coordinates on 3D surfaces	--
Templates	Templates for defining geometry and locating at multiple positions (data efficiency)	Yes
Transforms	Transforms for geometry for rotation, non-uniform scaling (data efficiency)	Yes
Arrays	Arrays of geometry at repetitive patterns (data efficiency)	Yes

Resource support for geometry definitions are shown in Table 5-16.

Table 5-16. Geometry definitions.

	2D			3D						Styles				Templates		
	2D Polygons	2D Arcs	2D Splines	3D Triangles	3D Polygons	3D Cylinders	3D Spline	3D Sweeps	3D Booleans	Color	Reflections	Transparency	Textures	Templates	Transforms	Arrays
Collada	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N
buildingSmart IFC	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
GeoJSON	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N
OGC CityGML	Y	N	N	Y	Y	N	N	N	Y	Y	Y	Y	Y	N	N	N
OGC InfraGML	Y	Y	N	Y	Y	Y		Y	N	N	N	N	N	N	N	N
OpenBrIM	Y	Y	N	Y	Y	Y	N	Y	Y	Y	N	N	N	Y	Y	Y
WaveFront OBJ	N	N	N	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N

Note: Y implies that a given resource supports a specific geometry definition and N indicates that the opposite.

Support for various geometry forms varies across resources. For purposes of n CBTL to define libraries of components for bridges and roads, more is not necessarily better; the minimum geometry necessary should relate to the subject matter. For example, non-uniform rational B-spline (NURBS) surfaces are not used in practice for transportation structures, except for architectural add-on features that would just as easily be reduced to polygonal shapes with sufficient precision for construction. Similarly, styling functionality (e.g., colors) is unnecessary to convey construction detail, except perhaps for architectural features for which specific coating materials would be identified separately, though it may help for visual identification for features.

5.5 INTEROPERABILITY BETWEEN AUTHORING TOOLS AND CONTENT PORTALS

An object linking and embedding approach may be used to support content, definitions, and authoring tools from divergent data definitions, d languages, and the ability to edit the content from the hosting application.

The existing, well-adopted, and prescriptive research in this area is extensively addressed in representational state transfer (REST) architecture employed at the heart of most contemporary web-centric implementations. Alignment to that principal convention provides a direct means to achieve non-proprietary compatibility for current and future tooling.

All objects may be given a fully qualified URL property that identifies the origination of the data. If such URL exists, an authoring application may launch the URL in the web browser and read or update data according to well-known encoding formats (e.g., XML, JSON). Furthermore, extending or supporting existing practices around that foundation such as those defined in the OpenAPI specification, ensures an even greater delivery channel. Given such URL, the URL behaviors are presented in Table 5-17. Examples of parameters mentioned in Table 5-17 are presented in Table 5-18.

Table 5-17. URL behaviors.

HTTP Verb	Accept Header	Response Codes	Description
GET	HTML	200 OK 401 Unauthorized	View and edit contained content at referenced URL.
GET	JSON	200 OK 401 Unauthorized	Get latest content of object.
PUT	JSON	200 OK 401 Unauthorized	Change parameters of object and get updated geometry and any other dependent parameters.
POST	JSON	200 OK 401 Unauthorized	Create a new instance of object with parameters identified.
DELETE	--	200 OK 401 Unauthorized	Delete an object.
STATUS	--	200 OK 204 Not Modified 401 Unauthorized	Check if object has been updated.

Table 5-18. Parameter examples.

Parameter	Description
Length	Length along primary axis
Width	Width along lateral axis
Height	Height along vertical axis
Radius	Radius of horizontal alignment curve
SlopeStart	Slope at start of vertical alignment curve
SlopeEnd	Slope at end of vertical alignment curve

5.6 USING A CENTRALIZED BIM TRANSPORTATION LIBRARY FOR ADDRESSING CHALLENGES IN MOVING DATA BETWEEN FORMATS

Moving data between different formats is one challenge that most BIM data engineers understand. Figure 5-19 shows an example of different formatting challenges. Engineers, fabricators, contractors, or inspectors each require different specifications of the beam. The underlying data of the beam do not need to be defined in these different ways, but a system should be in place that can support and drive such information for each phase of the asset lifecycle.

In addition, a solution that can map between different data formats would be useful. A CBTL could be used to provision functions as API-based operations that transform data from one format to another. For example, CBTL functions could be used to transform parametric geometry to primitive geometry. Parametric geometry could be defined using formats available design CAD software applications and bridge structural design software that have CAD-based geometry modeling features. The transformation to primitive geometry formats could be accomplished using functions available in a CBTL.

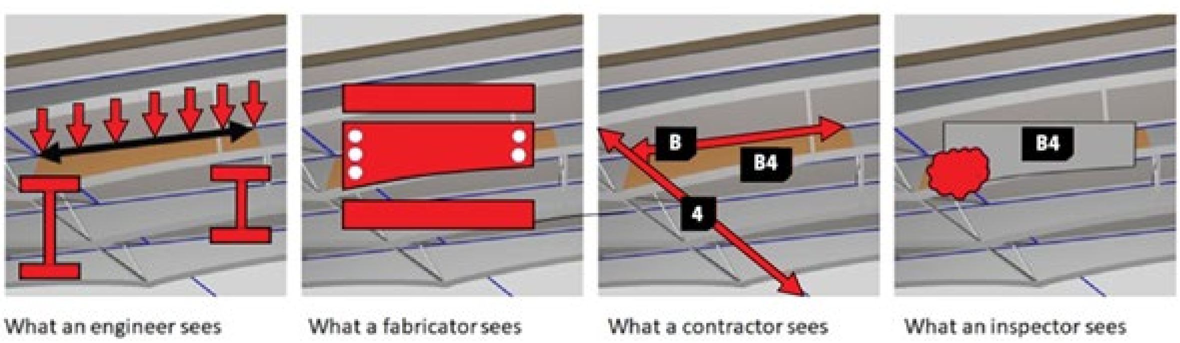


Figure 5-19. Illustration. What different types of users see when creating a data model.

5.7 SUMMARY

This chapter presents examples of the type of content that could be provisioned through a CBTL and how such content could be organized. The examples focus on one of the BIM artifacts (i.e., the OTL and data dictionary). Other BIM artifacts such as business processes, data workflows, IDMs, ILSs, and MVDs, should be analyzed to determine which content could be provisioned through an CBTL and how such content could be categorized.

CHAPTER 6. BIM WORKFLOWS AND CENTRALIZED BIM TRANSPORTATION LIBRARY DEVELOPMENT, DEPLOYMENT, AND ADMINISTRATION PLAN

6.1 INTRODUCTION

This chapter presents a plan for developing, deploying, and administrating the CBTL architecture that was presented in Chapter 5. First, information about the people and processes that are likely to be associated with managing a CBTL are presented. Next, CBTL development and administration processes and technical concepts are presented, primarily to cover various aspects associated with CBTL deployment and maintenance.

6.2 IMPLEMENT BIM NATIONAL STRATEGIC ROADMAP ACTIVITIES

The NSR for advancing BIM for Infrastructure in the United States discusses the importance of establishing digital workflows and various BIM artifacts that are identified in Chapters 2 and 3 of this report. Figure 6-1 presents how the NSR advises incremental development of BIM artifacts as part of the early, extended, and mainstreaming pilots, by executing activities D1 (for creating information needs as shown in Section 3.2), D2 (for creating OTLs and data dictionaries as shown in Section 3.3), D3 (for creating IDMs and exchange specifications as shown Section 3.4 and Section 3.5), A3 (for creating model construction documents as shown in Section 3.7), A4 (for creating BIM execution plans for enabling digital workflows as mentioned in chapter 2), and A5 (for creating templates for employer information requirements as referenced in section 3.2). The execution of the CBTL development, deployment, and administration plan that is presented in this chapter will allow the CBTL to be ready and available for these pilots and development activities in the NSR.

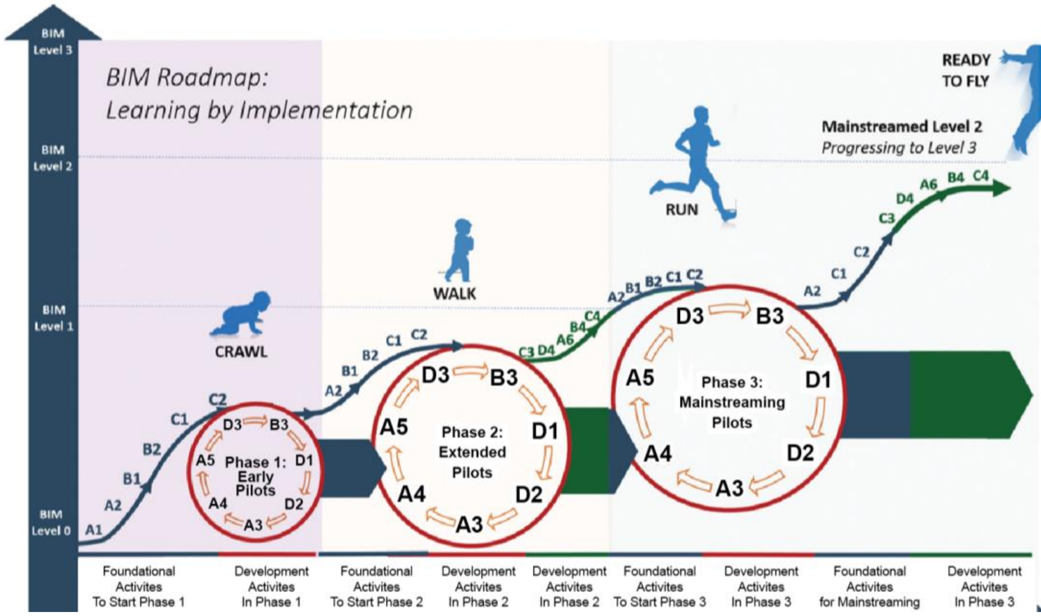


Figure 6-1. Illustration. Supporting FHWA's BIM for Infrastructure National Strategic Roadmap (Mallela and Bhargava, 2021) pilots and activities with a centralized BIM transportation library.

6.3 ESTABLISH CENTRALIZED BIM TRANSPORTATION LIBRARY PEOPLE AND PROCESS REQUIREMENTS

Management of the type of CBTL content described above should involve stakeholders working collaboratively with well-defined roles and responsibilities. This section provides some insights into a CBTL management process, specifically the stakeholders, their roles and responsibilities, and the specific content management function and processes that should be carried out if a CBTL were to be established[8].

6.3.2 Identify Centralized BIM Transportation Library Stakeholders

The stakeholders anticipated to play a key role in the development and ongoing maintenance of a CBTL would likely include the following:

- ***AASHTO, FHWA, National Information Exchange Model (NIEM), and the Federal Geographic Data Committee (FGDC)****:* TRB and FHWA have developed significant resources in research and development activities related to BIM for Infrastructure.
- ***National and International SDOs:*** CBTL content, especially the object types and the object-type relationships can be defined based on open standards such as IFC, InfraGML, CityGML, HPMS, NBE-BME, and MIRE. The role of SDOs in

[8] FHWA is not committing to or requiring a CBTL.

developing, aligning, and maintaining their respective OTLs therefore becomes a critical factor in developing and maintaining a CBTL. The updates made to the OTLs defined by each SDO would be considered to ensure interoperability with CBTL object types and the object types defined in the OTLs of SDOs. Aligning these OTLs and ensuring that all SDOs work together would be key to developing a streamlined process for adoption and use of the object types from SDOs in a CBTL.

- ***State DOTs*:** State DOTs (and potentially local agencies) manage their own object types, terms, and definitions that have been defined around open standards such as HPMS, ARNOLD, and MIRE as well as the business needs and requirements of the agency. These agencies also define ILS that are unique. Therefore, data administrators at these agencies would have many inputs and insights on what object types, object-type relationships, and attributes could be managed, and which ones could be standardized nationally.
- ***Software Vendors and Infrastructure Service Contractors:*** The data management system vendors, data modeling service providers, and highway infrastructure design and construction contractors would play an important role in defining the content in a CBTL. This group of stakeholders works with many State and local transportation agencies. So, they have information on practices at various agencies, and often contribute to deployment of proprietary but standard OTLs. Information from such OTLs and experiences of this group can be used to not only develop a CBTL, but also provide inputs to these vendors and service providers on CBTL content that is being finalized based on inputs from other stakeholders and sources.

6.3.3 Content Management Functions

As described in the previous sections, management of the content would involve developing a national master library of object types, relationships, attributes, terms, and definitions and identifying which of these OTL entities are part of the various ILS between stakeholders and systems. As part of the development of the national master library, mapping of the entities in the national master (with the entities defined by SDOs, vendors, and contractors associated with data modeling), as well as local and State DOT OTLs would occur. Figure 6-2 illustrates this concept. For management of this type of CBTL content, as described in the previous section, inputs and data model-related work products developed by each of the stakeholders would be integrated. This section describes some CBTL content management functions that would be associated with such an OTL and ILS integration and routine maintenance.

Open OTLs Import Function*:* An import function would be used to periodically pull updates to open-standard OTLs. This import function would allow the content in an CBTL to remain consistent with the content in open-standard libraries from SDOs like bSI, OGC, and W3C. The import function could be designed such that it could pull in the version history of schemas.

Object Types, Object Properties (Attributes), and Property Sets Content Management Function: State DOTs manage different properties (attributes) and property sets in their design, construction, and asset management systems corresponding to the different transportation object types. A CBTL would allow agencies to map CBTL object types, attributes, and object-type relationships with the corresponding entities in the national master library (as shown in Figure 6-2).

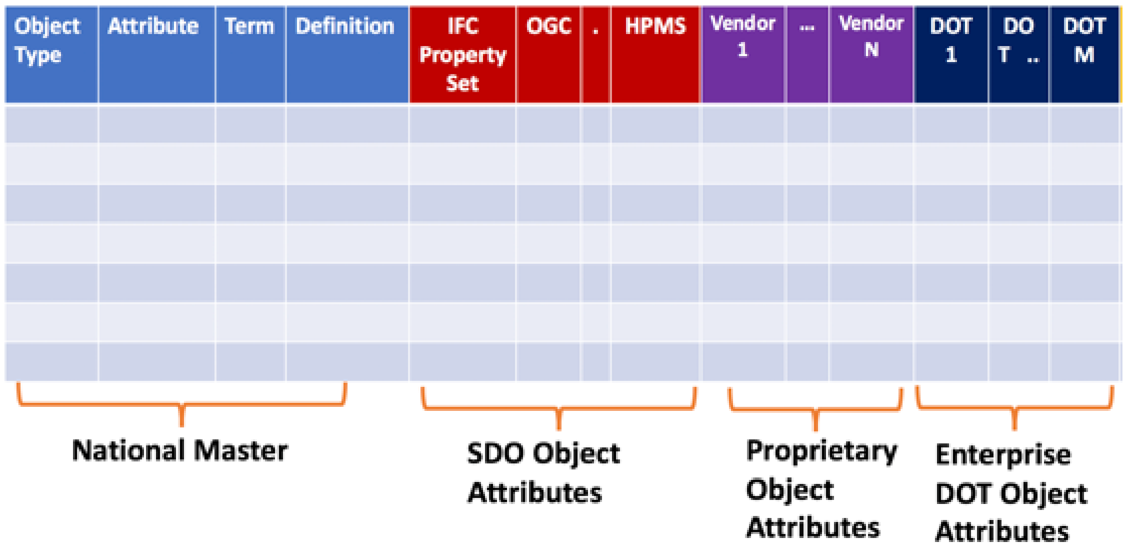


Figure 6-2. Illustration. Managing library of centralized BIM transportation library object types and their mapping to open, proprietary, and agency OTLs, terms, definitions, and information exchange specifications.

ILSs Content Management Function: A CBTL would allow flagging of high-value object types and attributes that are going to be exchanged between various stakeholders and systems. These items would be candidates for development of MVDs or ILSs that may get adopted by various national and international transportation agencies to standardize the publication and sharing of data.

Object Types, Object Properties (Attributes) and Property Sets Version History and Metadata Management Function: As CBTL content is updated, version history and associated version metadata would be recorded automatically and maintained using schema version management repositories. This section outlines the versioning data and metadata that would be managed when CBTL content is updated.

6.3.4 Key Roles and Responsibilities

To perform the functions outlined above and to manage the content in a CBTL, the following roles would be defined and developed within and across the stakeholder agencies, organizations, and groups identified in the previous section.

- **Technical Experts and Admins (Data Model Architects)**
  - U.S. centralized BIM OTL administrator.
  - State DOT BIM OTL administrator or enterprise data dictionary developers.
  - Software industry BIM OTL representative(s), preferably from multiple vendors.

    - SDO(s) - BIM OTL administrator.
    - BIM OTL researchers (academicians and private industry).
    - Data stewards (from federal, State, and local transportation agencies).
    - Roadway design engineers.
    - Bridge design engineers.
    - Asset managers (e.g., bridge, pavement, and traffic and safety assets).
    - Road network data managers (e.g., linear referencing system, HPMS, and ARNOLD managers).
- **Chief Data Officers (Leaders, Policy and Decision-makers)**
    - FHWA data officer.
    - State DOT and local agency data managers.

6.3.5 Centralized BIM Transportation Library Content Development and Maintenance Process

Figure 6-3 presents the anticipated high-level process associated with development and ongoing maintenance of a CBTL. The swim lanes in the process diagram show the potential responsibilities of the various stakeholder groups (as described in the previous sections). The technical experts (data architects), data stewards, and data officers at these organizations would collaborate to perform these functions. The steps followed within each organization may be different. For example, organizations producing and reviewing CBTL content may wish to organize the content contributors by business group and assign permissions to contributors to edit or view content internally and externally. Rather than one centralized library, it may make sense for States, regions, or ad hoc groups to collaborate on library content separately, and commonalities may be found over time and integrated into a centralized library. This approach does not necessarily reflect technical issues but rather recognizes the motivation of different stakeholders to collaborate to find commonalities in which to combine similar definitions and compromise as needed. For example, there could be cross sections of parapets that slightly differ among stakeholders that could be merged to support some or all features of similar designs. Irrespective of how the individual stakeholder organizations organize themselves, at a high level, the steps that would likely be performed by each group are shown in Figure 6-3.

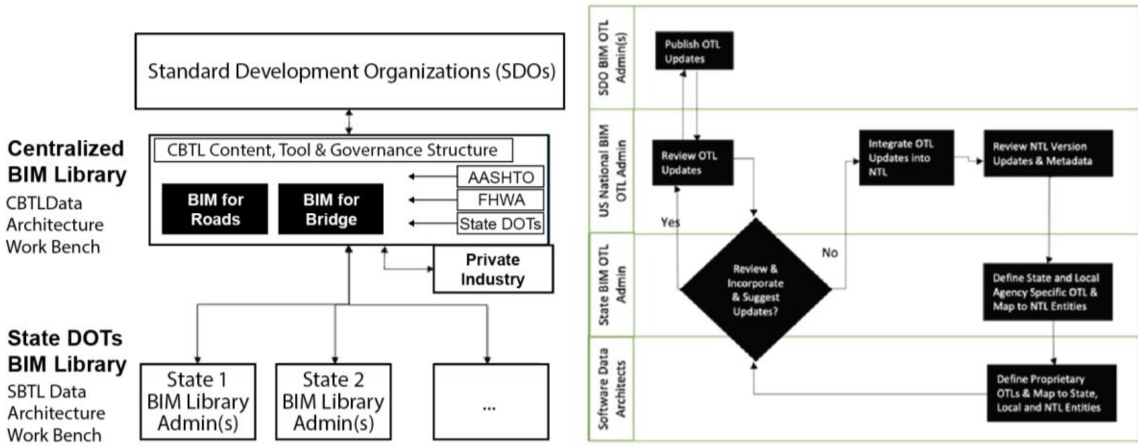


Figure 6-3. Flowchart. High-level centralized BIM transportation library content management process.

As discussed in previous sections, CBTL content development would start with identifying and comparing OTL entities published by SDOs. Centralized BIM administrators would review these OTL entities. The centralized BIM administrators may be sitting either in a dedicated BIM organization or working group that is established at the national level, or they may come from various organizations that have come together as part of the national initiative on BIM (e.g., pooled fund groups). The primary responsibility of this group would be to develop and review updates to CBTL content. The updates may come from SDOs who publish new versions of their OTLs periodically, or they may come from the national BIM group based on the group's processes associated with identification, definition, and further development of CBTL content. The national BIM group would have representatives from all stakeholder groups (i.e., State agencies, software vendors, contractors) who would coordinate within their respective agencies to perform a detailed review of CBTL updates. If these stakeholder groups decide to accept the CBTL updates, those changes would be integrated and formally incorporated into a CBTL (with version history managed by using tools). If updates are discussed further, including providing feedback to SDOs, then the national BIM OTL administrators would facilitate such back and forth review and editing processes. Once the updates have been integrated officially into a CBTL, State and vendor groups would review the final version updates. They may decide to incorporate all or some CBTL entities into the definition of their respective OTLs. At this stage, they may propose creating new object-type attributes (e.g., IFC property sets) and may table them for review by all stakeholders.

6.4 ESTABLISH CENTRALIZED BIM TRANSPORTATION LIBRARY DATABASE

6.4.2 Database Purpose

A CBTL database would serve as one part utility mechanism and one part reference repository to compile and curate all associated artifacts. This database would act as a clearinghouse with the capability to ingest terms, definitions, object types, taxonomy, and the full range of corresponding meta descriptors within the constituent library. As a principal component of the database, human-interpretable and meaningfully descriptive text information would supplement all definitions. An element within the data dictionary would be given an unconstrainted free-form textual annotation, including key phrases, subject tags, and references. The text content would add detailed context and clarity to a particular data structure, property, or relationship and support the full-text and semantic search engines used to intelligently cross-reference similar data elements, regardless of their definition, origin, or specification. Administrative roles, capabilities, restrictions, activity, and collaboration supports would be included as part of a CBTL database focused on the necessary utility components. Authoring, ingestion, and management of all CBTL information assets would be managed through this dedicated channel.

6.4.3 Segmentation by Product or Specification

CBTL BIM artifacts would be a true composite of multiple disparate contributions where each may be tailored to a distinct purpose, a subcomponent of a larger portfolio, or the initial crystallization of an open or consortium specification. Within a CBTL database hierarchy, the definition source would be appropriately segmented accordingly to enforce the clear delineation of its underlying model(s) from other distinct quantities. A full inventory of resources drawing from currently adopted or popular candidates would reside distinctly in tandem. Traversing data definition components, object types, and relational hierarchies would become simple and familiar even when the artifacts may fundamentally differ in their applied usage. The resources described in Table 5-14 illustrate the spectrum of identified potential CBTL sources. Again, each would be distinctly segmented according to its associated information. However, using the foundation capabilities in a CBTL database, it would then be possible to search and resolve results concerning the data definition(s) across all entries.

6.4.4 Scaffolding and Application Management

A CBTL database would store information attributed to three main tiers. Primarily, the database would organize, structure, extend, and annotate every functional or practical aspect necessary to replicate or generate a metadata repository of BIM artifacts. The scaffolding to capture the database structures, relationships, data types, constraints, and expressions would be robust. Secondarily, a CBTL would outline a lightweight but essential application management layer to allow the administration of the data dictionary contents as well as the simple necessities often found in a more general-use content or digital asset management. Finally, the ability to collaborate, discuss, contribute, and selectively extract components would extend the application features concerns. This would differ from the administrative-controlled and more restricted scenarios and focus on the non-administrator roles that still benefit from the dynamic capabilities of a living repository.

6.4.5 Features

Significant features could be derived from the CBTL database resource. As identified and referenced in other current domestic and international initiatives, contemporary methods that have been historically reserved for software development practitioners are now widely used to manage schema definitions and similar libraries. The crossover utility and popularity in adoption reinforces a good fit solution in this space. However, given the broad audience and stakeholders to a CBTL, it is also necessary to lower the barrier to technological access while still leveraging the most appropriate platforms. The CBTL database would bridge the technological platform gap in that regard and add its own extended benefits. The ability to compose, revise, author, and review contributions, and then publish to a version-controlled archive with no prior familiarity with version control systems dramatically increases the CBTL reach. Along the same lines, having a CBTL's full data dictionary inventory from which to draw, non-administrator users can formulate and construct their own unique schemas. These may be completely compiled from CBTL-curated sources, they may be purely self-authored (controlled as such), or they may exist as a hybrid for the purposes of extensibility. Regardless of the modality, the same publishing, generation, collaboration, and reference utilities would be equally exposed.

6.4.6 Collaboration Support

As part of the application tier for the CBTL database, fundamental aspects are defined for simple but powerful collaboration. The ability to share, reference, annotate, discuss, search, and review contents is intrinsic to the underlying design. Furthermore, consideration has been given to currently deployed (commercial) collaboration platforms to achieve straightforward interconnection. Holistically, a CBTL would accommodate and address an exceptionally varied audience with equally varied productivity and communications tooling. As such, the collaboration would establish a near universal foundation that is as easy as email for the common denominator. That would then be translated to an open capability framework that would suit modern plug-in capabilities. In addition, an opportunity exists to interconnect CBTL collaboration aspects into dedicated work processes, native to the tooling in which they apply.

6.5 ESTABLISH CENTRALIZED BIM TRANSPORTATION LIBRARY VERSION-CONTROLLED SCHEMA GENERATION WITH ADMINISTRATOR CONTROLS

6.5.2 Content Management

The CBTL database would contain all descriptive elements to extract, format, generate, and annotate a formal data schema (definition) to a target convention with consideration to versioned and active modifications. Although version control systems and their core uses can be generalized, the specific CBTL management of schema definition elements would allow a fully reversible operating means to ingest or generate the discrete pieces contained within a version-controlled hierarchy. In most cases, version control systems would parse and partition a complete schema model into a discrete set of folder and file structures to achieve individual change management at the most appropriate level of granularity. However, this commonplace approach would not be universally strict. Even if the modeling definition language or convention were the same, how the elements would be split and organized for version control may not be. To further complicate navigating potentially intricate mapping to folders and files, subtle elements defining hierarchical dependencies may be contained in the structuring but less easily resolved in the file contents themselves. The content within a CBTL would be stored to facilitate and regiment assets to avoid those precise predicaments due to variability in version control methods. Ingesting an external definition would be brought into a CBTL uniformly. The expectation would be to periodically update, refresh, or synchronize the externally managed definition (from its resident, presumably public, version control repository) as compared to activating the manual editing of required changes. Administrators would have the ability and desire to reference that externally defined scaffolding and then author through extension, composition, or both a derivative work to suit their needs. As an example, an external definition may fully express a hierarchical framework with object types or limited property assignment options. The CBTL would allow the hybridization and active refinement of the hierarchical starting point with a completely different OTL or property set (source). That hybrid result could then be used to generate the same outputs to commit to a version control system.

6.5.3 Admin Segmentation

As part of the CBTL, supplemental and application-oriented resources would be formally segmented for controlled administration. The control of those components would allow for simple access usage restrictions as well as more sophisticated permissions definition. For example, a conceptual work in progress may not be suitable for discovery in the search (CBTL database) engine until a particular checkpoint is reached or specific flag is set. There may also be more nuanced operational restrictions, applied rules, or the effective deployment of contingent terms of use that the CBTL administrative outline would deal with explicitly. Administrators would have elevated rights against a segmented or dedicated constituent in a CBTL—OTL, MVD, data dictionary, and the like. The administrative responsibility would be a role that is suitable to assign and delegate to more than one individual and would apply to the target-managed CBTL content. This permission model and role concept would be simple and extensible.

6.5.4 Collaborative Supports

The ability to review, comment, compare, revise, revert, and finalize would all be basic collaborative functions associated with formulating content within a CBTL. Administrative collaboration would focus on determining which elements or (sub) portions of a CBTL resident content would be suitable for dissemination. Progressive changes to annotations and what would otherwise be seen as non-functional impacts to the CBTL content would be important in a review or revision process. Feedback from stakeholders who are subject matter experts and those using a CBTL who want to provide a wish list request are valid drivers in that same regard. The feedback and revision process can be incorporated but is not required as a soft-gate check prior to finalization under the collaborative umbrella in a CBTL. The same data storage and repository that contains the CBTL assets would also contain the information accumulated through the process in the form of discussion elements, mark up, notes, and commentary.

6.5.5 Non-Administrator Capabilities

The data, processes, controls, and features employed by administrative delegates may have to be different from the capabilities that are made available to non-administrative users of a CBTL. Such decisions on admin and non-admin capabilities would have to be made for the CBTL database and content management functions. For example, different capabilities would have to be configured and correspond to oversight scope and asset control over CBTL governance-compliant content meant for sanctioned-only stewardship. Short of the permissions and privilege differences, a non-administrator would fully employ the utility and CBTL feature suite as seen by an acting admin. In this role, the same data definition “shopping cart” of CBTL content and composition options are presented in the same fashion. Non-admin generated content would be managed by the creator with the optional ability to assign, delegate, or permission accordingly.

Collaboration in this case would also be the same. This framework would align to a CBTL and expand accessibility and utility to an increased stakeholder audience.

6.5.6 Schema Generation and Version Control

Leveraging the administrative and non-administrative content created within a CBTL, the methodology would generate consistent outputs ideally formatted to commit to a version control platform. The automation of that process and the data modeling-centric authoring, especially for those not familiar with version control, would eliminate a formidable barrier that prevents disseminating a valuable information asset on a national or international scale. Automation of version control would contribute to the visibility of the asset(s) and accelerate the potential evolutionary extension as a result. As content in the CBTL database is built out, all the prerequisite attributes, details, relationships, descriptions, and dependencies would be included through explicit definition or automatic deduction based on how the assembly was conducted. Leveraging that collected, tracked, defined, and stored information, the CBTL database and utility component would parse and generate the desired schema output. That output as folders and files would adhere to a naming and structure convention suited to the version control upload format. Secondarily, a single output could also be generated to allow for specialized tools that cannot effectively parse the folder file structure for its purposes. The version control contexts and (broad) tooling supports would be formatted output channels for schema generation of CBTL content. Figure 6-4 illustrates how the different stakeholders would operate in a version-controlled environment to develop CBTL content, such as the national OTLs and data dictionaries. This example shows how an CBTL administrator could consolidate various OTLs and data dictionaries (as demonstrated in Figure 4-7) and publish a new version of the national OTL and data dictionary. The SBTL administrators, software vendors, and other industry participants could contribute to the version engineered by an CBTL administrator, and the contributions could be accepted by an CBTL administrator(s) as part of a collaborative and systematic process for national OTL development. Figure 6-5 illustrates how these different actors would use the version control system to manage and integrate their respective versions.

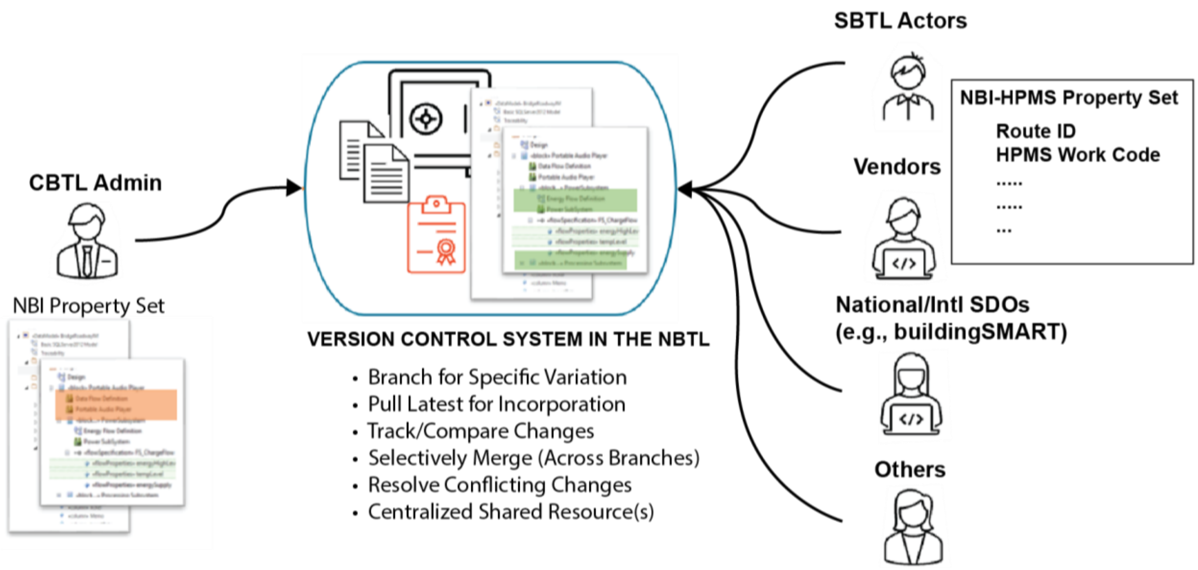


Figure 6-4. Illustration. Centralized BIM Transportation Library editing using version control system.

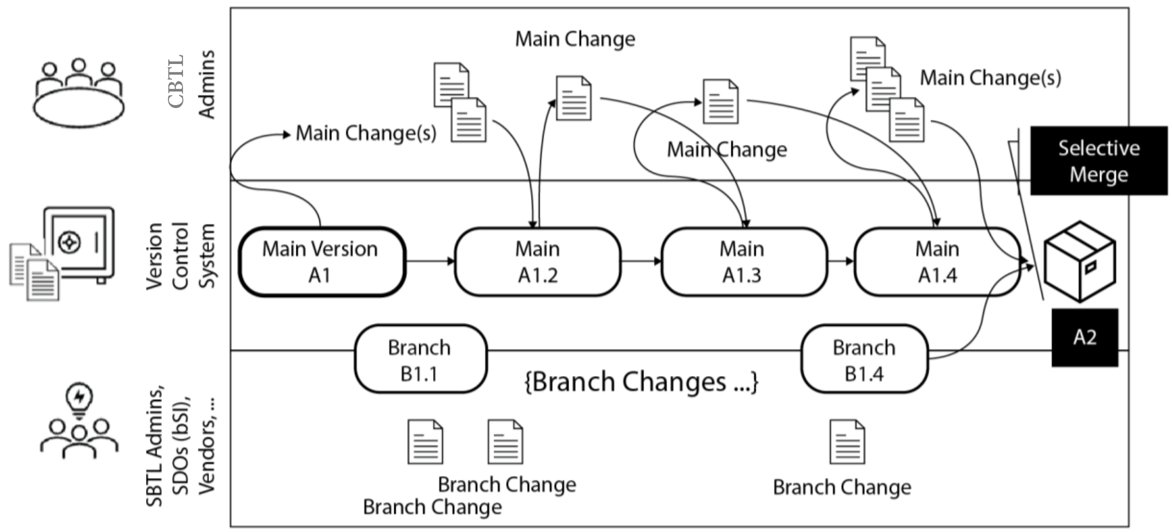


Figure 6-5. Illustration. Collaborative version editing process for national BIM transportation library contribution.

6.6 ESTABLISH APPLICATION PROGRAMMING INTERFACE FOR CENTRALIZED BIM TRANSPORTATION LIBRARY COLLABORATION

6.6.2 Content Application Programming Interface

The CBTL database containing content schema, object type, and hierarchical and supporting information would be the principal source used in all supporting capabilities. The ability to expose, manage, and manipulate those data would be paramount to the goals identified for an CBTL. As such, in addition to fully qualified management tools or the use of familiar methods (a dedicated portal or similar), it would also be important to extend those same fundamental operations in an open, but not public, platform. As a companion to the database, a matching API using the OpenAPI specification would be a core component to an CBTL to access the data in the database. The standard operations for administrators, non-administrators, stakeholders, and a near limitless number of utility automation scenarios would be delivered through the CBTL API. The same basic ability to search data dictionary definitions or to generate outputs suitable to use in a version control system are examples of the functionality achieved with the CBTL API. Although the API operational capabilities expose virtually all CBTL assets, it would not circumvent the processes or access gate checks defined during its use. The CBTL data dictionary API would be an interoperation, integration, and automation extension with the end goal of eliminating what would otherwise be manual or cumbersome tasks. This applies to collaboration, data modeling, research, or analyses that would involve often repetitive steps. Additionally, most modern technologies platform integrations are predicated on the use of similar API frameworks as the systems access channel.

6.6.3 Generating Full Application Programming Interface Scaffolding from Centralized BIM Transportation Library Metadata Repository Content

In the same capacity that full schema, object type, and other data definition centric outputs could be automatically generated from CBTL content, more functional aspects would be just as easily achieved. The recurring themes addressed in the CBTL would allow a low-friction translation from data design modeling concepts to fully realized systems with API utility taking center stage. Once an entry within the outlined CBTL reaches an appropriate referencing point, the same methods that would be expressed in generating outputs for version control submissions would also be extensible and adept in producing matching APIs definitions. These definitions would garner great value as a tangible reference artifact; however, they would be easily converted into actual application solution starting points by a variety of toolsets.

Furthermore, given the open specification from which the API definitions are founded, the tool suites used therein would be familiar, equally well-adopted, and in many cases part of much larger open-source or no-cost initiatives. Once composed, the API definitions generated by the CBTL would be viable for creating functional data services, and they would be the standard basis to register, expose, and orchestrate the availability of said data service. An OpenAPI specification-compliant definition could be used in an integration capacity—integration platform as a service (iPaaS)—to accelerate delivery and dramatically reduce infrastructure complexity.

The CBTL would plot a start-to-finish, concept-to-consumption ideation catalyst collaborative framework. One of the primary potential outputs, in the form of an API definition, may then be leveraged for later registration as part of a greater portfolio of agency-empowering data services. This may align to a greater cross-agency adoption of conventions and shared-interest standardizations, or it may simply be an execution incubator that lowers barriers to entry that would otherwise stymie an agency acting alone. In all cases, the collective collaboration, and new avenues to go from concept to sanctioned delivery present bold new innovation opportunities.

6.6.4 Application Programming Interface Management Platform

The ability to operate, monitor, govern, and control an open API resource that would be publicly accessible but not open to the public would be a non-trivial matter. As such, the API framework and delivery mechanisms for an CBTL would include the detailed and comprehensive guidelines to achieve a real-world system. As such and affirmed by the state of similar industry practices, an API management platform would be deployed to achieve and offload the most challenging infrastructure and operational concerns. This architectural framework would distinctly separate functional concerns that dictate the capabilities achieved in the API from the governance and operational requirements. That distinction would help to the ensure the separation of not only conceptual concerns but also separation of delivery responsibilities. Furthermore, supplemental components to support the distribution, adoption, and visibility of the CBTL API (as an offering) would be tied to the same API management platform. Many of the common logistical tasks in commissioning a viable API service would be addressed through the implementation of a management platform. The API management platform, as the name suggests, would be a combination of infrastructure, operational monitoring, controls, and access management that would be tailored to API delivery within a service environment.

6.6.5 Application Programming Interface Access Process

The CBTL API would be based on open specifications and publicly accessible. However, the resource would be fully controlled, capable of enforcing governance policies, and would be not open to the public. The difference in the designation of publicly accessible but not open to the public would be that the CBTL API could be accessed via any standard internet-connected means, but the access to the functionality, data, and capabilities would be preconditioned on the resolution of an identity with permissions assigned to that identity. In the simplest of terms, the CBTL API would be available over the internet without any specific network controls, VPN, or intermediary. However, it would not be available to access anonymously. As such, a flexible streamlined registration and identification process would be part of the steps in gaining access to the CBTL API. The API management platform would be beneficial here as well. The registration, minimal threshold identification, and potential extension of controls would all be achieved within the API management platform. Access grants and revocation would occur using the API management platform that would be aligned to formal compliance, governance, and better-practices guidance.

6.6.6 Exploring the Application Programming Interface Capabilities

The exposure and management of the CBTL API would be only an initial starting point. As a matter of practicality and onboarding, the basics support to explore, understand, and test the CBTL API would require attention. Again, the API management platform would offload the simple content management of reference material, static portal-equivalent content, and the prototyping-suitable constructs as part of its basic features set. Using the platform-provided starting points, administrators, non-administrators, and anyone who would create dependent applications or integrations that consume the API could conduct a self-directed exercise to investigate the API.

6.6.7 Using and Integrating the Capabilities

The OpenAPI specification for the CBTL API would be the most supported modern API technology in terms of functional adoption, productivity tools, and publicly published reference materials. In addition to the simple interactive prototyping aspects built into the discussed API management platform, application vendors would provide OpenAPI tools at varying licensing cost and no-cost levels. There would be ample supports to quickly cultivate benefits from the CBTL API. Furthermore, by leveraging the shared and common foundations, a community of practice would undoubtedly grow around CBTL resources and specifically around the API therein.

6.7 CENTRALIZED BIM TRANSPORTATION LIBRARY COMMUNITY PORTAL

6.7.2 Centralized BIM Transportation Library Application Programming Interface and Community Portal Overview

The CBTL API portal (Figure 6-6) would be the destination hub for much of the CBTL reference material and the starting point to gain the more complete API access. The API portal would be intended as a community, developer, integrator, stakeholder, and generalized API consumer destination. The public-facing aspects of the CBTL would naturally be compiled for dissemination at this point. Additionally, alignment to other such information resources would extend the broader set of goals in both content and context. That overarching umbrella of resources would be provided with simplicity through the CBTL API portal.

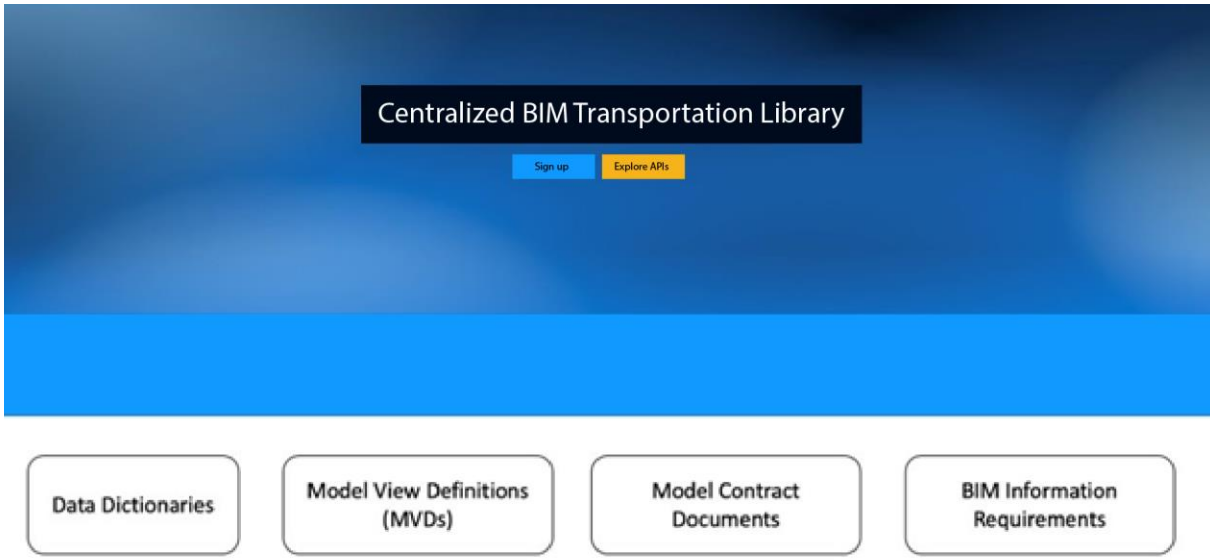


Figure 6-6. Screenshot. Centralized BIM transportation library application programming interface portal example site.

6.7.3 Content

To support a diverse audience and the associated diverse areas of practice or interest focus, a full spectrum of CBTL-related documents, articles, references, and media would all reside within the portal. These materials would be subject to archival, updates, periodic distribution, and equivalent distributions. The content formatting and concepts would align to both the evolving technical and communication goals established against CBTL objectives.

6.7.4 Community

A vibrant, contributing, and active community of practitioners, stakeholders, and end-usage beneficiaries would be critical to achieve a platform of innovation. Again, as a central hub, community activity and the corresponding presence surface area for the CBTL would be derived from the portal information resources.

6.7.5 Collaboration

As the proverbial basecamp, the collaboration features would be included as part of the portal aspects. As the de facto starting and consolidation point, the collaboration channels, moderation, and catalysts would branch from the portal destination.

6.7.6 Support

A robust end-user support infrastructure and staff resources will be necessary to operationalize the CBTL. This may include anything from simple frequently asked questions regarding everything from navigation of the outlined portal site to more deeply technical focused queries in implementing CBTL (data) aspects via the reference API. In all cases, the portal destination would also serve as the end-usage support gateway.

6.7.7 Summary

Development, deployment, and subsequent administration of a CBTL are expected to involve multiple stakeholders. This chapter begins with a description of the envisioned CBTL management process and the agencies (people) that would likely be involved in the process from across all sectors. Anticipated roles and responsibilities of these stakeholders are defined, including key roles such as CBTL administrators, and users are provided an account of how the BIM artifacts in a CBTL could be managed in a CBTL database and provisioned via APIs and a collaboration portal to various stakeholders. The management of the CBTL content in a version-controlled hub environment is also discussed. Such architecture for management of BIM data dictionary would be already in place by bSI. Therefore, the CBTL architecture, development, and administration approach presented in this chapter would already be a proven concept in the industry.

CHAPTER 7. SUMMARY AND RECOMMENDATIONS

7.1 SUMMARY

This research investigated 10 traditional data and process workflows that commonly occur during the project lifecycle (from planning to operation and maintenance) to explore the potential to convert them to BIM-based workflows to help State DOTs and their construction supply-chain partners gain attendant efficiencies and productivity. These 10 workflows—deemed to provide the greatest near-term benefits from a BIM implementation standpoint—were prioritized from among dozens of others that arose during workshops held as part of this research. BIM considerations for these workflows involved modeling the data created during each workflow by using open standards in a more structured and systematic manner compared to traditional workflows to enable easier extraction, transformation, and exchange of these data with other enterprise data users and systems. The 10 workflows investigated for BIM process adoption were as follows:

1. Establish project scoping documents for design engineers from planning data.
2. Create visualizations for alternatives evaluation and public outreach.
3. Provide data for interdisciplinary coordination during design.
4. Develop final structural analysis.
5. Produce final plans and model as legal documents.
6. Create detailed QTO and estimate.
7. Provide design information for AMG.
8. Develop and review shop drawings and models.
9. Verify construction results and record as-built data.
10. Provide routine bridge inspection data for asset management.

These workflows, except for Workflows 8 and 10, apply to bridges and roadways. The investigation involved analyzing each of these processes from three perspectives:

- Data modeling involved an assessment to determine:
    - Would the content created and captured in the (data) model during the business process meet the requirements of the owner organization and the pertinent business stakeholders?
    - Would data be captured in an interoperable form and format in the data model?
    - Would the data model adhere to an open or proprietary data standard that would ensure data model interoperability?

    - Would the data model have the right LOD (i.e., the right level of detail from the perspective of business stakeholders) and the right level of information (i.e., would captured data be comprehensive and complete)?
- Data management focused on assessing:
    - Would the data captured in a model during the information transaction process adhere to the data content and quality standards established at the agency level?
    - Would the organization have a reliable, potentially automated, and repeatable way to store, extract, transform, and provide data in the model that would be created during the business process?
- Data use was assessed to make the following assessments:
    - Were the downstream processes and business stakeholders that would use the data identified?
    - Would the stakeholders use data captured in the model in the identified business processes?

Even though some of the workflows are more mature than the others in terms of current state of practice, all 10 workflows were found lacking from the perspective of comprehensive data modeling, data management, and data use. The following key issues were identified from the perspective of these criteria:

- During assessment of data modeling practices, the research team found that the data being modeled during the process were being created to meet the needs of only a limited number of stakeholders—notably those immediately downstream from the lifecycle stage where the data would be created. For example, design data models were being created to meet the needs of a limited number of construction stakeholders. For data models created in the construction process, the research team found that the data requirements were not being met from the perspective of asset inventory managers. In some cases, data modeling using BIM-based processes is virtually non-existent (e.g., planning data handoff to design [existing site conditions, inventory, topography, etc.]). In fact, the information requirements from the perspective of all the users or stakeholders are not even being captured at each lifecycle stage during model creation. The data captured in the models are also not being captured and stored for easy exchange and delivery to stakeholders. Most design and construction data modeling processes capture a large volume of data in semi-structured or unstructured format even when data from these models needed to be exchanged (i.e., in the form of images, text, and documents with little to no metadata) making it difficult to extract data for delivery to other enterprise users.
- The assessment of data management practices revealed that data quality assessments are not done consistently across applications, and in many cases the focus of the data quality assessment is limited to certain key requirements and needs or user requirements. Data were also not being shared and provisioned using modern techniques and practices, such as through the APIs. In most cases, data exchanges

were being done by delivering files or storage of files to a central repository, and metadata such as data editor, accuracy, precision, resolution were not being captured.

- The data created and captured (i.e., modeled) during several of the business processes, with the notable exception of design coordination, were being used by a limited number of users in the organization. For all the business processes, data modeled were not mapped to stakeholders and business use cases within the organization. Therefore, users were not aware of either how to utilize the data or the presence of data, and in many cases, were unable to extract the data or found the data incomplete and insufficient for use.

To address these issues in the data modeling, data management, and data-use practices across these business processes, certain BIM artifacts could be created at the enterprise level so that these could be used as templates and customized by organizations to meet data governance standards. The following BIM artifacts were found to be essential for operationalizing more efficient and mature BIM processes:

- Information requirements: The requirements for what data needs to be created would be established for each of the business processes and each of the data models created during the business process. These requirements would be established from the perspective of all stakeholders in the organization (i.e., OIRs created for each process and data model).
- OTL and data dictionary: Once the information requirements are identified, data models would be created using the objects and properties in the databases that are associated with each of these requirements. For interoperability of data across applications and data models, it is important to maintain an OTL and data dictionary for all applications in the organization, ensuring that data captured in one model using a certain application can be mapped to data in another model and application, for a given information requirement.
- Information delivery manual: To address issues associated with data management (as outlined above), an IDM would be created that describes what data need to be delivered or provisioned from one business process, data model, and application to another.
- Information exchange specifications: In addition to capturing what data need to be delivered, it is also important to capture the specifications associated with the data that need to be exchanged. That is, for each process and data exchanges associated with it, information about aspects such as the following would be captured in a specifications document: level of detail, level of accuracy, precision, tolerance, data type and any reference data sets that should be utilized.
- Model view definitions: Definitions of the different subsets of a data model that are being shared with stakeholders would be defined and managed in the form of implementable, templatized, and automated tools. Such tools facilitate data exchanges and ensure minimal effort on the part of an agency in terms of establishing standards for data exchange.

These artifacts have also been identified in the BIM NSR (Mallela and Bhargava, 2021). Establishing these artifacts can ensure better data management across the different business processes, data models, and applications in an enterprise, which in turn would have a direct impact on the maturity of BIM deployment at an agency.

To develop and administer these BIM artifacts, the need for building a CBTL was established. The concept and vision for CBTL as a repository that would be used to maintain open standards-based BIM artifacts in a version-controlled environment was presented. The CBTL could hold information about the previously references BIM artifacts that have been established as templates at the national level for use by any transportation agency. The library could also be used to manage customizations of these artifacts that would be created by a State DOT or a public, academic, or private-sector agency that would choose to share these artifacts for use by others. It was also established that a CBTL could be used to store these BIM artifacts from international transportation agencies or standard development organizations. Example CBTL from other countries were presented, and the requirements for building a U.S. CBTL were presented. Additionally, an architecture for a CBTL was developed based on the metadata model that would be recommended for such libraries in The Open Group Architecture Framework. Deployment of such an open standards-based repository at the national level would be key to ensuring that stakeholders in the public and private sectors, including BIM SDOs and transportation organizations at the regional, State, and national levels, could use the content in the repository and contribute to its development. In addition to a CBTL, the concept and vision to deploy an SBTL was presented, to recognize that State DOTs would likely use the metamodel architecture and content of a CBTL to develop, catalog, and manage their respective State-specific versions of the BIM artifacts to enable State-specific BIM workflows.

A prototype of CBTL was developed using one of the artifacts in a CBTL (i.e., the data dictionary). To develop this prototype, an open-standard library from one of the SDOs—the bSI bSDD—was used. It was noted that any SDO's data dictionary could have been used as the starting point for establishing a CBTL data dictionary, and the bSDD was used only for demonstration and prototyping. Further, it was shown how data dictionaries from other national performance management databases (e.g., HPMS) or roadway and traffic data inventory guidance (e.g., MIRE) could be used in addition to the bSDD to create an integrated, multiple standards-based national data dictionary. The OTLs and data dictionaries in a CBTL could be classified based on the type of content in the library. Four types of OTL and data dictionary categories were described: languages, definitions, content, and software.

7.2 SUGGESTED IMPLEMENTATION PLAN

A plan to develop and implement BIM-based workflows and a CBTL from a practitioner's perspective is essential as a wayfinding tool to stitch together the multiple BIM related developments that take place simultaneously in the U.S. and to create a repository and governance for the various BIM artifacts being developed. Chapter 6 presents such an implementation plan by describing the activities needed to develop detailed BIM business process workflows, develop BIM artifacts, and implement a CBTL. The plan would consider the findings from the investigation of the BIM business processes, the need for creating foundational BIM artifacts at national level, and the need to deploy a CBTL to manage the BIM artifacts. The activities included in the plan align with the recommendations in the NSR for advancing BIM for Infrastructure implementation in the U.S. The following activities are included in this plan:

1. Establish a centralized BIM program and U.S. stakeholder group to direct the program.

This activity would involve connecting the various existing and planned national BIM initiatives and creating a national BIM program. A U.S. stakeholder group could be formed to monitor the national BIM program.

The FHWA, AASHTO and States are leading multiple BIM initiatives. The BIM pooled fund efforts TPF-5(372) and TPF-5(480) in association with bSUSA are creating a data dictionary to be hosted in bSI's bsDD and coordinating with AASHTO, FHWA, the Open geospatial consortium, and other data modeling and exchange standard development organizations. These efforts have unique as well as overlapping scopes and deliverables. It would be helpful to create a national U.S. stakeholder group to administer and oversee a national nonregulatory BIM program that integrates, authorizes, supports, and aligns all BIM-related efforts at the national level.[9]

2. Develop national BIM program and projects portfolio.

A national nonregulatory BIM program should review the different types of projects, the requirements for BIM from the perspective of various highway infrastructure assets, and existing state of practice and state-of-research to develop a national BIM program charter. The charter could lay out the following:

- Criteria for selection, scoping, and definition of BIM projects.
- Deliverables, milestones, and performance metrics.
- Roles and responsibilities of the various stakeholder groups and administrators.
- BIM coordination and communication in the U.S.
- Scope and vision of BIM and a roadmap that can be used to accomplish the vision.
- Risks, challenges, and mitigation strategies.
- References to national BIM website(s), marketing, and training collateral.

3. Develop a BIM workforce training program.

Developing a workforce training and certification program at the national level could be key to enabling and aligning the various BIM experts currently engaged in leading the BIM initiatives or looking to help their organizations to deploy BIM workflows. The industry could align terms and definitions and specific standards that need to be used for development of digital data models, and to exchange data across data models in various authoritative systems. A national multi-module BIM training program designed to meet the needs of different stakeholders would be needed. Such a program could be built on the recognition that BIM is not limited to survey,

[9] FHWA is not committed to creating such a group or requiring the creation of such a group.

design, and construction and that BIM involves better information management that requires better data modeling, data integration, data engineering, etc. Such a program would therefore be designed for leaders at State DOTs, civil engineers (structural, roadway, pavement, utility, etc.), as well as managers of the data programs (chief information officer, chief data officer, data governance council etc.). A training curriculum that has dedicated courses to address the needs of all these stakeholders would be developed.

4. Execute pilot projects to develop national BIM artifacts.

The BIM artifacts that were identified in Chapter 3 of this research report could be developed iteratively and incrementally as part of the pilot projects. These pilots were introduced as “early” pilots, “extension” pilots, and “mainstream” pilots in the BIM NSR. The pilots could allow for development of BIM processes, policies, tools, technology, data, standards and for execution of BIM capacity-building pilots. As part of the pilots, an assessment of their impact on the maturity of BIM data and process flows should be done as the BIM artifacts are developed and implemented.

The following BIM artifacts would be developed and implemented as part of the pilots (see Figure 7-1):

- Develop requirements for implementing BIM projects.
- Develop catalog of information model requirements.
- Develop national OTL for creating data models.
- Create information delivery specifications for data exchange between systems.
- Establish project selection criteria for BIM implementation.
- Develop digital model and data to facilitate construction.
- Develop BIM Execution Plan templates.

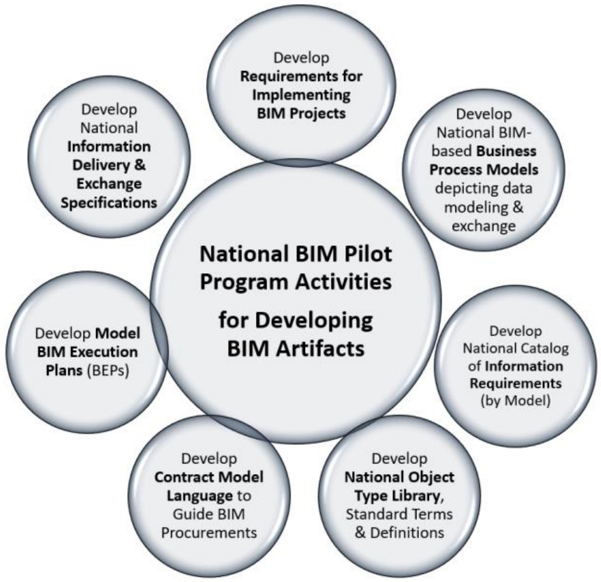


Figure 7-1. Graphic. BIM artifacts recommended for development as part of a national BIM pilot program.

The information requirements, IDMs, and exchange specifications would be created for each of the business processes in the BIM framework. In addition to creating a national version of these BIM artifacts, each State could create a State-specific version based on their business process requirements. The National and State-specific information requirements, OTLs, and data dictionaries would be used to create business process specific data modeling requirement and information delivery specifications.

The BIM NSR activities associated with organizational setup, workforce training, and policies associated with deploying BIM would also be executed to ensure that other elements associated with deploying BIM-enabled processes are being implemented.

5. Develop and deploy a CBTL for hosting BIM artifacts and for BIM administration.

The execution of activities in the BIM NSR would generate several BIM artifacts that would be created at the national and State levels. To manage these artifacts and ensure that a storage repository would be available when they are ready, the activities associated with setting up a CBTL could be initiated and executed simultaneously with the BIM NSR activities. After implementing a CBTL, the following activities should be considered for its development, deployment, and administration:

- ***Establish people and process requirements for a CBTL*:** This activity would involve identifying CBTL stakeholders, roles, and responsibilities and coordinating with these stakeholders to establish and firm up the requirements associated with managing the BIM artifacts using a CBTL. The stakeholders would include U.S. national and standards development organizations, as well as international standards development organizations. Discussions on how different versions of the various national and international standards and artifacts would be used to create CBTL BIM artifacts would be between stakeholders to ensure buy-in into the metadata content management process and functions, as well as the metadata management repositories.

The end would be to ensure that all stakeholders buy into the concept and vision of a CBTL as presented in this research. Modifications and suggested improvements to CBTL scope, vision, implementation approach would be incorporated as input into the research work products from this study to update CBTL information presented in this study and release a version that has been validated and agreed by all stakeholders.

- ***Establish a CBTL database:*** Establishing a CBTL database involves defining the database purpose, architecting the metadata repository based on CBTL BIM artifacts that would be stored in the database, creating a database scaffolding, creating an application management layer, and establishing database administration roles. The goal would be to create a CBTL content metadata repository using open standards such as The Open Group Architecture Framework and ensuring that the fundamental aspects such as the ability to share, reference, annotate, discuss, search are defined for simple but powerful collaboration, during the development of the application tier of a CBTL database.
- ***Establish CBTL administration and enable version-controlled schema generation:*** This activity would establish the administrative roles and privileges for the stakeholders and users of a CBTL. The goal would be to ensure that supplemental and application-oriented supporting qualities and resources are formally segmented for controlled administration. For example, different capabilities may have to be configured for administrators corresponding to CBTL content oversight scope and asset control. A CBTL would also have to be configured to establish how the administrators would collaborate with each other and how they would review, comment, compare, revise, revert, and finalize content in a CBTL to be disseminated. CBTL governance-compliant content may have to be limited to sanctioned-only stewardship. Additionally, a version control system would be deployed for content management as well as for version control and management of the metadata associated with a CBTL database schema. A version control platform would be selected, and permissions would be established to manage who would commit changes, manage versions, and approve content for checking into a CBTL content library.
- ***Establish API for CBTL collaboration*****:** This activity would establish the content for a CBTL API, generating full API scaffolding based on a CBTL metadata repository, establishing the API management platform, defining the API access process, exploring API capabilities, and deploying the capabilities to be used by stakeholders. Technical documentation for CBTL administrators and users would be developed to share information about how the BIM artifacts in a CBTL would be accessed and used through the portal, and how they would be managed in a CBTL database and provisioned via APIs.
- ***Establish CBTL collaboration community portal***: A public-facing API portal would be designed, developed, and deployed to disseminate CBTL content to the community of developers, integrators, data architects, data scientists, data engineers, and other such stakeholders who want to use the API to integrate CBTL content into their products, business processes, or systems. The goal of this activity would be to provision the full spectrum of CBTL-related documents, articles, references, and

media through the portal. The portal would also be designed to be used by non-technical users—particularly the subject matter experts such as bridge and roadway engineers, asset managers, and the various data stewards at a transportation agency who want to use the content for developing agency-specific information requirements, OTLs, data dictionaries, IDMs, exchange specifications, model views, and digital model for construction.

APPENDIX A: GLOSSARY

Business process: Defines and describes the work executed by a group of individuals (internal and external to the transportation agency). This is the highest level that the work can be functionally separated into describing the management of information about highway and bridge infrastructure assets. The tools may include computer software (e.g., CAD software, document management software, databases, spreadsheets); hardware (e.g., GPS-enabled devices, LiDAR, infrared cameras, automated machines); and paper-based tools (hard copy, printed documents). The ultimate objective would be to perform the work required to manage the transportation infrastructure.

Workflow: The details of how work would be executed in sequence by people inside and outside a transportation agency. The steps are described in terms of policies and processes, people and skills, data and standards, and technology and tools. The internal and external resources may include stakeholders such as designers, fabricators, owners, contractors, and inspectors.

Use case: Defines and describes the work done for a specific step or combination of steps within a business process. A business process likely involves multiple use cases. Data can be generated and exchanged to perform a task or achieve a goal. For this project, the term “BIM use case” is used to describe the common functions used in the industry as they relate to BIM processes. Both the current state of practice as well as a future desired state with more mature BIM workflows are described.

Building Information Modeling (BIM): BIM for Infrastructure is a collaborative work method for structuring, managing, and using data and information about transportation assets throughout their lifecycle. The collaborative work involves creating digital data models or information models of infrastructure assets using open or proprietary data modeling standards. The models are created using open-source and proprietary software tools, and data are created and updated in the models using both software and hardware devices. The people involved in the collaborative process include internal agency resources as well as external contractors and data vendors. The software and hardware tools are developed by software vendors and the transportation agencies themselves. Business processes and workflows describe how the data are modeled and exchanged between the systems. BIM also involves creating upfront policies so that guidelines can be provided to the people involved in creating and exchanging the data models.

Data Model: Data models are used to represent the structure and relationships of data elements that describe the real world. Data elements refer to the attributes or properties of highway infrastructure assets. The attributes can be graphical or non-graphical. The dimensionality of a data model determines the type of asset data that is captured in the model. 2D/3D models contain data elements that represent asset design and geometry (in 2D/3D); 4D models contain asset construction and maintenance scheduling data elements; 5D models contain detailed quantity and cost of asset and its components; and 6D models contain data elements associated with lifecycle of asset and its components.

Model View Definition (MVD): bSI defines an MVD as a subset of the overall IFC schema to describe data exchange for a specific use or workflow, narrowing the scope depending on the need of the receiver. It defines a subset of the IFC schema that would be needed to satisfy one or many exchange requirements such as the design-to-construction exchange in a bridge project (buildingSMART International, 2020).

Data Flow Diagrams: A data flow diagram shows how data move through an information system but does not show program logic or processing steps. A set of data flow diagrams provide a logical model that shows what the system does, not how it does it.

Project Information Model (PIM): The PIM contains information about design and construction aspects of a project or facility. The PIM consists of documents, non-graphical data, and graphical information that define the constructed asset(s).

APPENDIX B: BIM Data Models For Interdisciplinary Coordination

Table B-1: Drainage-hydraulic data model – design interdisciplinary coordination.

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Storm Sewer	Main or Lateral Line or Pipe	NA	NA	NA	X	X	NA	NA	NA
	Culvert	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Inlet	NA	NA	NA	X	X	NA	NA	NA
	Outfall	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Stormwater Pond	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

BIM Model Production Delivery Table or Information Delivery Manual (IDM)

Phases: S=Survey; P=Planning; CD=Conceptual Design; PD=Preliminary Design; DD=Detailed Design; FD=Final Design; C/F=Construction/Fabrication - PIM AM=Asset Management or Operations & Maintenance – AIM; X=Level of Development (LOD) to be Applied; NA=Not Applicable

Notes: See existing conditions survey data model. Other hydraulic and hydrologic data model components can be included and additional components or elements identified.

Table B-2: Geotech data model – design interdisciplinary coordination.

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Drilled Shaft	Location	NA	NA	NA	X	X	NA	NA	NA
	Drilled Shaft Diameter	NA	NA	NA	X	X	NA	NA	NA
	Drilled Shaft Length	NA	NA	NA	X	X	NA	NA	NA
	Drilled Shaft Section	NA	NA	NA	X	X	NA	NA	NA
	Drilled Shaft Elevation	NA	NA	NA	X	X	NA	NA	NA
	Casing Length	NA	NA	NA	X	X	NA	NA	NA
	Rock Socket Diameter	NA	NA	NA	X	X	NA	NA	NA
	Rock Socket Length	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Micropile	Location	NA	NA	NA	X	X	NA	NA	NA
	Pile Elevation	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Augercast Pile	Location	NA	NA	NA	X	X	NA	NA	NA
	Pile Elevation	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Driven Pile	Location	NA	NA	NA	X	X	NA	NA	NA
	Batter	NA	NA	NA	X	X	NA	NA	NA
	Pile Depth	NA	NA	NA	X	X	NA	NA	NA
	Pile Diameter	NA	NA	NA	X	X	NA	NA	NA
	Pile Length	NA	NA	NA	X	X	NA	NA	NA
	Pile Section	NA	NA	NA	X	X	NA	NA	NA
	Pile Width	NA	NA	NA	X	X	NA	NA	NA
	Pile Elevation	NA	NA	NA	X	X	NA	NA	NA
	Encasement	NA	NA	NA	X	X	NA	NA	NA
	Rock Socket Diameter	NA	NA	NA	X	X	NA	NA	NA
	Rock Socket Diameter Length	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Seal Coat or Tremie Seal or Seal Slab	Pile or Seal Coat Location	NA	NA	NA	X	X	NA	NA	NA
	Length	NA	NA	NA	X	X	NA	NA	NA
	Thickness	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Width	NA	NA	NA	X	X	NA	NA	NA
	Design Water Elevation	NA	NA	NA	X	X	NA	NA	NA
Spread Footing	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Cofferdam	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Boring	Soil Boring Location	NA	NA	NA	X	X	NA	NA	NA
	Rock Boring Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

BIM Model Production Delivery Table or Information Delivery Manual (IDM)

Phases: S=Survey; P=Planning; CD=Conceptual Design; PD=Preliminary Design; DD=Detailed Design; FD=Final Design; C/F=Construction or Fabrication - PIM AM=Asset Management or Operations & Maintenance – AIM; X=Level of Development (LOD) to be Applied; NA=Not Applicable

Notes: See also structural data model. Other geotechnical data model components can be included and additional components or elements identified.

Table B-3: Grading or landscaping data model – design interdisciplinary coordination.

Entities	Property Sets	S	P	CD	PD	DD	FD	C/F	AM
DTM Surface	Roadway	NA	NA	NA	X	X	NA	NA	NA
	Ramp	NA	NA	NA	X	X	NA	NA	NA
	Median	NA	NA	NA	X	X	NA	NA	NA
	Intersection	NA	NA	NA	X	X	NA	NA	NA
	Foreslope	NA	NA	NA	X	X	NA	NA	NA
	Backslope	NA	NA	NA	X	X	NA	NA	NA
	Ditch	NA	NA	NA	X	X	NA	NA	NA
	Gore	NA	NA	NA	X	X	NA	NA	NA
	Breaklines	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

BIM Model Production Delivery Table or Information Delivery Manual (IDM)
Phases: S=Survey; P=Planning; CD=Conceptual Design; PD=Preliminary Design; DD=Detailed Design; FD=Final Design; C/F=Construction or Fabrication - PIM AM=Asset Management or Operations & Maintenance - AIM

Notes: See also existing conditions survey data model and pavement model. Other grading or landscaping data model components within the ROW can be included and additional components or elements identified.

Note for all tables: The data models herein exclude temporary elements, fences, environmental, ROW, etc. and these models can be provided as additional data models.

Table B-4: Pavement data model – design interdisciplinary coordination.

Entities	Properties	S	P	CD	PD	DD	FD	C F	AM
Top Course (Finish Grade)	Hot Mix Asphalt (HMA)	NA	NA	NA	X	X	NA	NA	NA
	Concrete	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Compaction	NA	NA	NA	NA	NA	NA	NA	NA
	Machine Control (AMGor Stringless Pavingor Other)	NA	NA	NA	NA	NA	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Base Course (Aggregate Untreated)	Class 6 Road Gravel or Base Stone	NA	NA	NA	X	X	NA	NA	NA
	Class 5- 1½" Stone	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Compaction	NA	NA	NA	NA	NA	NA	NA	NA
	Machine Control (AMG or Other)	NA	NA	NA	NA	NA	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Granular Subbase (Select Backfill)	Class 3/4	NA	NA	NA	X	X	NA	NA	NA
	CA1-1"-3" Shoulder	NA	NA	NA	X	X	NA	NA	NA
	Grade 1/2 3"-6" Gravel Road Base/Soft Subbase	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Compaction	NA	NA	NA	NA	NA	NA	NA	NA
	Machine Control (AMG or Other)	NA	NA	NA	NA	NA	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Subgrade (Engineered Soil)	Cut	NA	NA	NA	X	X	NA	NA	NA
	Fill	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Compaction	NA	NA	NA	NA	NA	NA	NA	NA
	Machine Control (AMG or Other)	NA	NA	NA	NA	NA	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C F	AM
Salvaged Materials	Full-Depth Reclamation (FDR)-Class 7	NA	NA	NA	X	X	NA	NA	NA
	Recycle Asphalt Pavement-Class 7	NA	NA	NA	X	X	NA	NA	NA
	Recycle Concrete Aggregate-Class 7	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Compaction	NA	NA	NA	NA	NA	NA	NA	NA
	Machine Control (AMG or Other)	NA	NA	NA	NA	NA	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Pavement Safety	Rumble Strips	NA	NA	NA	X	X	NA	NA	NA
	Safety Edge	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Paint Striping	Center Line Striping	NA	NA	NA	X	X	NA	NA	NA
	Lane Marking	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

BIM Model Production Delivery Table or Information Delivery Manual (IDM)

Phases: S=Survey; P=Planning; CD=Conceptual Design; PD=Preliminary Design; DD=Detailed Design; FD=Final Design; C/F=Construction or Fabrication - PIM AM=Asset Management/Operations & Maintenance – AIM; X=Level of Development (LOD) to be Applied; NA=Not Applicable

Notes: See also existing conditions survey data model and roadway geometry or corridor data model. Other pavement data model components can be included and additional components or elements identified.

Table B-5: Roadway geometry or corridor data model – design interdisciplinary coordination.

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Roadway Cross Section	Road Width	NA	NA	NA	X	X	NA	NA	NA
	Lane Width and Number	NA	NA	NA	X	X	NA	NA	NA
	Center Line or Reference Line or Edge Line	NA	NA	NA	X	X	NA	NA	NA
	Shoulder	NA	NA	NA	X	X	NA	NA	NA
	Slope	NA	NA	NA	X	X	NA	NA	NA
	Offset	NA	NA	NA	X	X	NA	NA	NA
	Station	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Roadway Horizontal Alignment	Length	NA	NA	NA	X	X	NA	NA	NA
	Line or Center Line or Reference Lines	NA	NA	NA	X	X	NA	NA	NA
	Tangent	NA	NA	NA	X	X	NA	NA	NA
	Circular	NA	NA	NA	X	X	NA	NA	NA
	Spiral	NA	NA	NA	X	X	NA	NA	NA
	Radius	NA	NA	NA	X	X	NA	NA	NA
	Bearing	NA	NA	NA	X	X	NA	NA	NA
	Direction	NA	NA	NA	X	X	NA	NA	NA
	Station	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Roadway Vertical Profile	Length	NA	NA	NA	X	X	NA	NA	NA
	Elevation	NA	NA	NA	X	X	NA	NA	NA
	Grades	NA	NA	NA	X	X	NA	NA	NA
	Grade Line	NA	NA	NA	X	X	NA	NA	NA
	Parabolic	NA	NA	NA	X	X	NA	NA	NA
	Tangent	NA	NA	NA	X	X	NA	NA	NA
	Station	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Median	Raised	NA	NA	NA	X	X	NA	NA	NA
	Painted	NA	NA	NA	X	X	NA	NA	NA
	Flush	NA	NA	NA	X	X	NA	NA	NA
	Closed	NA	NA	NA	X	X	NA	NA	NA
	Depressed	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Sidewalk/Walk	Sidewalk	NA	NA	NA	X	X	NA	NA	NA
	Shared Path	NA	NA	NA	X	X	NA	NA	NA
	Trail	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Curb and Gutter	Vertical Face	NA	NA	NA	X	X	NA	NA	NA
	Rolled Face	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

BIM Model Production Delivery Table/Information Delivery Manual (IDM)

Phases: S=Survey; P=Planning; CD=Conceptual Design; PD=Preliminary Design; DD=Detailed Design; FD=Final Design; C/F=Construction/Fabrication - PIM AM=Asset Management/Operations & Maintenance – AIM; X=Level of Development (LOD) to be Applied; NA=Not Applicable

Notes: See also existing conditions survey data model and pavement data model. Other roadway geometry or corridor data model components can be included and additional elements identified.

Table B-6: Structural data model – design interdisciplinary coordination.

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Bridge Cross Section	Bridge Width	NA	NA	NA	X	X	NA	NA	NA
	Lane Width and Number	NA	NA	NA	X	X	NA	NA	NA
	Center Line, Reference Line or Edge Lines	NA	NA	NA	X	X	NA	NA	NA
	Shoulder	NA	NA	NA	X	X	NA	NA	NA
	Slope	NA	NA	NA	X	X	NA	NA	NA
	Slope	NA	NA	NA	X	X	NA	NA	NA
	Offset	NA	NA	NA	X	X	NA	NA	NA
	Station	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Bridge Horizontal Alignment	Length	NA	NA	NA	X	X	NA	NA	NA
	Line, Center Line or Reference Lines	NA	NA	NA	X	X	NA	NA	NA
	Tangent	NA	NA	NA	X	X	NA	NA	NA
	Circular	NA	NA	NA	X	X	NA	NA	NA
	Spiral	NA	NA	NA	X	X	NA	NA	NA
	Radius	NA	NA	NA	X	X	NA	NA	NA
	Bearing	NA	NA	NA	X	X	NA	NA	NA
	Direction	NA	NA	NA	X	X	NA	NA	NA
	Station	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Bridge Vertical Profile	Length	NA	NA	NA	X	X	NA	NA	NA
	Elevation	NA	NA	NA	X	X	NA	NA	NA
	Grades	NA	NA	NA	X	X	NA	NA	NA
	Line or Grade Line	NA	NA	NA	X	X	NA	NA	NA
	Tangent	NA	NA	NA	X	X	NA	NA	NA
	Parabolic	NA	NA	NA	X	X	NA	NA	NA
	Station	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Bridge Configuration	Clearance	NA	NA	NA	X	X	NA	NA	NA
	Length	NA	NA	NA	X	X	NA	NA	NA
	Span	NA	NA	NA	X	X	NA	NA	NA
Bridge Control	Location	NA	NA	NA	X	X	NA	NA	NA
	Station (Bridge or Pavement or Road Work)	NA	NA	NA	X	X	NA	NA	NA
	Station (Bridge Centerline of Bearings at Abutment or at Pier)	NA	NA	NA	X	X	NA	NA	NA
	Azimuths or Skew Angles or Station (Centerline of Bearings at Abutment/at Pier)	NA	NA	NA	X	X	NA	NA	NA
	Horizontal Curve (Point of Tangency or Radius)	NA	NA	NA	X	X	NA	NA	NA
	Vertical Curve (Point of Tangency or Radius)	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Approach Slabs	Location (Skew Angle or Station)	NA	NA	NA	X	X	NA	NA	NA
	Slab Thickness	NA	NA	NA	X	X	NA	NA	NA
	Joint	NA	NA	NA	X	X	NA	NA	NA
	Protective Sealant	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Sleeper Slabs	Location (Skew Angle or Station)	NA	NA	NA	X	X	NA	NA	NA
	Slab Thickness	NA	NA	NA	X	X	NA	NA	NA
	Joint	NA	NA	NA	X	X	NA	NA	NA
	Protective Sealant	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Bearing (Super-structure)	Location	NA	NA	NA	X	X	NA	NA	NA
	Bottom Plate	NA	NA	NA	X	X	NA	NA	NA
	Disc Bearing	NA	NA	NA	X	X	NA	NA	NA
	Elastomeric	NA	NA	NA	X	X	NA	NA	NA
	Masonry Plate	NA	NA	NA	X	X	NA	NA	NA
	Pot Bearing	NA	NA	NA	X	X	NA	NA	NA
	Rocker Bearing	NA	NA	NA	X	X	NA	NA	NA
	Sliding Bearing (Diameter, Height, Material, Shape, Width, or Type)	NA	NA	NA	X	X	NA	NA	NA
	Sole Plate	NA	NA	NA	X	X	NA	NA	NA
	Top Plate	NA	NA	NA	X	X	NA	NA	NA
	Vulcanized Pad	NA	NA	NA	X	X	NA	NA	NA
	Anchor Bolt (Location, Diameter, Length, or Type)	NA	NA	NA	X	X	NA	NA	NA
	Bearing (Elevation, Station, Shape, Support, Hole Diameter, Pad Diameter, Height, Length, Material, Width, Steel, or Shim	NA	NA	NA	X	X	NA	NA	NA
	Layout (Centerline of Bearing Offset or Centerline of Bearing to Centerline of Support)	NA	NA	NA	NA	NA	NA	NA	NA
Bridge Curb	Location	NA	NA	NA	X	X	NA	NA	NA
	Conduit Drainage	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Deck	Location	NA	NA	NA	X	X	NA	NA	NA
	Skew Angle or Station at Deck	NA	NA	NA	X	X	NA	NA	NA
	Closure Pour (Thickness and Width)	NA	NA	NA	X	X	NA	NA	NA
	Deck Form	NA	NA	NA	X	X	NA	NA	NA
	Overhang (Thickness, Width, and Distance from Girder Centerline)	NA	NA	NA	X	X	NA	NA	NA
	Overlay	NA	NA	NA	X	X	NA	NA	NA
	Pour Sequence,	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Deck Drain	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA			NA	NA	NA
Deck Joints	Location	NA	NA	NA	X	X	NA	NA	NA
	Compression Seal	NA	NA	NA	X	X	NA	NA	NA
	Modular	NA	NA	NA	X	X	NA	NA	NA
	Strip Seal	NA	NA	NA	X	X	NA	NA	NA
	Tooth/Finger	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Haunch	Haunch	NA	NA	NA	X	X	NA	NA	NA
	Elevation	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Girder	Location	NA	NA	NA	X	X	NA	NA	NA
	Steel Girder Camber	NA	NA	NA	X	X	NA	NA	NA
	Conceptual Erection Sequence	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Concrete Girder Camber and Deflection	NA	NA	NA	X	X	NA	NA	NA
	Concrete Girder (End Diaphragm, Fillet, Height, Width, or Intermediate Diaphragm)	NA	NA	NA	X	X	NA	NA	NA
	Concrete Girder Camber and Deflection	NA	NA	NA	X	X	NA	NA	NA
	Drip Groove (Soffit)	NA	NA	NA	X	X	NA	NA	NA
	Girder Web Haunch (Haunch at Point-Start, End, Intermediate/Increment Units)	NA	NA	NA	X	X	NA	NA	NA
	Precast/Prestressed Concrete Girder	NA	NA	NA	X	X	NA	NA	NA
	Girder (Cross-section, Type, Length, Number, Section Orientation, and Spacing)	NA	NA	NA	X	X	NA	NA	NA
	Steel Girder Flange (Charpy V-Notch Testing Indicator, Fracture Critical, Material, Flange Plate Material, Thickness, Width, Splice Weld, at Top or Bottom)	NA	NA	NA	X	X	NA	NA	NA
	Steel Girder Web (Splice Weld, Charpy V-Notch Testing Indicator, Web Plate-Length, Material, and Thickness)	NA	NA	NA	X	X	NA	NA	NA
	Tension Zone	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Bridge Median	Location	NA	NA	NA	X	X	NA	NA	NA
	Conduit Drainage	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Parapet (Barrier)	Bicycle Railing	NA	NA	NA	X	X	NA	NA	NA
	Handrailing	NA	NA	NA	X	X	NA	NA	NA
	Surface Texture (Architectural Treatment)	NA	NA	NA	X	X	NA	NA	NA
	Utilities	NA	NA	NA	X	X	NA	NA	NA
	Barrier Transition	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Railing	Location	NA	NA	NA	X	X	NA	NA	NA
	Bicycle Railing	NA	NA	NA	X	X	NA	NA	NA
	Handrailing	NA	NA	NA	X	X	NA	NA	NA
	Surface Texture (Architectural Treatment)	NA	NA	NA	X	X	NA	NA	NA
	Utilities	NA	NA	NA	X	X	NA	NA	NA
	Barrier Transition	NA	NA	NA	X	X	NA	NA	NA
	MASH Compliant Railing	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Bridge Sidewalk	Location	NA	NA	NA	X	X	NA	NA	NA
	Conduits	NA	NA	NA	X	X	NA	NA	NA
	Utilities	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Deck Placement	Deck Segment Length Number of Concrete Placement	NA	NA	NA	X	X	NA	NA	NA
	Number of Deck Segments	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Pour Stage	NA	NA	NA	X	X	NA	NA	NA
	Temporary Shoring	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Sound Wall (Barrier)	Location	NA	NA	NA	X	X	NA	NA	NA
	Load	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout (Barrier Transition/Block Treatment)	NA	NA	NA	NA	NA	NA	NA	NA
Transverse Member	Location	NA	NA	NA	X	X	NA	NA	NA
	Fit Type for Detailing (No Load, Steel Dead Load, Total Dead Load)	NA	NA	NA	X	X	NA	NA	NA
	Bottom Chord (Strut) Length (Work Point to Work Point), Diagonal Length (Work Point to Work Point), Distance between Bottom Girder Work Point, Top of Girder Work Point, Slopes and Length of Top Chord (Strut)	NA	NA	NA	X	X	NA	NA	NA
	Bottom Chord (Strut) Section, Cross-Frame Type (e.g., K, V, X, etc.), Diagonal Section, Gusset Plate Location, Member Coating, Member Drop, Quantity of Traverse Members, orTop Chord (Strut) Section	NA	NA	NA	X	X	NA	NA	NA
	Charpy V-Notch Testing Indicator, Fracture Critical, Material Indicator	NA	NA	NA	X	X	NA	NA	NA
	Bolts Coating	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Cantilever	NA	NA	NA	X	X	NA	NA	NA
	Cross-Frame	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Diaphragm	NA	NA	NA	X	X	NA	NA	NA
	Floor Beams	NA	NA	NA	X	X	NA	NA	NA
	Lateral Bracing	NA	NA	NA	X	X	NA	NA	NA
	Utility Support	NA	NA	NA	X	X	NA	NA	NA
	Work Point (Horizontal and Vertical Distance between Work)	NA	NA	NA	X	X	NA	NA	NA
	Layout (Angle with Respect to Girder, Distance from Support, Number of Spaces, and Quantity of Members Spacing	NA	NA	NA	NA	NA	NA	NA	NA
Abutment or End Bent (Substructure)	Back Wall	NA	NA	NA	X	X	NA	NA	NA
	Cheek Wall	NA	NA	NA	X	X	NA	NA	NA
	Stem Wall/Breast Wall	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Pedestal	Location (Length/Width)	NA	NA	NA	X	X	NA	NA	NA
	Pedestal Location (Elevation, Skew, Angle, and Station)	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Pier/Bent	Location	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Pier Cap	Pier Cap Location (Elevation, Skew Angle, and Station)	NA	NA	NA	X	X	NA	NA	NA
	Cap Beam (Depth, Length, Thickness, and Width)	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Fillet Radius	NA	NA	NA	X	X	NA	NA	NA
	Top Offset	NA	NA	NA	X	X	NA	NA	NA
	Chamfer (Horizontal/Vertical)	NA	NA	NA	X	X	NA	NA	NA
	Hammer Head	NA	NA	NA	X	X	NA	NA	NA
	Inverted	NA	NA	NA	X	X	NA	NA	NA
	Multi-Column	NA	NA	NA	X	X	NA	NA	NA
	Stepped	NA	NA	NA	X	X	NA	NA	NA
	Tapered	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Pier Column	Pier Column Location Spacing and Elevation (Bottom andTop)	NA	NA	NA	X	X	NA	NA	NA
	Pier Column (Depth, Diameter, Length, and Width)	NA	NA	NA	X	X	NA	NA	NA
	Chamfer	NA	NA	NA	X	X	NA	NA	NA
	Fillet Radius	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Pier Wall (Crash Wall)	Location	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Wingwall/ Stem Wall	Wingwall Location, Skew Angle, and Elevation (Bottom and Top)	NA	NA	NA	X	X	NA	NA	NA
	Backfill	NA	NA	NA	X	X	NA	NA	NA
	Batter or Stem (Depth, Width, or Length)	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Slope Protection	Location	NA	NA	NA	X	X	NA	NA	NA
	Concrete	NA	NA	NA	X	X	NA	NA	NA
	Riprap	NA	NA	NA	X	X	NA	NA	NA
	Grouted Riprap	NA	NA	NA	X	X	NA	NA	NA
	Landscape Rockery	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Conduit	Location	NA	NA	NA	X	X	NA	NA	NA
	Conduit (Diameter, Length, and Shape)	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Bridge Drainage System	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Structure (Buried)	Location	NA	NA	NA	X	X	NA	NA	NA
	Arch	NA	NA	NA	X	X	NA	NA	NA
	Box Culvert	NA	NA	NA	X	X	NA	NA	NA
	Three-Sided Structure	NA	NA	NA	X	X	NA	NA	NA
	Elements (Bottom Slab, Corbel, Curtain, Cutoff Wall, Exterior Wall, Headwall, Parapet, Interior Wall, Joint, Stem Wall, Top Slab, Wingwall)	NA	NA	NA	X	X	NA	NA	NA
	Soil (Fill Height, Max Height, Min Height, Soil Density)	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Mechanically Stabilized	Wall Location, Elevation, Station, Alignment (Bottom and Top)	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Earth (MSE) Retaining Wall	Cast-in-Place	NA	NA	NA	X	X	NA	NA	NA
	Precast	NA	NA	NA	X	X	NA	NA	NA
	Backfill	NA	NA	NA	X	X	NA	NA	NA
	Batter or Stem (Depth, Width, Length)	NA	NA	NA	X	X	NA	NA	NA
	Coping, Facing, Leveling Pad, or Strap Zone	NA	NA	NA	X	X	NA	NA	NA
	Wall Profile (Bottom, Top, or Finished Grade)	NA	NA	NA	X	X	NA	NA	NA
	Tiebacks or Anchors	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Reinforced Concrete Retaining Wall	Wall Location, Elevation, Station, Alignment (Bottom and Top)	NA	NA	NA	X	X	NA	NA	NA
	Cast-in-Place	NA	NA	NA	X	X	NA	NA	NA
	Precast	NA	NA	NA	X	X	NA	NA	NA
	Backfill	NA	NA	NA	X	X	NA	NA	NA
	Coping (Material and Shape)	NA	NA	NA	X	X	NA	NA	NA
	Batter or Stem (Depth, Width, Length)	NA	NA	NA	X	X	NA	NA	NA
	Wall Profile (Bottom/Top/Finished Grade)	NA	NA	NA	X	X	NA	NA	NA
	Tiebacks or Anchors	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Soil Nail Retaining Wall	Wall Location, Elevation, Station, Alignment (Bottom and Top)	NA	NA	NA	X	X	NA	NA	NA
	Backfill	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Coping (Material and Shape)	NA	NA	NA	X	X	NA	NA	NA
	Batter and Wall Length	NA	NA	NA	X	X	NA	NA	NA
	Facing (Material and Thickness)	NA	NA	NA	X	X	NA	NA	NA
	Wall Profile (Bottom, Top, or Finished Grade)	NA	NA	NA	X	X	NA	NA	NA
	Soil Nail Anchor (Bearing Plate, Assembly, Diameter, Length, Material, and Type)	NA	NA	NA	X	X	NA	NA	NA
	Soil Nail Grout Material	NA	NA	NA	X	X	NA	NA	NA
	Soil Nail Layout (Diameter, Length, and Spacing)	NA	NA	NA	X	X	NA	NA	NA
	Soil Nail Sheathing (Diameter, Material, and Thickness)	NA	NA	NA	X	X	NA	NA	NA
	Tiebacks Anchors	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Soldier Pile Retaining Wall	Wall Location, Elevation, Station, Alignment (Bottom and Top)	NA	NA	NA	X	X	NA	NA	NA
	Cast-in-Place	NA	NA	NA	X	X	NA	NA	NA
	Precast	NA	NA	NA	X	X	NA	NA	NA
	Backfill	NA	NA	NA	X	X	NA	NA	NA
	Batter or Stem (Depth, Width, and Length)	NA	NA	NA	X	X	NA	NA	NA
	Facing	NA	NA	NA	X	X	NA	NA	NA
	Coping, Gutter, Lagging	NA	NA	NA	X	X	NA	NA	NA
	Pile (Encasement, Section, Shape, Size)	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Wall Profile (Bottom, Top, or Finished Grade)	NA	NA	NA	X	X	NA	NA	NA
	Shear Stud Spacing	NA	NA	NA	X	X	NA	NA	NA
	Tiebacks or Anchors	NA	NA	NA	X	X	NA	NA	NA
	Reinforcement	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

BIM Model Production Delivery Table/Information Delivery Manual (IDM)

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Notes: See also existing conditions survey data model, geotechnical data model and roadway geometry/corridor data model. Other structural data model components can be included and additional components/elements identified. Structure types included: Slab bridges, Girder (i.e. I-girder, I-beam, box girder, deck beam) bridges, Common buried structures (box culverts, three-sided structures, arches), retaining walls associated with or adjacent to a bridge including Mechanically stabilized earth (MSE) walls, soil nail walls, soldier pile walls, reinforced concrete retaining walls. Component elements (e.g., substructure) may be replaced by individual elements (e.g., abutments, etc.). Structure types excluded can be included: truss bridges, tied-arch bridges, arch bridges, cantilever bridges, cable-stayed bridges, suspension bridges, rigid frame bridges, sign structures/sign gantries, ground-mounted sound walls/sound barriers and tunnels.

Reference: TPF5(372) Building Information Modeling (BIM) for Bridges and Structures under the Transportation Pooled Fund Program.

Table B-7: Traffic/safety data model – design interdisciplinary coordination.

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Traffic Signals	Traffic Control Signal	NA	NA	NA	X	X	NA	NA	NA
	Traffic Control Signal-Freeway Ramp	NA	NA	NA	X	X	NA	NA	NA
	Highway Traffic Signal-Tollway	NA	NA	NA	X	X	NA	NA	NA
	Pedestrian Hybrid Beacon	NA	NA	NA	X	X	NA	NA	NA
	Flashing Beacon	NA	NA	NA	X	X	NA	NA	NA
	Emergency Vehicle Access Beacon	NA	NA	NA	X	X	NA	NA	NA
	Lane-Use Control Signal	NA	NA	NA	X	X	NA	NA	NA
	In-Roadway Light	NA	NA	NA	X	X	NA	NA	NA
	Signal Head	NA	NA	NA	X	X	NA	NA	NA
	Signal Bracket	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Signal Pole	NA	NA	NA	X	X	NA	NA	NA
	Signal Pole Base Plate/Cover	NA	NA	NA	X	X	NA	NA	NA
	Signal Pole Anchor Bolts	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Traffic Sign	Regulatory Sign (MUTCD)	NA	NA	NA	X	X	NA	NA	NA
	Warning Sign (MUTCD)	NA	NA	NA	X	X	NA	NA	NA
	Guide Sign (MUTCD)	NA	NA	NA	X	X	NA	NA	NA
	1E Sign (MUTCD)	NA	NA	NA	X	X	NA	NA	NA
	2E Sign (MUTCD)	NA	NA	NA	X	X	NA	NA	NA
	Mount Position (Right, Left, Overhead)	NA	NA	NA	X	X	NA	NA	NA
	Mount Type (One Post, Double Post, Cantilever Tube, Other)	NA	NA	NA	X	X	NA	NA	NA
	Sign Pole	NA	NA	NA	X	X	NA	NA	NA
	Sign Pole Anchor Base	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
ITS/FTMS	ITS/FTMS Hut	NA	NA	NA	X	X	NA	NA	NA
	Fiber Optic Line/Cable	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Barrier- Guardrail or Guiderail Terminal	Type I (ET-Plus)	NA	NA	NA	X	X	NA	NA	NA
	Type II (ET-2000)	NA	NA	NA	X	X	NA	NA	NA
	Type III (SRT-350)	NA	NA	NA	X	X	NA	NA	NA
	Type IV (SoftStop)	NA	NA	NA	X	X	NA	NA	NA
	Type V(SRTM10)	NA	NA	NA	X	X	NA	NA	NA
	Type VI (SKT-SP)	NA	NA	NA	X	X	NA	NA	NA
	Type 31 (SKT 350)	NA	NA	NA	X	X	NA	NA	NA
	Turndowns (MSKT)	NA	NA	NA	X	X	NA	NA	NA
	Terminal Section Single	NA	NA	NA	X	X	NA	NA	NA
	Station	NA	NA	NA	X	X	NA	NA	NA
	Height	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA
Lighting	Light Head or LED	NA	NA	NA	X	X	NA	NA	NA
	Light Mast or Bracket	NA	NA	NA	X	X	NA	NA	NA
	Light Pole	NA	NA	NA	X	X	NA	NA	NA
	Light Pole Base Plate or Cover	NA	NA	NA	X	X	NA	NA	NA
	Light Pole Anchor Bolts	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout	NA	NA	NA	NA	NA	NA	NA	NA

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Notes: See also existing conditions survey data model. Other traffic/safety data model components and MIRE FDE data can be included and additional components/elements identified.

Table B-8: Utility data model – design interdisciplinary coordination.

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
Water	Main, Lateral Line, or Pipe	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Hydrant	NA	NA	NA	X	X	NA	NA	NA
	Valve	NA	NA	NA	X	X	NA	NA	NA
	Meter	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA
Sanitary Sewer	Main, Lateral Line, or Pipe	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Cleanout	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA
Gas	Pipe or Line	NA	NA	NA	X	X	NA	NA	NA
	Valve	NA	NA	NA	X	X	NA	NA	NA
	Meter	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA
Steam	Pipe or Line	NA	NA	NA	X	X	NA	NA	NA
	Valve	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA
Electric	Cable or Conduit	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Pedestal	NA	NA	NA	X	X	NA	NA	NA
	Box	NA	NA	NA	X	X	NA	NA	NA
	Meter	NA	NA	NA	X	X	NA	NA	NA

Entities	Properties	S	P	CD	PD	DD	FD	C/F	AM
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA
Communication	Cable or Conduit	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Pedestal	NA	NA	NA	X	X	NA	NA	NA
	Box	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA
Fiber Optic/ITS	Cable or Conduit	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Pedestal	NA	NA	NA	X	X	NA	NA	NA
	Box	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider or DOT)	NA	NA	NA	NA	NA	NA	NA	NA
Telephone/Data	Cable/Conduit	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Pedestal	NA	NA	NA	X	X	NA	NA	NA
	Box	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA
CATV/Data	Cable or Conduit	NA	NA	NA	X	X	NA	NA	NA
	Manhole	NA	NA	NA	X	X	NA	NA	NA
	Pedestal	NA	NA	NA	X	X	NA	NA	NA
	Box	NA	NA	NA	X	X	NA	NA	NA
	Appurtenance	NA	NA	NA	X	X	NA	NA	NA
	Location	NA	NA	NA	X	X	NA	NA	NA
	Layout (Provider)	NA	NA	NA	NA	NA	NA	NA	NA

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Notes: See also existing conditions survey data model. Other utility data model components within the ROW can be included and additional components/elements identified.

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