Member Bulletin

Building Information Modeling & Bridges in British Columbia: Background

Developed by

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1.0 INTRODUCTION

In this position paper we survey the current state of Building Information Modeling (BIM) as it relates to bridges in British Columbia (BC). The discussion consolidates published information from authoritative sources, information from peer jurisdictions and adjacent sectors of the construction industry, and first-hand experience on bridge design and construction projects.

We recognize that each source will have different interests and agendas with regards to BIM. In our discussion we interpret the sources to reflect the interests of the BC bridge industry and its stakeholders, comprising bridge owners (including the BC Ministry of Transportation and Infrastructure (MoTI)), the bridge supply chain (including Association of Consulting Engineering Companies BC (ACEC-BC) member organizations, academia, advocacy groups, and regulatory bodies.

Our purpose is to support strategic discussions around BIM adoption in the BC bridge industry. If our industry moves to adopt BIM, we should move knowing the opportunities and risks, the benefits, and costs. If we are to change deeply engrained ways of work, we should change understanding the implications for our stakeholders, for our projects, and for the bridges that we design, build, and maintain.

2.0 MOTIVATION FOR BIM

Drawings are the basis for communicating the design and construction of buildings and infrastructure. However, advancing computing technology now enables digital models to replace drawings. Using models for design and construction is called *BIM—building information modeling*.

Advocates cite improved design and construction outcomes as a key incentive for adopting BIM. Some also see the opportunity to move to a completely digital workflow; the relentless advance of digital technology can make BIM adoption seem inevitable. Nevertheless, BIM involves changing deeply engrained ways of work.

At the onset of 2024, we see evidence of this change across the global bridge industry.

- In Europe, the Swedish Transport Administration has had BIM requirements for all new procurements since at least 2015[i].
- In the United States, the Federal Highway Administration (FHWA) published a national roadmap *Advancing BIM for Infrastructure*[ii] in 2021. FHWA and other US federal agencies continue to invest in BIM adoption projects to support state departments of transportation. A recent outcome is the 2023 report *Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management*[iii].
- Some jurisdictions are now implementing BIM strategic plans. Utah's Department of Transportation (UDOT) released a comprehensive Digital Twin Strategic Plan[iv] in 2021. In Quebec, the Ministère des Transports et de la Mobilité durable (MTQ) is a participant in a 2021-26 provincial BIM roadmap for public works[v].
- Many transportation agencies, including UDOT[vi] and Ontario Ministry of Transportation, are pursuing BIM pilots and intentionally deploying the technology on bridge projects.

We also see evidence of this change within the BC bridge industry.

- Designers, fabricators, and constructors have been experimenting with BIM for more than a decade. Examples include the new Keith Road Bridge (2013, North Vancouver District), the Vedder Bridge replacement (2016, City of Chilliwack), and the 01598 CNR Highway 99 Overhead seismic renewal (2019, MoTI).
- Designers have been acquiring BIM experience working on major infrastructure projects (particularly transit projects) in other markets. Canadian examples include Ottawa LRT and, in Toronto, the Union Station Enhancement Project, GO Regional Express Rail Project, and the Ontario Line. International examples include the BART Silicon Valley extension, Bogota Metro, and the UK's High Speed 2.

3.0 WHAT IS BIM?

3.1 DEFINITION

The standard definition of *BIM—building information modeling*—is *“the use of a shared digital representation of an asset to facilitate design, construction and operation processes to form a reliable basis for decisions”*[vii].

- Here, the “asset” is any component of the built environment. In this position paper, we are interested in bridges and related structures.
- The “digital representation” is a *BIM model* or, simply, *model*.
- The model is “shared”—BIM is a collaborative technology.
- BIM addresses “design, construction and operation processes”—it addresses the entire lifecycle of a bridge.

For bridges, some prefer the term *BrIM—bridge information modeling*. Aside from this specialization, both *BIM* and *BrIM* refer to the same concept.

3.2 RELATED TECHNOLOGIES

3.2.1 GIS

BIM and GIS (geographic information systems) are complementary technologies. GIS is typically applied to model assets at larger scales, often purposes of planning or management. BIM typically applies at smaller scales, and typically for design. GIS objects are readily convertible to BIM components.

3.2.2 CAD

BIM is an extension of CAD (computer-aided design). CAD is design using computer graphics. CAD data is purely graphical data, either 2D or 3D. BIM is an approach to creating and managing all forms of bridge data. All BIM models contain graphical data—frequently 3D CAD data. All models also contain non-graphical data.

3.2.3 Drawings

BIM shifts the basis of communication from drawings to models—see **Figure *1***.

- Conventionally, drawings describe a bridge’s design and construction, and they inform the creation of other documents, such as renderings, material quantities, cost estimates, and special provisions. Design and documentation are often the same process.
- With BIM, the drawings and all other documents are products (“renditions”) of a central model. BIM separates design and documentation into distinct processes.

Models and drawings communicate the same information in different ways.

- Drawings communicate implicitly. The creator of a drawing relies on interpretation and shared understanding to express intent. This is efficient and effective—but can sometimes lead to misunderstanding.
- Conversely, a model is an explicit description of a bridge. If the model does not describe something about a bridge, then that thing does not exist. It also means that a model must contain substantially more information than a set of drawings to describe the same bridge.

Thus, models are not direct replacements for drawings—BIM does not necessarily make drawings redundant.

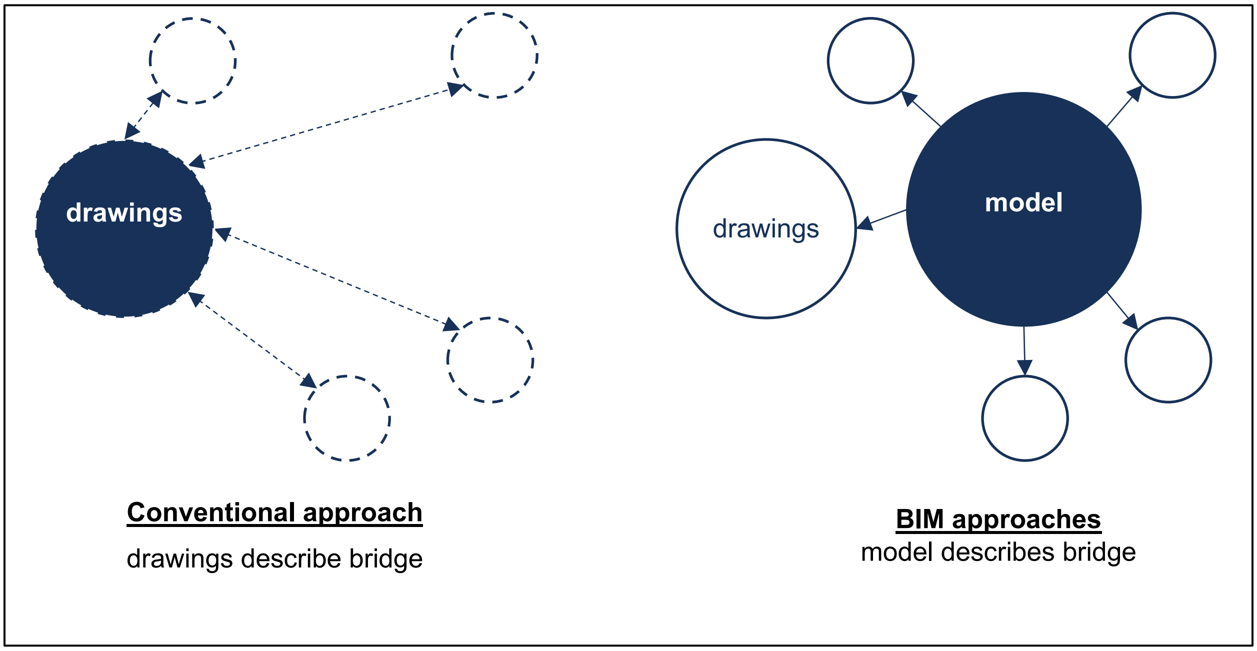


Figure 1 Conventional Design (communication via drawings) relative to BIM Design (communication via model)

3.2.4 Databases

A BIM model is a database. It is a collection of data that describes bridge.

- As data, the model may suggest that details of a bridge are more accurate than they are. BIM is not good at inference or subtlety.
- As data, the model is open to computation. We can use software and write scripts to create, modify, combine, analyze, render, and present models, and to automate the process of design.
- As data, the model's usefulness is a function of its scale. A single model that joins up several bridges over their life cycles is more useful than separate models for each bridge and phase.(**Figure 2**)

3.3 RELATED CONCEPTS

3.3.1 Virtual Design and Construction

Virtual Design and Construction (*VDC*) can be understood as the systematic and intentional application of BIM to improve design and construction outcomes. According to Trimble[viii], VDC "*means building the project once digitally and working out the big problems, then building it more efficiently in the physical world*". This paper addresses aspects of VDC applicable to bridge design and construction.

3.3.2 Digital Twins

Digital twins are general-purpose simulations. According to IBM[ix], a digital twin is "*is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision making*". While a digital twin of a bridge would likely involve a BIM model, a BIM model of a bridge is not a digital twin.

4.0 BIM OBJECTIVES

As cited, key motivations for adopting BIM include improved productivity. Stakeholders can use BIM to make bridge design, construction, or management more effective. For example:

- BIM can enable better quality control by identifying more issues at an early stage in the life cycle of a bridge,
- BIM can allow for exploring a greater numbers of design options, and
- BIM can enable accounting of modern design metrics, like embodied carbon.

Stakeholders can also use BIM to create entirely new sources of value that are separate from bridge design, construction, or operation. For example, BIM can be used to increase the value of the information about a bridge—**Figure 2**.

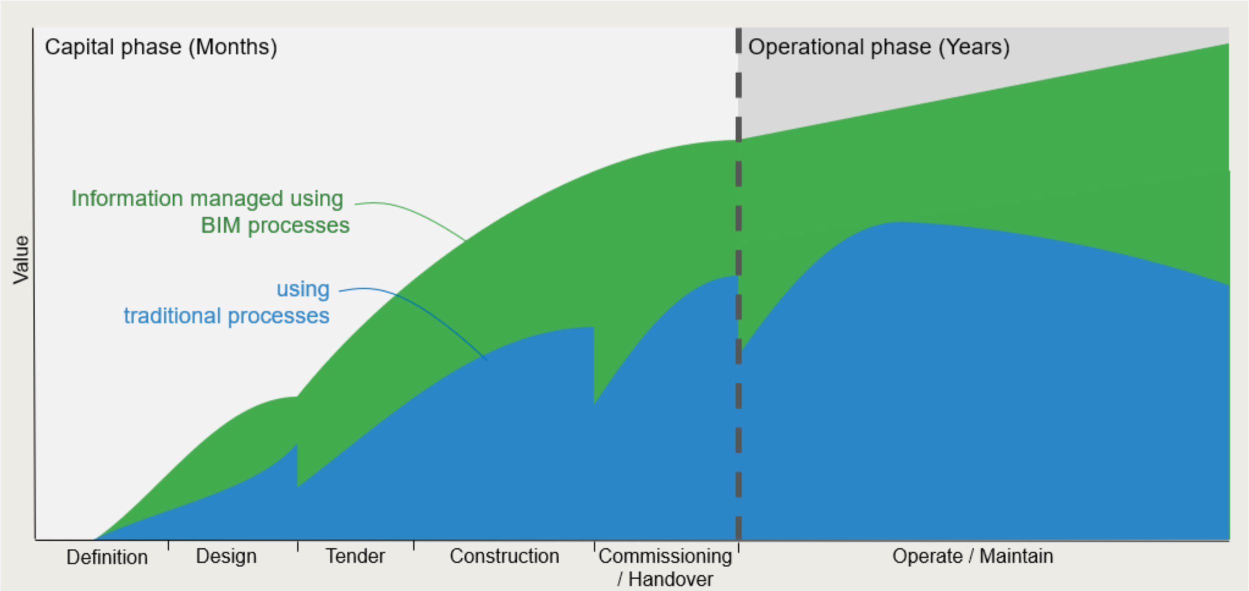


Figure 2 BIM can be used to increase the value of the information about a bridge (figure provided by Mott MacDonald Canada)

Since these objectives are sometimes conflicting, stakeholders need to identify priorities and plan BIM practices accordingly. Dr Sheryl Staub-French, director of the BIM TOPiCS lab at UBC, recommends that you “*always keep your ends in mind*”[x]—that is, to start from value that you aim to create. BIM is a means to creating that value; it should never be applied for its own sake.

Achieving the objectives demands execution—stakeholder buy-in, effective tools, efficient processes, and demonstrated results.

5.0 TYPICAL BIM PRACTICES

Many BIM practices are recognizable from conventional approaches to bridge design and construction, but most are not. To understand the range of BIM practices, remember that models are data.

- Some practices address how models are managed—**information management**.
- Some address how they are created—**model authoring**.
- Some address how they are combined—**BIM coordination**.
- Finally, some address how they are used—**BIM applications**.

5.1 INFORMATION MANAGEMENT

Information management is, plainly, the discipline of collecting, storing, maintaining, and sharing all forms of information, including models.

5.1.1 Common Data Environments

Stakeholders collect, store, maintain and share information in *common data environments* (CDE). CDEs are collections of computing resources (computer servers, network drives, shared folders, databases, etc.) combined with agreed rules, processes, and templates for using those resources.

A CDE is colloquially referred to as the "single source of truth"[xi]—see **Figure 3**. The aim is to centralize information to improve its accessibility and reliability. An effectively managed CDE (or group of connected CDEs) reduces duplication of asset information and the associated quality risks. It also enables interoperable workflows that streamline communication among bridge stakeholders and across life cycle phases.

Stakeholders typically implement CDEs from cloud database services.

- For models and CAD information, typical packages include Bentley *ProjectWise*, Autodesk *BIM 360*, and *Autodesk Construction Cloud*.
    - *ProjectWise* is a mature product. Its strengths are robust information management and reliability, but it has a steep learning curve and may not be accessible to non-specialists.
    - The Autodesk products are newer. Their strengths are accessibility and user experience, but they can be unreliable for non-*Revit* model formats.

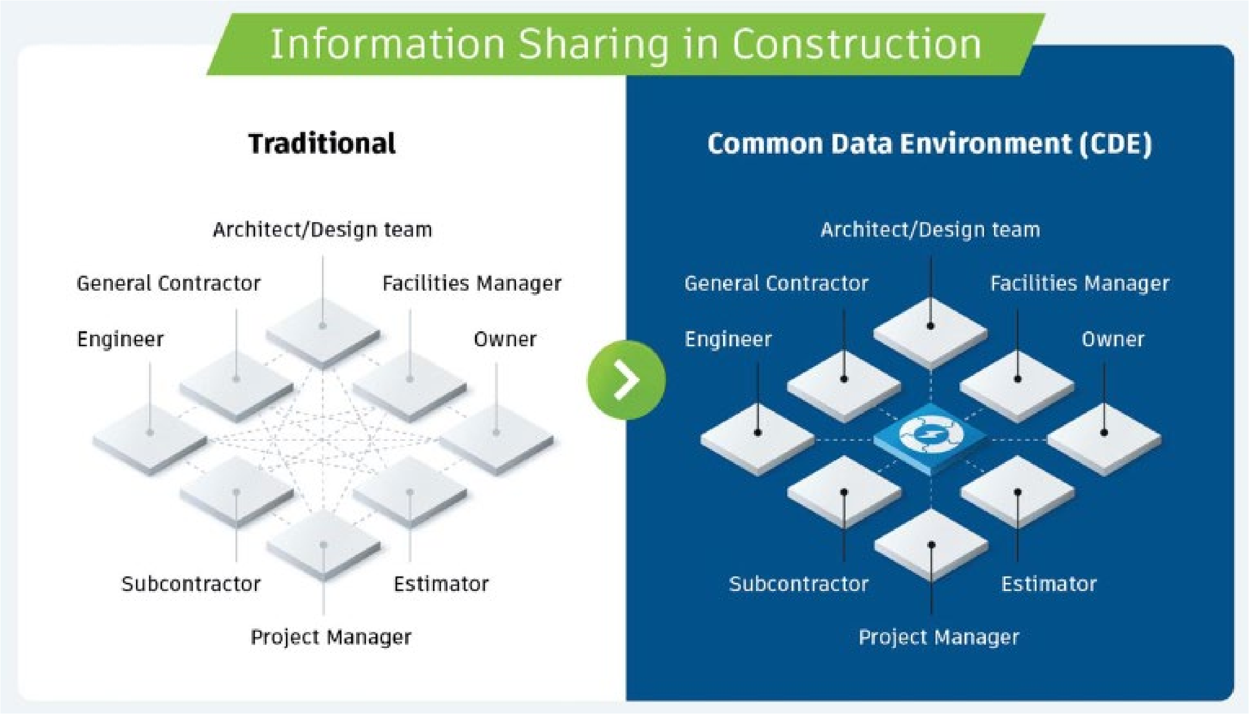


Figure 3 A CDE is colloquially referred to as the "single source of truth" (Autodesk)[xii]

- For specialized construction management information, particularly on large construction projects, typical packages include Procore and Oracle Aconex.
- MoTI’s BMIS bridge management is a database could be considered part of a CDE for bridge asset management.
- For general project information, typical packages include Microsoft SharePoint and cloud-hosted SQL databases.

None of these services is suited the complete range of information about a bridge’s design, let alone its construction and management. In practice, stakeholders implement CDEs from two or more services. It can require substantial effort to delineate the interface between different services within a single CDE: to define robust, efficient processes for handling, checking, and sharing information.

5.1.2 Information Management and Project Delivery

As a discipline, information management aligns closely with project delivery. For example:

- Information management elaborates conventional deliverable lists, schedules, and milestones into structured “Task Information Delivery Plans” (TIDPs) and an overarching “Master Information Delivery Plan” (MIDPs).
- Information management extends document control from printable documents to all forms of data. Document control is a subset of information management.

- Because information management joins up technical and management data streams, it streamlines progress tracking and facilitates project controls.

It could be argued that information management is central to project delivery. Information management (and, by extension, BIM) is certainly most effective if it is considered from the earliest stages of planning project delivery.

5.1.3 Information Management and Data Analytics

Most project managers and engineers are very comfortable with spreadsheets, and they commonly use *Excel* as an informal data analytics tool—tracking lists and budgets and schedules. *Excel* is suitable at small scales, but it becomes ineffective as the volume of data, its connectivity, and the number of users increases. Even basic information management strategies require a rigorous approach to data analytics.

- This might involve replacing spreadsheets with custom "Lists" implemented using Microsoft *SharePoint* or relational (SQL) databases implemented on cloud platforms like Amazon *AWS* or Microsoft *Azure*.
- It also might involve combining data from different sources and visualizing that data on dashboards using platforms like Microsoft *PowerBI*.
- Recently, products such as *Plannerly* (BIM execution planning)*, Morta* (MIDPs) combine purpose-built relational database and data visualization for specific information management applications.

Rigorous data analytics can provide insights for project management decisions that save time and money. It is the foundation for development of useful key performance indicators (KPIs) and "data driven" project management processes.

5.1.4 ISO 19650 Standard

The ISO 19650:2018 suite of standards describes a standardized approach to information management for all buildings and infrastructure—including BIM and bridges[xiii]. ISO 19650 is the current iteration of BS 1192, a British information management standard first released in 1990. Notably, it addresses the entire life cycle of an asset, emphasizing clearly defined information requirements across the planning, design, construction, and management phases. ISO 19650 is perceived as an exacting standard—it certainly demands more planning and organization than normally exists in the industry.

- Rigorous applications of ISO 19650 to infrastructure in North America are limited to large design and construction projects with sophisticated stakeholders and complex coordination requirements—projects with sufficient motivation and the resources to overcome the long learning curve.
- While all major CDE packages acknowledge ISO 19650, the best practice for implementing these standards is still emerging.

5.2 MODEL AUTHORING

Models are authored either (i) to describe the existing condition of a bridge—for context, or (ii) to describe a proposed new condition—for design.

5.2.1 Existing Conditions—Context

High-definition scanning

So-called “reality capture” extends conventional site surveys to include high-definition methods such as photogrammetry and LiDAR scanning. The purpose of high-definition scanning is to “bring the site back to the office”—to capture overwhelming amounts of information about a bridge or its site to enable post-hoc inspection.

- Scanning technology is advancing rapidly. Current models of the Apple iPhone include basic photogrammetry and LiDAR capabilities sufficiently accurate for bridge and construction inspections. High-quality, high-accuracy LiDAR scanners—both handheld (SLAM) and fixed—are increasingly available at lower price points. Leica is a typical hardware supplier.
- Scanning can be paired with UAVs (drones) to enable data collection and inspection from aerial perspectives that are difficult or unsafe to access. These could be, for example, a high-resolution birds-eye view of a site, or the underside of a bridge. UAVs present unique (but manageable) liability risks and are subject to Transport Canada regulations.
- LiDAR scanning can also be completed underwater with specialized hardware.
- Scanning is not limited to traditional surveying organizations: particularly where high-volume use cases (recurring site inspections, construction progress tracking, etc.) justify equipment rentals or investments. Not all scanning applications are survey controlled, and, with appropriate procedures, existing scans can be survey controlled post-hoc.

Point Clouds

High-definition scanning yields dense, true colour *point clouds*. Modelers post-process raw point clouds into existing condition models.

- At the very least, the modelers “clean” and assemble separate point clouds into a single model.
- Modelers often reduce heavy point clouds into lighter “meshes” models for ease of use. Machine learning is helping to make meshing an increasingly efficient and accurate process.
- Modelers can also split the existing condition models into discrete components according to a taxonomy (piers, girders, deck slabs, etc.). Machine learning can also help with feature recognition.
- Autodesk *ReCap* and Bentley *ContextCapture* and *Pointools* are typical software packages for point cloud post-processing, inspection, and analysis.

Point clouds are big data sets demanding significant computing resources to process—often more than is available with a standard computer.

Recent advances in cloud computing have made it increasingly practical to work directly with point clouds. One high-profile application is automated progress tracking for construction—comparing scans of constructed progress against reference BIM models of the expected progress.

5.2.2 New Conditions—Design

New models are authored from parametric components according to a taxonomy (piers, girders, deck slabs, etc.). To model a new condition, a designer chooses the required components, places them in the model, and configures their parameters. BIM components are analogous to parametric CAD blocks in drawing production.

- Some parameters might help the components "adapt" to suit the layout of the bridge, connect to adjacent components, etc. These might include its stationing, offset, elevation, etc.
- Other parameters address non-graphical information about the component. These might include:
  - "Class" or "family" within the taxonomy;
  - Some metadata—e.g., a suitability code describing whether the component is "WIP" (work in progress), "Shared" (e.g., for coordination), or "Published" (i.e., for delivery and use);
  - Relevant specifications such as product names, material types and grades, and owner-specific requirements, for example, MoTI Special Provision references;
  - Relevant properties such as an estimated unit cost or expected construction duration;
  - Its "Level of Detail" or "Level of Definition" indicating the state of the component's information (see figure next page).

The modeler can build custom components to suit unique or specific conditions; this, however, is time-consuming. A comprehensive library of well-designed, re-useable components minimizes the need to build custom components and supports standardization across multiple bridge designs. Comprehensive component libraries are therefore necessary for efficient and effective *model-based design*.

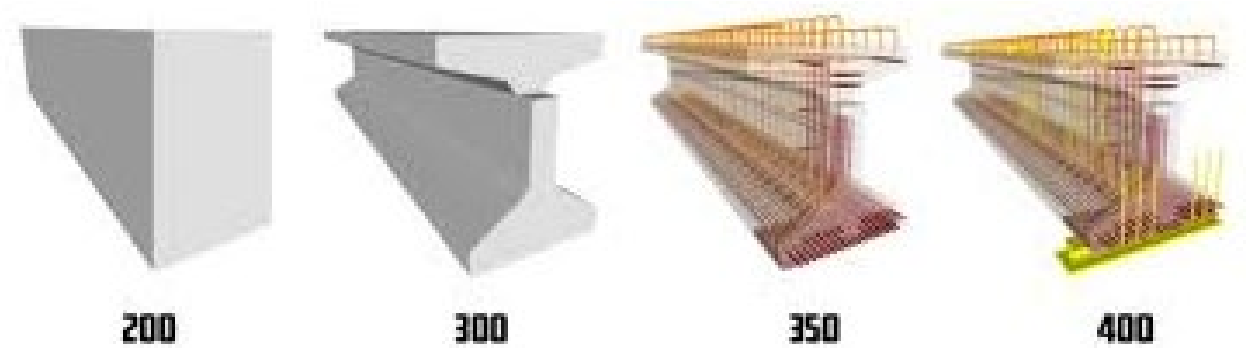


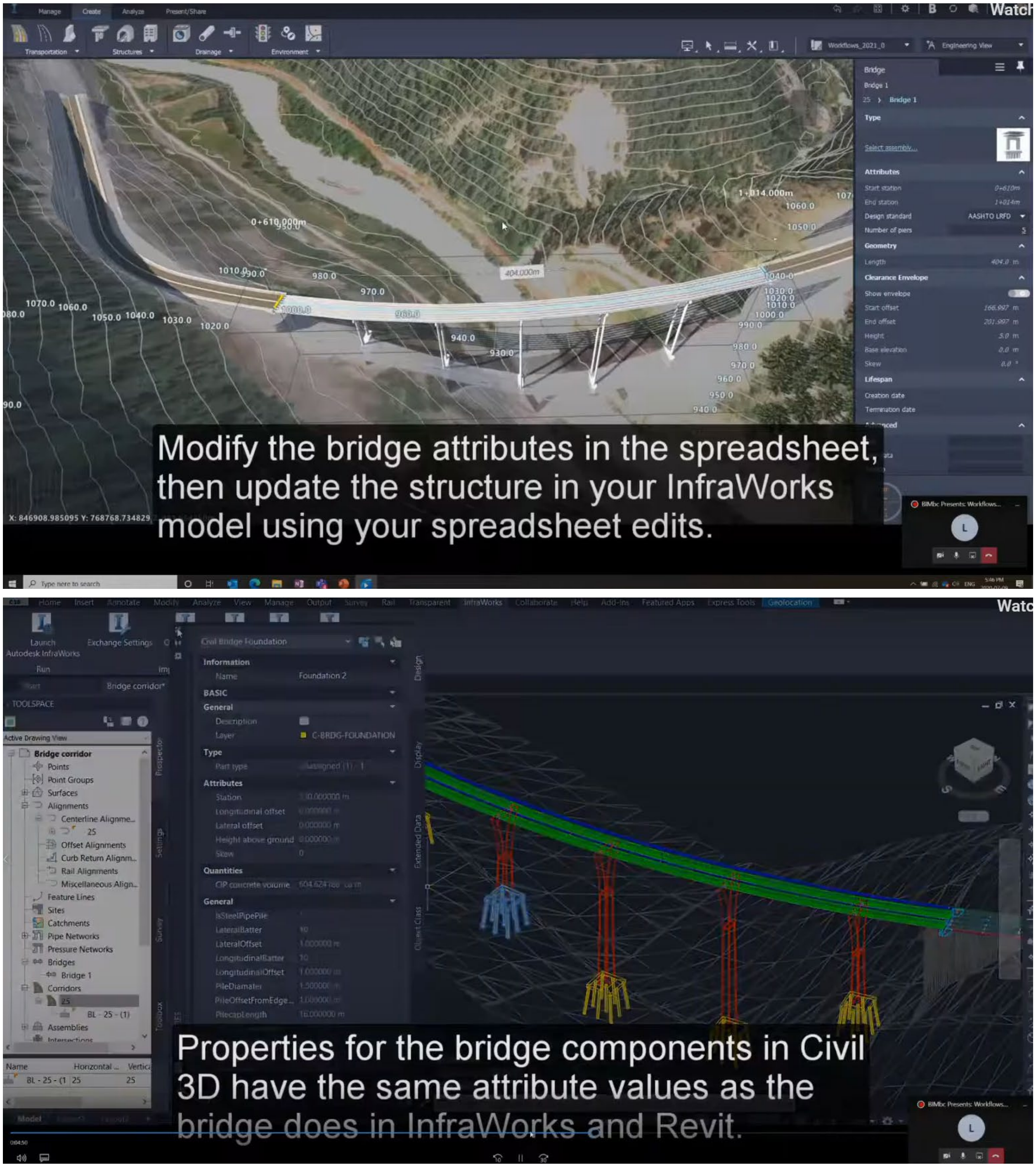
Figure 4 A greater level of definition suggests the component information is more detailed (BIMForum[xiv])

5.2.3 Proprietary Workflows

Autodesk

Autodesk does not offer purpose-built model authoring software for bridges. Instead, it offers a model authoring workflow joining four software packages: *Infraworks*, *Civil 3D*, *Revit*, and *Inventor*.

- *Infraworks* addresses parametric bridge modeling and layout. It is generally suitable for concept design.
- *Civil 3D* enables detailed modeling of topographic surfaces, road alignments, and extruded (linear) shapes. Civil 3D does not understand bridge taxonomies (piers, girders, deck slabs, etc.).
- *Revit* enables detailed modeling of discrete components. It was originally developed for buildings and does not understand bridge taxonomies and the CAD engine sometimes struggles to represent curved geometries typical of highway bridge decks.
- Modelers can use *Inventor* to create custom parametric bridge components for both *Revit* and *Infraworks*.



Modify the bridge attributes in the spreadsheet, then update the structure in your InfraWorks model using your spreadsheet edits.

Properties for the bridge components in Civil 3D have the same attribute values as the bridge does in InfraWorks and Revit.

Figure 5 Autodesk's bridge design workflow can involve up to four different software packages[xv] (BIMbc Vancouver)

Bentley

Bentley offers a more-compact bridge model authoring workflow revolving around the *OpenRoads* and *OpenBridge Designer* packages.

Trimble

Trimble's *Tekla Structures* can import highway geometry and understands bridge taxonomies. Because of its strength in detailed design and fabrication modeling, *Tekla Structures* is attractive for BIM workflows that eliminate contract drawings.

5.2.4 Custom Workflows

Custom model authoring workflows are also possible. Modelers have three techniques for moving data between software packages: file exchange, scripting, and interoperability platforms.

File Exchange

A modeler can use file exchange (export/import) to move model data between different software packages.

- File exchange using proprietary formats is generally unreliable—even among software packages from the same supplier.
- File exchange using the *IFC* (*Industry Foundation Classes*) open BIM format would be reliable—but support for bridges is still very new, only added to the IFC 4.3 standard in 2022. Software support is neither comprehensive nor widespread: this may change as the standard matures. AASHTO has endorsed IFC for bridges, sending a market signal to the major software suppliers.

Automation and Scripting

Most BIM design and analysis software packages have APIs (application programming interfaces)—back doors to their functionality. A modeler can write scripts to pull model data from an upstream API, manipulate that data, and push it through another API downstream. User interfaces are avoided, and no files exchanged.

- A popular scripting workflow involves *Rhino's* popular *Grasshopper* visual scripting plugin. Modelers use *Grasshopper* scripts to import geometry from *Civil 3D*, to create accurate bridge geometry in *Rhino*, to build custom *Revit* components, and to place those components in *Revit* models at the correct stationing, offsets, and elevations.
- A similar workflow involves Autodesk's own *Dynamo* visual scripting plugin for *Revit* and *Civil 3D*. Autodesk calls this workflow *Civil Connection*.
- Modelers can also use the general-purpose scripting languages *Python* and *C#*.

Scripting is a powerful data portability tool. The learning curve, however, is steep: it requires both coding experience and detailed knowledge of the low-level operation of bridge design software packages.

Interoperability Platforms

An interoperability platform is a collection of pre-scripted connections between software packages that are accessible through a user interface.

- Some bridge designers use Arup's *Speckle* platform to move model data between *Civil 3D, Rhino*, and *Revit*. *Speckle* is a general-purpose interoperability hub joining software packages from several different software suppliers.
- Some bridge designers also use McNeel's *Rhino.Inside.Revit* platform to integrate *Rhino* and *Revit* their workflows.

Interoperability platforms provide much of the power of scripting without the learning curve. They can be effective data portability tools. Because interoperability platforms are typically maintained by independent software suppliers and third parties, they are not included in enterprise agreements with major software suppliers.

5.3 BIM COORDINATION

BIM models can be combined into larger models for stakeholders to collaborate. The process of combining models is called BIM coordination.

5.3.1 Informal Coordination

A structural model of a bridge may have related civil and electrical models, e.g. for the site context, grading, utilities and bridge lighting. The lead modeler can coordinate these models by linking them directly in the principal authoring software, e.g., *Revit*.

This informal coordination may be suitable for smaller, standalone bridge design and construction projects.

5.3.2 Systematic Coordination

A bridge model might also be a component of a larger, highway corridor model. A dedicated BIM coordinator can use software such as Autodesk *Navisworks* or, increasingly, the capabilities of newer CDE packages like *Autodesk Construction Cloud*, to aggregate separate models into a *federated model*. The federated model becomes the shared context for everyone's work. Because this context is always changing, the coordinator regularly updates and re-publishes the federated model for everyone's use.

Systematic BIM coordination is the basis of collaboration within larger, corridor design and construction projects.

- For example, systematic coordination drives design collaboration and review. Views into the federated model provide insight to the design interfaces. Stakeholders can identify and resolve design issues through the models.

- To support collaboration and review, BIM coordination packages feature model issue tracking and comment resolution tools—analogous to PDF comment resolution in Adobe *Acrobat* or Bluebeam *Revu* – and basic quality control automations such as "clash detection" (*spaceproofing*).

Systematic BIM coordination also enables collaboration across a bridge's life-cycle phases.

- For example, an engineer's detailed design model may flow into a model that contractor uses for estimating and tracking bridge construction progress. The construction model, in turn, may flow into an as-built model for the owner's management of the bridge.

5.3.3 Information Requirements

Effective BIM coordination relies on a consistent quality, quantity, and granularity of model information. The information needs to suit the task at hand—have an appropriate level of definition. Stakeholders write specifications to define their "information need" for coordination, and for other applications downstream. These specifications are called *information requirements*.

ISO 19650 defines a hierarchy of information requirements.

- *Organizational information requirements* (OIRs) are high-level policies and practices. For example, MoTI's adoption of Autodesk *Civil 3D* and *AutoCAD* is an OIR. Other examples of OIR include data governance practices, information security policies, and templates.
- *Asset information requirements* (AIRs) are mid-level standards for a particular asset or class of assets. They address longer-term information requirements for managing and maintaining the asset. For example, MoTI's bridge CAD standards are AIRs as they pertain to management of bridges in BMIS. Asset information requirements are driven by asset management objectives.
- *Project information requirements* (PIRs) are mid-level standards for a particular project or type of project. They address shorter-term information requirements for constructing assets. Examples of PIRs include deliverable lists and "Master Information Delivery Plans" (discussed previously). Project information requirements are driven by project delivery and execution objectives.
- *Exchange information requirements* (EIRs) are detailed requirements for asset and project stakeholders. The define who is creating what information and for whom. Examples of EIRs include "BIM Execution Plans" and model responsibility matrices (RACIs—sometimes called "model production delivery tables"). Exchange information requirements are driven by the specific project or asset context.

5.4 BIM APPLICATIONS

BIM models can be applied throughout a bridge's lifecycle: to improve design, construction and operation and maintenance.

5.4.1 Design Applications

Key BIM applications to design include drawing production, structural analysis, visualization, and computational design.

Drawing Production

Overview

Most BIM authoring packages include automations for generating plans, cutting sections and projecting elevations from BIM models, and for laying these 2D views onto drawing sheets. They create a "dynamic" link from the models to the drawings: the views can respond automatically to design changes in the model.

Design packages also include conventional drafting toolsets for elaborating these views with annotations and further detail. The tools can also be used for "conventional" drafting. These tools are usually "static": they do not respond to changes in the model, at least not reliably.

Thus, while BIM can create efficiencies for drawing production, it is by no means an automatic process.

Autodesk example

Within the Autodesk workflow, modelers typically use both *Civil 3D* and *Revit* to produce bridge drawings from BIM models. These are two fundamentally different tools, requiring different standards and templates.

- *Civil 3D* automates for civil works, including alignments, profiles, and grading.
- *Revit* automates for building structures, including section cuts and plans and elevations defined from a rectilinear grid.
- Some modelers use custom scripting workflows to automate missing bridge-specific capabilities, including 2D developed elevations along curved alignments (unrolled elevations), and skewed sections.

BIM and drawing norms

Drawings produced from models look different than conventionally-drafted drawings—even if they adhere to the same CAD standards.

Drawing sets produced from models are often sequences of plans, elevations and sections completed with sheets collecting conventionally drafted details and notes. They typically reflect the logic of the model and available automations. This can run against long-standing industry norms, which emphasize the logic of the bridge design. BIM-produced drawings that are objectively accurate and complete still may not feel "right". They often do not communicate as expected, which may not be acceptable to stakeholders.

As such, norms for bridge drawings constrain the productivity of BIM drawing production workflows. Over time, stakeholders' expectations may change. Until then, drawing production will retain elements of manual drafting.

Drawing completion versus design progress

Conventionally, bridge engineers use drawing completion as a proxy for design progress. With BIM, this heuristic may not apply.

BIM approaches always start with model authoring. Design progress is recorded in the model, not the drawings. Drawings may not be required until later in the project, e.g., to document the design for tendering and construction. When drawings are required, an efficient workflow enables drafters to rapidly produce drawings from models.

Visualization

Engineering drawings are one means for communicating the design and construction of a bridge. Illustrations, including still images and animations, are another, complementary means. Designers often use illustrations for early-stage concept reviews and for communication with non-technical stakeholders.

Conventionally, illustrations are labour-intensive products, separate from and additional to the engineering drawings. With BIM, stakeholders have many opportunities to create illustrations, and more sophisticated 3D visualization products, directly from the central model.

Simple Visualizations

Simple visualizations are by-products of everyday model authoring and BIM coordination. Most BIM coordination packages, including Autodesk *Navisworks*, have tools for creating static images and flythrough animations of federated models. Plugins such as *Enscape* enable modelers to create rendered model views within design software packages.

The quality of simple visualizations varies. They are often sufficient for stakeholder communication, but not for public consumption.

High-quality Renderings

When realistic visualizations are required, visualization specialists use packages like Autodesk *3ds Max* to create rendered scenes from BIM models.

Rendering workflows can be very efficient if the central model is complete with material information indicating surface textures and colour. Usually, the crux for rendering workflows is not the bridge, but its context. BIM models typically contain much less information about the site (detailed grading, adjacent infrastructure, trees, vegetation) than these visualizations require.

For most regions in BC, low-resolution topographic meshes and airphoto textures are available through packages like Autodesk *Infraworks* and (recently) the Google *Maps* API. These provide a reasonable starting point: much artistic effort is required develop them into a convincing scene.

Alternately, the scene can be set using high-resolution point clouds and detailed meshes from site reality capture. This approach can be very effective at small scales where the detailed context is very important—e.g. pedestrian bridges in urban environments.

Real-Time Visualization

Visualization specialists can produce static images and fly-through animations from rendered scenes. They can also develop the scenes into interactive 3D environments for real-time visualization, using Epic's *Unreal* gaming engine or the *Unity* gaming engine.

Interactive environments are technically demanding and labour intensive to produce. While the end products are generally intuitive and easy to use, they can be difficult to deliver to audiences: gaming engines demand substantial computing resources.

Real-time visualization technology is advancing rapidly. For example, Epic's *Twinmotion* software—currently in beta testing—adapts *Unreal Engine* for construction industry. *Twinmotion* provides a toolset for creating interactive environments, and "pixel-streaming" feature to serve any device with an internet connection and a web browser.

Virtual Reality and Augmented Reality/Mixed Reality

Virtual reality (*VR*) and augmented reality/mixed reality (*AR/MR*) headsets are particularly suited to real-time visualization. For example, fully immersive VR headsets (e.g. Meta *Quest*) enable bridge designers to inhabit their designs, to experience them as pedestrians, cyclists, and drivers would. VR offers a rich feedback loop for complex design considerations that would otherwise rely on simple heuristics or assumptions. It is for this reason that some describe VR as an "empathetic" technology[xvi].

Partially immersive AR/MR headsets (e.g. Apple *Vision Pro*, Microsoft *Hololens*) combine virtual environments with the real world. For example, during a MR design review meeting, a bridge model could be "present" at the table among the headset-equipped stakeholders.

VR and AR/MR have significant potential for design and construction—and they have had this potential for many years now. Among early adopting organizations, the principal use cases still revolve around marketing and creating "buzz". The higher-value use cases rely on pervasive model-based design and efficient visualization workflows—i.e. widespread BIM adoption. User acceptance is another constraint—headsets are highly personal devices. This constraint will likely persist until users perceive headsets as "normal" computing devices like smartphones and laptops. To this end, the major technology suppliers are currently investing heavily in mass-market VR and AR/MR applications.

Structural Analysis

Proprietary workflows

Both Autodesk and Bentley extend their proprietary bridge model authoring workflows with structural analysis packages.

- Autodesk *Structural Bridge Design* pulls model information *Civil 3D* and *InfraWorks* for structural analysis of certain kinds of short- and medium-span bridges.
- Bentley *OpenBridge Designer* incorporates *RM Bridge* for structural analysis of bridges of all kinds.

Custom workflows

Extending a model authoring workflow with a third-party structural analysis package requires an additional measure of interoperability. Most structural analysis packages have IFC import and export functions, including *CSiBridge*/*SAP2000* and Midas *Civil*. As discussed previously, the usefulness of these is limited by lack of widespread industry support for IFC.

Many structural analysis packages offer APIs for scripting and automation. Some, including Midas *Civil* and *SOFiSTiK,* offer *Grasshopper* connectors that enable designers to interrogate BIM models, automate finite element modeling, and drive parametric structural analyses from a scripting environment—**Figure 6***.* The independent *Geometry Gym* plugin for *Grasshopper* enables similar capabilities for CSi *SAP2000*. Arup's *Speckle* interoperability platform has a beta connector that enables similar capabilities for *CSiBridge*.

Alternately, the *Karamba 3D* package embeds structural analysis capabilities directly into *Grasshopper*. *Karamba* is highly visual and uniquely interactive: enabling parametric investigation of idealized structural models. It is particularly useful for concept development: when a BIM model might not yet exist or—even if it does—a full-scale model might obscure understanding of fundamental structural behaviour.

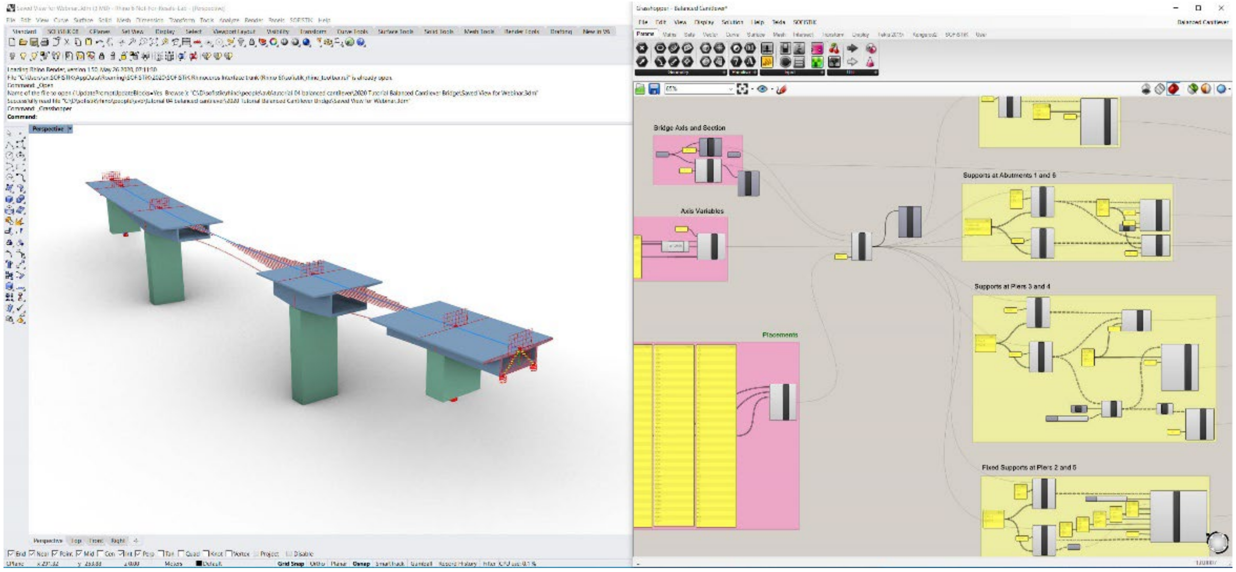


Figure 6 Grasshopper bridge parametric structural analysis[xvii] (SOFiSTiK)

Computational Design

Designers can also use scripting tools like *Grasshopper* to support, enhance and automate the process of designing a bridge—this is called computational design. A practical use case is to automate the calculation of design metrics ("takeoffs") from BIM models—indicative costs, embodied carbon, etc. Relevant design metrics can be combined and visualized on live dashboards, e.g. with Microsoft *PowerBI*, to enable iterative, "data-driven" design processes.

A prominent use case is to apply evolutionary solvers or machine learning algorithms to optimize parametric BIM models for desired metrics. This can work well where the design considerations are easy to quantify, and the so-called "solution space" consists of related alternatives. For example, it is likely practical to optimize an arrangement of hangers for a network arch, but not to identify a network arch as an optimal structural system.

5.4.2 Construction Applications

Scheduling

Some refer to extensions of BIM from three dimensions into "4D" (and onwards)[xviii]. The additional dimension refers to scheduling applications.

Estimators and construction managers can use packages like Bentley's *SYNCHRO 4D* to develop construction schedules and link them to BIM models. A scheduler might use *SYNCHRO* as they would a conventional scheduling package: identify activities, define logic, run critical path analyses, track against baselines, produce Gantt charts. Linking schedules to models also enables construction sequence animations and progress visualizations.

Quantity Takeoff

Most BIM authoring and coordination packages, including *Revit* and *Navisworks*, have in-built quantity "takeoff" modules, which estimators and construction managers can use to generate tables for material scheduling or further analysis using *Excel*.

Costing

Estimators and construction managers can also use packages like *SYNCHRO 4D* to directly build out "5D" cost models from both schedules (considering resource loading, labour rates) and model quantity "takeoffs" (considering unit prices).

Supply Chain Integration (Replacing Drawings)

Models can be used to replace drawings across the bridge supply chain, even if the two are not equivalent.

In Design-Build arrangements, some contractors request models from designers, in lieu of drawings, for estimating purposes. The models provide a (more) direct entry to the BIM scheduling, "takeoff", and costing applications described above.

Within Design-Build (and Alliance) teams, some contractors also seek to integrate design with fabrication modeling. Many see the potential for models as standalone contract documents, replacing drawing sheets altogether.

The more that stakeholders employ automated processes for bridge design, construction, operation, and maintenance, the more each are motivated to replace drawings and communicate directly through models.

5.4.3 Operation and Maintenance Applications

Digital Asset Management Systems

With a BIM workflow, digital asset information can be assigned to any model component and can be fed directly into asset management software. Asset components can be further broken down to a granular level of elements that can be inspected and rated individually. In such an application, the information collected by inspections can be linked back to the design model for condition assessment of degraded/damaged asset components as well as provide the opportunity to prioritize repairs and give financial insight along the bridge lifecycle. Furthermore, simulations of different scenarios could also be run using digital asset data either on a corridor scale or on a network scale (often GIS) to predict what impacts could have on traffic patterns if there was loss of bridge span or narrowing of bridge deck due to maintenance.

Because the models for digital asset management systems flow from design and construction projects upstream, it is critical to define clear information requirements up front.

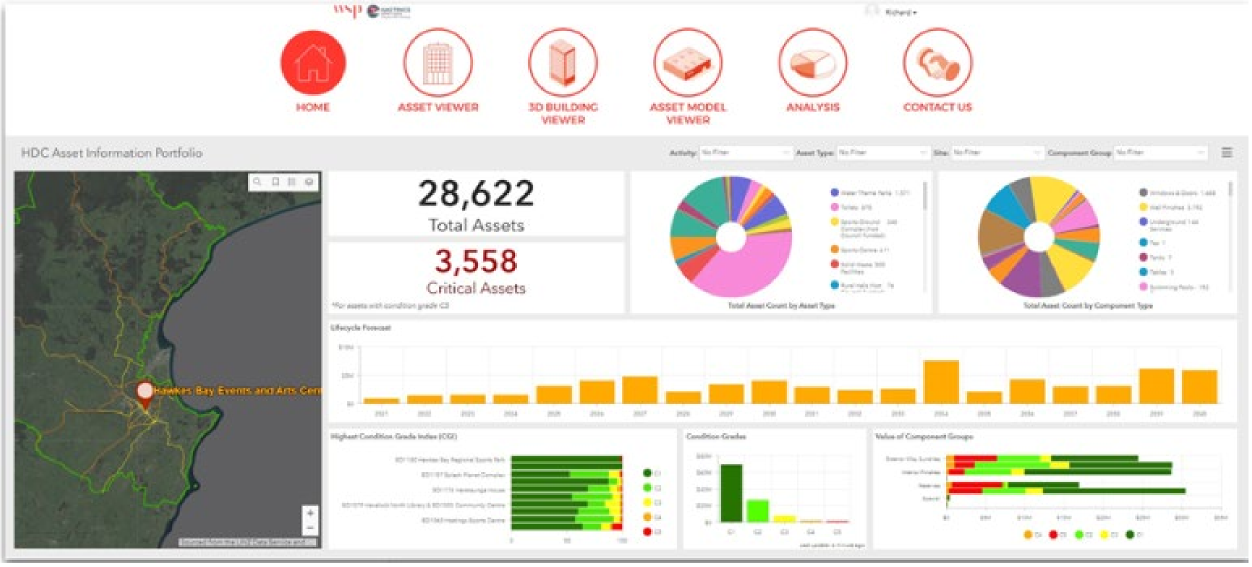


Figure 7 Digital Asset Management Dashboard (figure provided by WSP Canada)

6.0 CONSIDERATIONS FOR BIM IMPLEMENTATION

6.1 PEER JURISDICTION EXPERIENCE

As cited, many peer jurisdictions are investing in BIM implementation for bridges and highway infrastructure—others are on the same journey.

- In North America, Utah's UDOT and MTQ in Québec are perceived as leaders in BIM implementation.
- A 2021 FHWA global benchmarking scan[xix] identified the Nordic countries in BIM implementation for highway infrastructure.
- Since 2016, the UK has had a BIM mandate for publicly funded infrastructure projects[xx].

Within BC, other provincial government Ministries are considering BIM strategies within their scopes.

- According to a consultant[xxi], the Ministry of Citizens' Services in 2022 "*is reviewing the application of BIM and explore the risks and benefits that BIM brings to the government and industry. The aim is to assess the value of BIM in relation to BC Government infrastructure and building projects with a view to informing the development of BIM standards for future government projects*."
- The Ministry of Jobs, Economic Development and Innovation acknowledges BIM as a foundational technology in its 2022 Mass Timber Action Plan[xxii].

The experience of peer jurisdictions implementing BIM is accessible through both published reporting and informally through professional networks.

6.2 INDUSTRY ORGANIZATION

BC bridge industry stakeholders include:

- Bridge owners—for example MoTI, Ministry of Forests, Lands and Natural Resource, municipalities, TransLink, and other public and private owners.
- The bridge supply chain, including:
  - Engineering consultants: represented by ACEC-BC;
  - Contractors: for example those represented by the BC Road Builders & Heavy Construction Association;
  - Fabricators; and
  - Suppliers including technology suppliers such as Autodesk and Bentley.
- Academia, including:
  - Researchers: for example, UBC's BIM ToPICS Lab, in the Faculty of Applied Science, which is the centre of academic BIM research in the province; and

  - Educators: for example, accredited university engineering programs and technical institutes and colleges.
- Advocacy groups: for example, Building Transformations (formerly CanBIM) and buildingSMART Canada.
- Regulatory bodies including Engineers and Geoscientists British Columbia (EGBC), Applied Science Technologists and Technicians BC, and the provincial and federal governments.

Each group has a different interest in BIM, and a different perspective on its benefits and risks. Within each group, different organizations have different capacities for implementation and change.

6.3 EXPECTED VALUE

Industry stakeholders' expectations of value will constrain BIM implementation. These expectations are a function of:

- Organizational cultures (risk tolerance, appetite for innovation);
- The perceived value of the technology;
- Competitive pressures;
- Existing technology base including investments to date; and
- Individual buy-in—staff acceptance of new systems.

The alignment of cost/benefit expectations among multiple stakeholders signals an opportunity for BIM implementation.

6.4 CONTRACTING METHODS

As a collaborative technology, BIM is particularly suited to collaborative contracting methods[xxiii]. These include Alliance agreements and, to a certain extent, Design-Build.

Conversely, Design-Bid-Build methods, which isolate stakeholders across contractual interfaces, tend to limit BIM's potential to improve design and construction outcomes.

6.5 BIM REQUIREMENTS

Clear BIM requirements identify the information that stakeholders should create as well as the controlled, systematic processes for information to be created to specifications across the supply chain and asset life cycle stages.

- As such, they determine the level of effort to implement BIM on a particular contract or project.
- Requirements and standards need to be addressed up front, during budgeting and procurement.

BIM requirements are frequently maintained as strategic, general-purpose documents, with only limited exceptions among different projects and assets. The best-practice model for BIM requirements is comparable to MoTI’s approach to standard specifications and special provisions.

6.6 HARDWARE AND SOFTWARE

BIM technology suppliers have been pushing, for some years, to transition from an “on-premise” model, in which customers purchase and maintain hardware and software licenses, to a cloud-based model, in which customers rent functioning software—deployment, operations and maintenance included. The cloud-based model is frequently called “software as a service”. Each model has pros and cons.

- The “on-premise” model gives organizations full control over their information, including “residency”, or where it is physically located (cloud server location). It also assigns to the organizations full responsibility for information security, which is increasingly challenging year over year.
- Cloud-based systems delegate a measure of control of the information to the service provider, including data residency and the basic responsibility for information security. In turn, cloud systems are highly scalable: subscriptions are easy to accumulate and (in theory) relinquish.

Budgeting approaches for the two models are quite different.

- The costs of “on-premise” technology are split between capital costs for hardware and software, and operating costs for IT services.
- Cloud-based systems tend to move hardware and software capital costs into operating budgets. Larger organizations typically negotiate custom service agreements with technology suppliers—often including support, training, and other inducements—to ensure service and manage subscription costs.

6.7 DIGITAL CAPABILITY

Effective BIM implementation demands a wide range of digital capabilities among individuals within the industry.

- Model authoring—arguably the core digital capability—is an elaboration of CAD and is widely taught in engineering technology programs in BC.
- Many “hard” digital capabilities—e.g. databases, software development, cloud computing—are common in the tech sector. The skills are widely available, but relevant experience in the bridge industry is not.
- Many “soft” digital capabilities—e.g. knowledge of standards and workflows—are accessible through continuing education training, workshops, and conferences.
- Many technical staff arrive to the bridge industry as “digital natives”—with considerable digital capability and enthusiasm to apply their skills (that can sometimes go unrecognized in entry-level positions).

Crucially, BIM implementation requires effective identification and management of digital capabilities, that they mobilize and combine to improve the design, construction, and management of bridges.

6.8 PROFESSIONAL PRACTICE

BIM implementation changes the basic workflows of bridge engineering practice.

For example, quality control (checking and review) guidelines are imagined in terms of the current state of practice, i.e., assuming drawing sheets that can be reliably printed or rendered on a screen. The concept of quality control certainly applies to BIM workflows, but the implementation does not.

A key task for BIM implementation will be to update (and develop new) professional practice guidelines that address the unique characteristics and complexities of the technology. Currently, EGBC professional practice guidelines permit authentication of BIM models with digital "seals"—a digital certificate that can be embedded in a digital file.

- One can enclose a BIM model within an authenticated PDF/A-3 archive. Although this is consistent is professional practice guidelines, it is cumbersome and not feasible for very large files.
- Some BIM packages support digital certificates directly—they can embed digital certificates in models and will raise a flag if the contents of a model have changed since it was certified. Such capabilities are not widely understood.

Best practices for digital authentication are unlikely to emerge until the industry demands models to replace drawings as the principal means of encoding and communicating professional work.

6.9 COST

Direct BIM implementation costs include software procurement, development of new templates, standards, and workflows, and staff training. Direct costs are intentional investments, typically front-end loaded at the time of implementation.

Indirect BIM implementation costs include over- and under-scoping BIM execution (i.e., it does not meet project needs), and costs incurred from poor execution of new processes. Indirect costs are the costs of making mistakes, typically greatest during the early stages of BIM implementation, and moderating as experience accumulates and best practices (including standardization and automation) emerge.

BIM implementation costs do not accrue equally to all stakeholders—they tend to be higher for model-authoring stakeholders than for model-consuming stakeholders. The misalignment costs and expected values of BIM among stakeholders may constrain BIM implementation across the industry.

7.0 CONCLUSIONS

- Conventional drawings-based approaches constrain the productivity of bridge engineering practice.
    - BIM offers possibilities to overcome these productivity limits.
    - Budget and time pressures create incentives to explore these possibilities and consider implementing BIM in the BC bridge industry.
- A BIM model contains more information than a comparable set of drawings.
    - This creates a strong imperative for automation, to develop this information with a comparable level of effort comparable to conventional practice.
    - It also creates a strong imperative to create additional value from this information.
- BIM is a collaborative technology.
    - It can be used to integrate different stakeholders and deliverables across the lifecycle of a bridge.
    - Its value increases with the scale of collaboration—the level of connectedness among these stakeholders and deliverables.
- Implementing BIM will require investment across the BC bridge industry.
    - The potential benefits of making this investment can be improved outcomes for stakeholders across the industry, including:
        - better, more sustainable designs through improved efficiency,
        - improved construction quality through collaboration,
        - improved asset management through information gathering, and
        - lifecycle cost savings.
    - Effective BIM implementation is a goal, not a guarantee. It requires careful planning and effective execution.

APPENDIX A

Interview with Martin Krall, P.Eng., Ontario Ministry of Transportation (MTO)

Interview with Martin Krall, P.Eng., Ontario Ministry of Transportation (MTO)

Background:

Martin is a bridge engineer in the design section of MTO's structures office. Within this role, he is responsible for oversight of bridge BIM pilots project for the MTO.

Martin was interviewed on March 10, 2023, by (author) Jamie McIntyre, P.Eng. to assist the Task Force in understanding the scope of MTOs pilot projects and project lessons learned. The interview notes were edited for clarity.

Interview notes:

MTO bridge design pilots

- MTO has two BIM pilot projects.
    - Ministry in-house designed & delivered pilot project is using Tekla Structures
- The Ministry does not have a preferred/recommended vendor of BIM software.
    - Consultant design & delivered pilot project is using the Bentley suite: Open Bridge Modeler, ProStructures, MicroStation
- In-house BIM has experienced substantive setbacks/challenges at several points –still fighting the software to put in the shapes in the spots where they are supposed to go.
    - To deliver the project on schedule, the Ministry produced 2D sheets conventionally in AutoCAD. The Ministry continues to advance the 3D model of this pilot.
    - The intent was always to develop a model to LOD 350/400 as you describe in the next line/bullet.
- Pilots are proofs of concept. The 3D Model is not the legal document, and the contract requires the delivery of 2D sheets made from the 3D model to integrate into the standard contract documents (general conditions of contract, standards, specifications, etc.)
- MTO has concerns about future proofing for 3D model as legal document. Archival of bridge project information for future use only considers 2D drawings; users of the archive expect to open PDF files.
- The 3D modelling effort requires a level of detailing to which the engineering design office is unaccustomed. Detailing work typically associated with the shop drawings done by the General Contractor's subcontractors, suppliers, or fabricators is now part of the designer's 3D modelling effort.

Reference experience from other jurisdictions

- Finland: Considered leaders in this area. For reference, AASHTO Joint Technical Committee on Electronic Engineering Standards webinar "April 20 – BIM Global Benchmarking Scan."[xxiv]

- Australia (reference from information shared by a consultant to MTO)
    - A project was delivered using 2D drawings from 3D model. Contractor asked for the models, and they were provided.
    - Next project was tendered as model with no sheets. But received no bids.
    - Subsequent projects were delivered hybrid- some sheets (60%-70%). Enough detail went into the drawings to bid the project, but detailing need to build was found in the model.
- View is that hybrid delivery is a more likely than 3D models only. Certain details are not available from a 3D model of the final bridge configuration (e.g., camber diagram).
- Conclusions
    - Expect BIM to move slowly until business model switches to BIM model as legal document. MTO has no immediate plans to switch. MTO is exploring the development of a roadmap for larger digital delivery initiatives that would include BIM and 3D model as a legal document.

APPENDIX B

ACEC-BC/MoTI Bridge BIM Task Force Terms of Reference

ACEC-BC/MoTI Bridge BIM Task Force Terms of Reference

In 2020, the ACEC-BC/MoTI Joint Liaison Sub-Committee – Bridge struck a task force to evaluate opportunities for BIM in the BC bridge industry.

The Task Force's terms of reference are:

1. Understand current best practices for application of BIM to the design, construction, and operation of bridges.
2. Define objectives for application of BIM to the design, construction, and operation of bridges in BC.
3. Identify high-value BIM practices that contribute to these objectives and are practical to implement in the BC context.
4. Develop a roadmap for industry stakeholders to adopt high-value BIM practices.

Considerations for the Task Force's work include:

- The current state of bridge engineering practice in BC,
- Stakeholder motivations (MoTI, consultants, contractors),
- BIM software platforms,
- BIM standards,
- Experiences of other jurisdictions (MTO, UDOT, South Korea, etc.), and
- Emerging technologies (automation, computational design, etc.).

The publication of this bulletin concludes item (1) of the Task Force's terms of reference. In 2024, the Task Force will work toward addressing items (2) and (3).

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