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Building Information Modeling for Bridges and Structures

From Design to Construction Workshop

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Building Information Modeling for Bridges and Structures

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Preface

Building information modeling (BIM) is a powerful tool that has been used in the vertical construction industry since the 1970s. In the last decade, the worldwide transportation industry has been pushing for the implementation of BIM for bridges and infrastructures. This process revolutionizes the way projects are delivered and, to be successful, it requires the cooperation of all parties involved in the realization of the structure.

Workshop 1007 Building Information Modeling for Bridges and Structures: From Design to Construction held at the 101st Annual Meeting of the Transportation Research Board (TRB) in 2022 gathered BIM specialists, owners, designers, fabricators, and contractors to discuss how the implementation of BIM is proceeding in the U.S. bridge industry. This E-Circular summarizes shared knowledge and firsthand experiences to inform the industry of the current state of the art of BIM for bridges that came out of this workshop. The document also highlights suggested improvements and developments needed to successfully progress the implementation of BIM, as a joined effort of all the parties involved in the realization of a bridge and the software industry.

The views expressed in this summary are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the technical committee, related federal agencies, American Association of State Highway and Transportation Officials (AASHTO), or TRB.

ACKNOWLEDGMENTS

The committee thanks Aaron Costin, Alexa Mitchell, Brad Dillman, Daniel Jensen, Joe Brenner, and Sam Scozzari for presenting and all participants to the workshop for sharing their valuable insight, experience, and knowledge.

The following TRB Standing Committees were cosponsors of the workshop, and their contribution has been key to the event success:

- Standing Committee on Innovative Highway Structures and Appurtenances (AKB10),
- Standing Committee on Steel Bridges (AKB20),
- Standing Committee on Concrete Bridges (AKB30),
- Standing Committee on Geospatial Data Acquisition (AKD70), and
- Standing Committee on Visualization in Transportation (AED80),

A special recognition goes to the people that planned and organized the workshop and prepared this document:

- Travis Konda, HNTB Corp., AKC40 Committee Chair;
- Chiara Rosignoli, Hardesty & Hanover LLC, AKC40 Committee Vice Chair;
- Minerva Bonilla, North Carolina State University, AKC40 Committee Member;
- Peter Wang, HNTB Corp., AKC40 Committee Member; and
- Snehal Sonawane, WSP USA, AKC40 Committee Member.

Opening Panel Session

This workshop was kicked off by Travis Konda and Chiara Rosignoli with a brief welcome, overview of the gathering purpose and layout of the event schedule. The workshop consisted of four Panel Sessions in which the panelists shared information related to bridge construction delivering projects through BIM modeling and explored the viewpoints of different stakeholders (such as designers, fabricators, construction engineers, and inspection staff) to see how they are working differently in the BIM environment.

Following the presentations, breakout sessions were held; participants were divided into four groups of more than 10 participants per table with different backgrounds in industry, government, and academics. The participants discuss limitations, takeaways, and future directions for digital modeling using the respective presentation as a catalyst.

PANEL SESSION 1

Use of 3D Models for Construction Inspection and Benefits to Owners

Samuel Scozzari
Greenman-Pedersen, Inc. (GPI), New York
Presenter

Samuel Scozzari presented an overview of the evolution of construction, its current practice, and how to productively integrate BIM models within construction. The presentation started by emphasizing some of the main differences between plans in 2D versus 3D models. 3D modeling allows users to have a conceptual understanding of the product by providing a realistic visualization. As can be observed in Figure 1, 3D modeling allows the users to detect clashes and understand the size and scale of the physical dimensions.

The use of 3D modeling for construction opens the opportunity to inspect as-built updates (% complete) and effectively communicate construction plans with owners and the public. The use of 3D modeling for construction has the potential to improve field operations, for example by providing customizable plans into staged segments where dimensions, space, or checklists based on contract specifications are provided. Using 3D models for visualization purposes allows users to have mixed-reality (MR) views and the ability to check material specifications. Other BIM software functions include the capability of collaboration by providing alternation between 3D models and 2D ..pdf design plans.

Scozzari also covered additional areas of growth for use of 3D models during construction. This includes augmented reality, which overlays a 3D model over the actual construction site to improve the spatial and dimensional accuracy of placement. Representative examples of using augmented reality with model overlay are presented in Figure 2. BIM technology also allows users to have an open checklist screen to document work progress and upload it to supervising engineers. Further benefits include leveraging 3D models as a tool for construction inspection and asset management. Examples of these inspection techniques include the use of hardware devices to view MR—digital twin and real space together. Some BIM capabilities include the ability to record any changes and maintain an asset management database for the owner post-project reports and nonconformity reports (NCRs).

Despite all the improvements and benefits of BIM, this technology needs to overcome current limitations prior to broader application and acceptance. Such improvements include issues related to internet bandwidth/connectivity in the field. Loss of signal and malfunction of tablets due to excessive sunlight exposure and current lack of staff software literacy. There is an equipment (sunlight, internet, etc.) and human (training) learning curve needed for all stakeholders to have the ability to navigate through, interpret and make changes to the 3D model. Additional barriers include the ability to record variations that allow the tracking of NCRs or incorporating Owner-authorized changes to the contract design model, for keeping “as- built” records.

This presentation concluded by highlighting several BIM anticipated improvements in functionality and applicability. BIM dimensional and spatial accuracy can be improved by

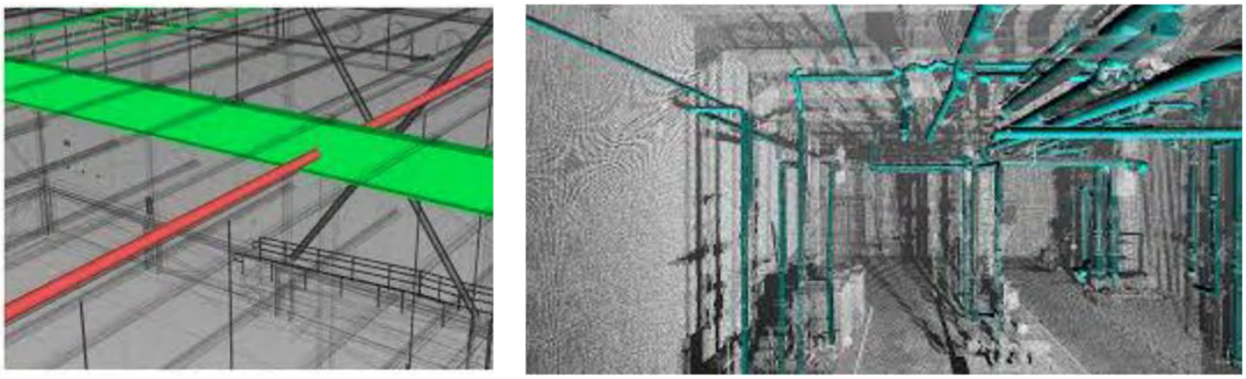

FIGURE 1 Evolution from 2D to 3D. Slide Prepared by Sam Scozzari.

FIGURE 2 Use of 3D Model in Construction. Slide Prepared by Sam Scozzari.

allowing one to view the work through multiple devices such as a tablet, phone, or HoloLens goggles that superimpose the 3D model over the actual work taking place in real space. This will allow using the model to detect unacceptable variations based on preset tolerances in construction or to confirm the acceptability of dimensions and location.

BREAKOUT SESSION

The following limitations and future needs were identified from the breakout session for the group associated with this presentation.

Current Limitations

- The ability to provide proficient and consistent inspection techniques (i.e., digital twin or augmented reality) that allow the use of BIM programs and software in the most-efficient way either in the field or in the office.
- BIM is considered an expensive technology; this limitation can be overcome by showing the value of investing in this tool. Small steps can be taken such as the incorporation of BIM technology for a limited number of activities.

Future Needs

As part of the future needs with respect to 3D modeling for construction, the participants identified the necessity of properly documenting the timeline–evolution of the 3D system and the capabilities of the technology and tools. In addition, it was mentioned that 3D modeling currently lacks accuracy because design plans are limited to the information that is incorporated, if the design plans are incorrect, the model is incorrect. The importance of identifying strategies to improve the reliability of the technology was mentioned. Participants mentioned the importance of emphasizing the cost-effectiveness of using BIM. Some stakeholders are currently reluctant to incorporate this technology into their business because it is perceived as an expensive tool whose benefits are often underestimated. However, when properly implemented, the main value to owners is more about the use of this digital information downstream from the construction phase of a program or project.

PANEL SESSION 2

Development of Building Information Modeling Exchange Standards in U.S. Bridge and Structures Industry

A Steel Bridge Fabricator's Perspective on the Exchange Process

BRAD DILLMAN
High Steel Structures, LLC, Presenter

AARON COSTIN
University of Florida, Presenter

Aaron Costin introduced the presentation on applying BIM within the bridges and structures industry, touching upon the general topics of digital models, digital exchange, data standards, and the means of sharing data. Brad Dillman followed with an example of a steel bridge fabricator's perspective on BIM and the information exchange process.

PART 1: DEVELOPMENT OF BIM EXCHANGE STANDARDS IN THE U.S. BRIDGES AND STRUCTURES INDUSTRY

Aaron Costin highlighted a major relevant work: the BIM for Bridges and Structures Pooled Fund study (TPF-5(372)). Administered by the FHWA and AASHTO Committee on Bridges and Structures, the study is ongoing and in its fourth year in 2022, with 23 participating states and over $2 million in commitments by project sponsors. According to the pooled fund's roadmap, the objective of the study is "to establish a standard for bridge semantic and geometric information that is common in the United States;" the study was motivated by the FHWA's interest to promote more efficient use of digitally shared information during construction. Costin noted that BIM has been used in the building industry for decades and has room for growth in the bridge industry. In the past 10 to 15 years, some strides have been made to capture bridge information through BIM, including defining the basics of how to represent data and understand a project situation digitally, how to develop standards, and how to develop a roadmap for state departments of transportation (DOTs) and the FHWA to move towards using BIM models. The pooled fund participants are currently concluding this project as it approaches the end of its 5-year timeline (2018–2023). Guidelines are being developed to create the first standard for digital exchange of design and fabrication data in the Industry Foundation Classes (.ifc) file format. Costin noted that AASHTO has resolved to adopt the .ifc file format as the AASHTO standard for approach-based structures. The study is summarized by the "BIM for Bridges and Structures TPF-5(372) Roadmap" (*1*).

Data Exchange

Costin described that one of the largest takeaways from the pooled fund study was the exchange process; Figure 3 displays the process of design through construction of a bridge, from bidding and letting to construction. In the exchange process, this involved identifying what specific information and data are needed for that activity and what data can be transferred digitally. In Figure 3, the data that can be transmitted digitally (BIM, digital twin, augmented reality, etc.) is represented by the green boxes, while traditional methods (phone calls, .pdfs, prints, emails, 2D drawings) are shown by the yellow boxes. The key was identifying where in the process the stakeholders can send information directly from the model, enabling creation of standards for the exchange, so that the designer can send off a model with the necessary information included.

Costin went on to define the digital exchange file as a file produced by software, to be interpreted by other software systems, and allowing for transfer of digital model information between software and users. Some examples of current digital exchange files are Word, Excel, and ..pdf. The problem he noted is that not all file types are able to be read by nonnative software; opening and accessing file information may be dependent on the software and data type, resulting in interoperability issues (i.e., what can be opened and read on the sender's computer may not be able to be opened and read on the recipient's computer). Therefore, Costin pushed the need for a standardized "neutral file" to represent the bridge industry, in a non-proprietary format so that any software (e.g., Revit, Bentley Systems, Civil 3D) can open and read it, manipulate it, and use it, thereby streamlining the exchange.

In the data access map of Figure 3, the exchange requirements model (green boxes) was not only the raw data itself, but also instructions on how to use the data. The inclusion of instructions provides receiving and sending users a map of how the information should be interpreted. For the exchange to be successful, the sending user must know what the receiving user needs, and the receiving user must understand what the sending user is planning to transfer.

Modeling Detail and Exchange Requirements

On the topic of data requirements, Costin emphasized that it is infeasible to include all details in the model since such effort takes too much time, money, storage, and results in data that does not add value. Therefore, exchange requirements must identify the data needed by the receiving stakeholder providing only the essential "snippets" of data for the bridge, and these exchange requirements must be accommodated by the software provider. The receiving user of the exchange file will define what data is mandatory and what is optional before the exchange requirements model is prepared and delivered with the required level of detail defined and agreed upon. The software vendors can then map these data needs into the data exchange requirements for the .ifc format.

Costin noted there are some preconceptions that need to be remedied before using the digital exchange process. The first preconception is that life-cycle information about the bridge can be created at any point for use at any time. Such a modeling approach requires excessive flexibility and makes it unclear what information is present and makes the intended use of the model difficult to define. A second preconception is that "data can be shared at any point" because users think it will be defined at the time of inquiry. Like the current delivery process, the timeline and data expected to be included for sharing should be clear and defined as

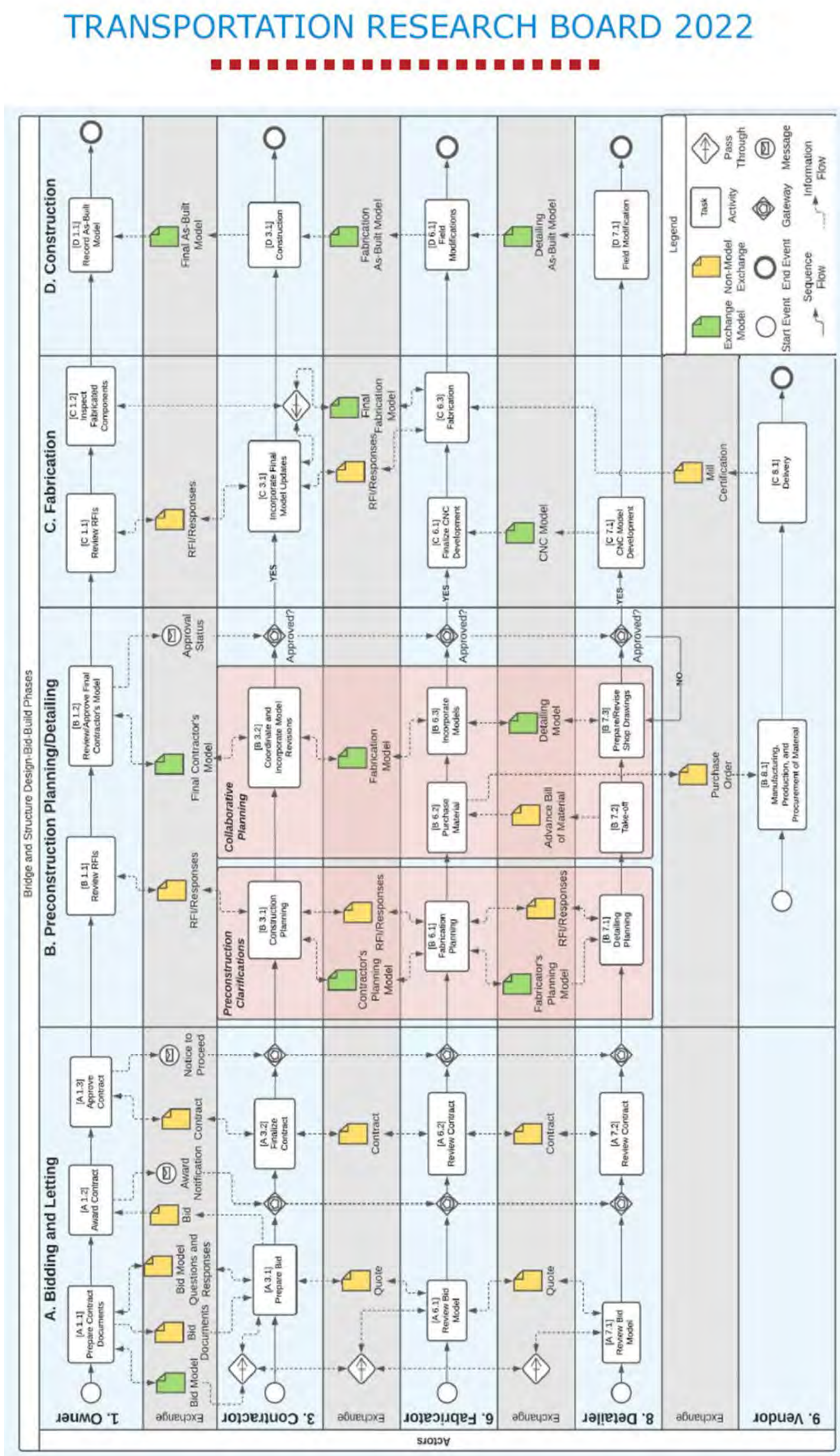

FIGURE 3 Exchange model versus traditional methods in the bridge and structure design–bid–build phases. Slide prepared by Aaron Costin.

the included data is developed with the project. A third preconception is the data needed by the different stakeholders is the same; each stakeholder oversees specific parts of the project development and requires different information. To emphasize this third point, the pooled fund study asked multiple stakeholders what data requirements they needed from the bid model to submit a bid during the bidding and letting period. Figure 4 shows the data requirements that different stakeholders (e.g., owner–designer, engineer–consultant, erector, and detailer–fabricator) need from the digital exchange model; the requirements are all different, though the information comes from the same dataset, bidding and letting period, and data file. It is clear from this figure that a software that is suitable (i.e., contains all the data requirements) for one stakeholder or client will not be identical or suitable to the software for another stakeholder based on their distinct data needs. Software must then be able to transfer critical data to various users.

Costin concluded stressing stakeholders must know what the data is and how to use it. The most common issue Costin reported hearing at TRB meetings is DOT users "have so much data, they don't know what to do with it. It is beneficial for stakeholders to understand the data exchange process—where the data comes from, what data is needed [e.g., laser scan, geographic information systems (GIS), digital twin], the effort required to create and send the data, and that other stakeholders who use the data exchange model may use the data in a different fashion. A wider understanding would allow stakeholders to not only use the data they possess, but also to share and utilize the data more efficiently.

PART 2: A STEEL BRIDGE FABRICATOR'S PERSPECTIVE ON THE DIGITAL EXCHANGE PROCESS

Next, Brad Dillman covered what an .ifc file exchange looks like from a fabricator's perspective. Dillman defined the steel fabricator's objective as "taking design information (e.g., contract plans, specs, special provisions) and fabricating steel to meet the intent of the design so that it can be constructed onsite." Structural steel fabricators do this by taking all the information currently provided to them in 2D contract plans and gleaning the information needed to recreate a 3D coordinate-based geometry of the structure. The fabricator manually inputs the 3D coordinate-based information into their detailing software to develop shop drawings for the structural steel to be fabricated. The detailing software drives the shop drawing production as well as production of CNC (computer numerically controlled) programs, for the purposes of cutting, drilling, punching, and marking the material; the 2D shop drawings and CNC programs are then pushed to the shop floor, leading to fabrication and erection of the structure. The manual process of creating shop drawings and CNC files from 2D plans is the relatively universal workflow for fabricators, as summarized visually in Figure 5.

While this is currently standard practice, Dillman noted that there are inefficiencies in the traditional designer to fabricator workflow; the designer uses information already available in a digital (and sometimes 3D) format to create 2D print contract drawing plans for the fabricator, which the fabricator uses to recreate a 3D digital coordinate-based representation to then print 2D shop drawing plans. At a high level, there is improvement to be made in the exchange between design and fabrication to cut down on the tediousness in the information transfer.

Information Groups	Entity	Property Group	Property	Owner/ Designer	Engineer/ Consultant	Erector	Detailer/ Fabricator
Project	Identification	Identification numbers	Project Identification Number (PIN)	M	M	M	M
			Bridge Identification Number (BIN)	M	O	M	M
			Contract number	M	M	M	M
		Names	Project name	M	M	M	M
			Bridge name	O	M	M	O
			Bridge alternative name (current)	N	O	M	N
			Bridge alternative name (existing)	N	O	M	N
		Over roadway identities (flyovers)	State highway name and number	N	O	M	M
			Route number	N	O	M	M
			Local road number name	N	O	M	M
			Functional classification	N	N	M	O
			Design classification	N	N	M	O
		Primary Road	State highway name and number	N	O	M	M
			Route number	N	O	M	M
			Local road number name	N	O	M	M
			Functional classification	N	N	O	O
			Design classification	N	N	O	O
		Under feature identities	Feature name (e.g. Highway, river, creek, etc.)	M	M	O	O
			Route number	N	O	O	O
			Local road number name	N	O	O	O
			Functional classification	N	N	O	O
	Location	Places	State	M	M	O	M
			Region	O	O	O	O
			County	O	M	O	O
			District	O	O	O	O
			Town	O	O	O	O
			City/Village	O	O	O	O
			Name of USGS quadrangle	O	N	O	N
		Coordinates	Project start coordinates (X, Y, Z or Northing, Easting, Elevation)	M	N	O	M
			Project end coordinates (X, Y, Z or Northing, Easting, Elevation)	M	N	O	M
			X plane coordinate	O	N	O	O
			Y plane coordinate	O	N	O	O
			Latitude	O	O	O	O
			Longitude	O	O	O	O

FIGURE 4 Required data for different stakeholders using the digital exchange model. M = mandatory, O = optional, and N = not needed. Slide prepared by Aaron Costin.

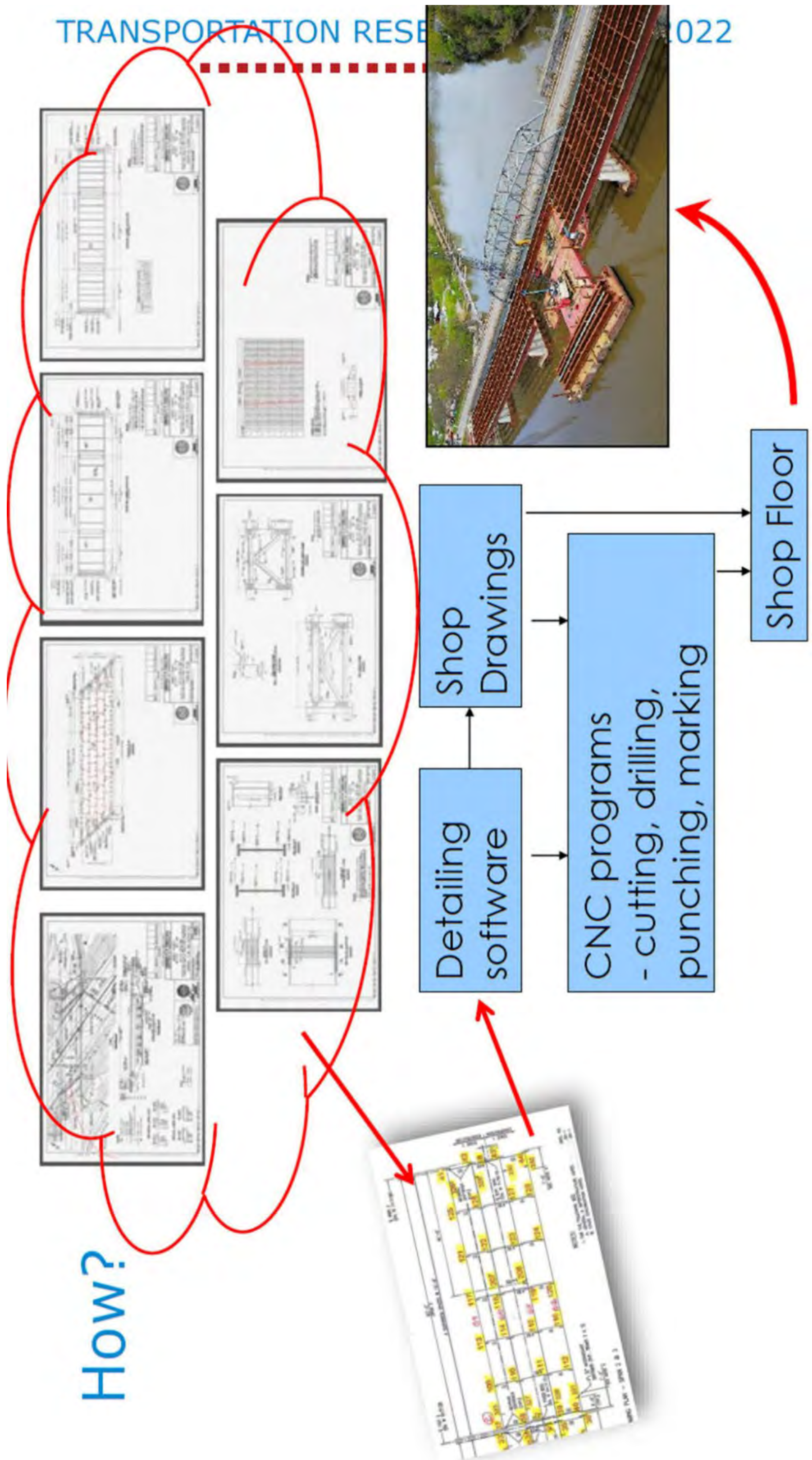

FIGURE 5 High-level fabricator workflow. Slide prepared by Brad Dillman.

With the advent of BIM, Dillman explained a fabricator can utilize the digital information that starts with the designer and feed that directly to everyone downstream (e.g., to the 3D coordinate-based system that starts with the fabricator), thereby skipping the 2D contract document stage altogether. The suggested streamline process is illustrated in Figure 6.

A recent example of experience with this “future fabricator workflow” is the New York State DOT Rte. 28 bridge replacement over Esopus Creek in Ulster County, NY, which was New York State DOT’s first model-based contract delivery project. Project photos and a summary of project details are given in Figure 7.

The design information for the project was delivered using Bentley modeling software. Dillman explained that all contract deliverables were contained within the model. No 2D contract plans were part of this bid package. Dillman noted that a common misconception is the 3D model is the sole source of information; in addition to the 3D model, there are also embedded Excel files (e.g., camber tables, geometry for the structural steel girders) and embedded pdfs (for special details for the structural steel). A set of instructions was also provided to tell the receiving user where to look for certain pieces of information, since it can be a bit of a challenge for the fabricator to locate the specific information needed.

Despite the different format of the received deliverable, Dillman maintained the process taken by the fabricator was the same. The fabricator still manually input all the information (this time from the 3D model with embedded Excel files and pdfs) into their detailing software to create the 2D shop drawings (subject to approval like a traditional project) and CNC programs needed to create the fabricated structural steel.

Relaying fabricator experiences, Dillman said the New York State DOT project was a strong first step to help push model-based contracting forward by testing the process, seeing what worked well, and identifying areas of improvement. Dillman noted the deliverable was in mixed formats (e.g., 3D model, Excel, and pdf) which proved to be challenging for the fabricator to locate and cross check information sources. Dillman said the challenges emphasized the benefit and the need of the neutral .ifc file to solve some of the challenges of mixed formats. For fabricators, it would be useful to have a standard file format where all users know by virtue of the file format where to find particular pieces of information. The file will allow different stakeholders to program and extract the necessary info from the file efficiently.

Dillman closed with a discussion of misconceptions about BIM for bridge projects. A major misconception is that fabricators receive a 3D model and go directly to the shop floor. Figure 8 shows the first misperception that fabricators can go from the delivered 3D design model (or even from traditional 2D plans) directly to the shop floor. This assumption shortcuts all the processes that fabricators implement to accommodate and create the final fabricated component drawings to meet the design intent.

The design deliverable must be adjusted by the fabricator to be properly implemented in the shop. For example, in a standard welded plate girder, a camber table is provided by designers and used to create web cutting diagrams and CNC code to burn the web lines. However, the CNC code produced by the fabricator does not match the design camber tables exactly, since the fabricator makes adjustments to account for weld shrinkage as well as tolerances. The design camber cannot be taken directly due to the need for this intermediate step. Another example is bearing stiffeners that are milled to bear. The bearing stiffeners must be made longer so they can be milled to bear, and the code to the CNC burner must account for this additional length which is not in the design data.

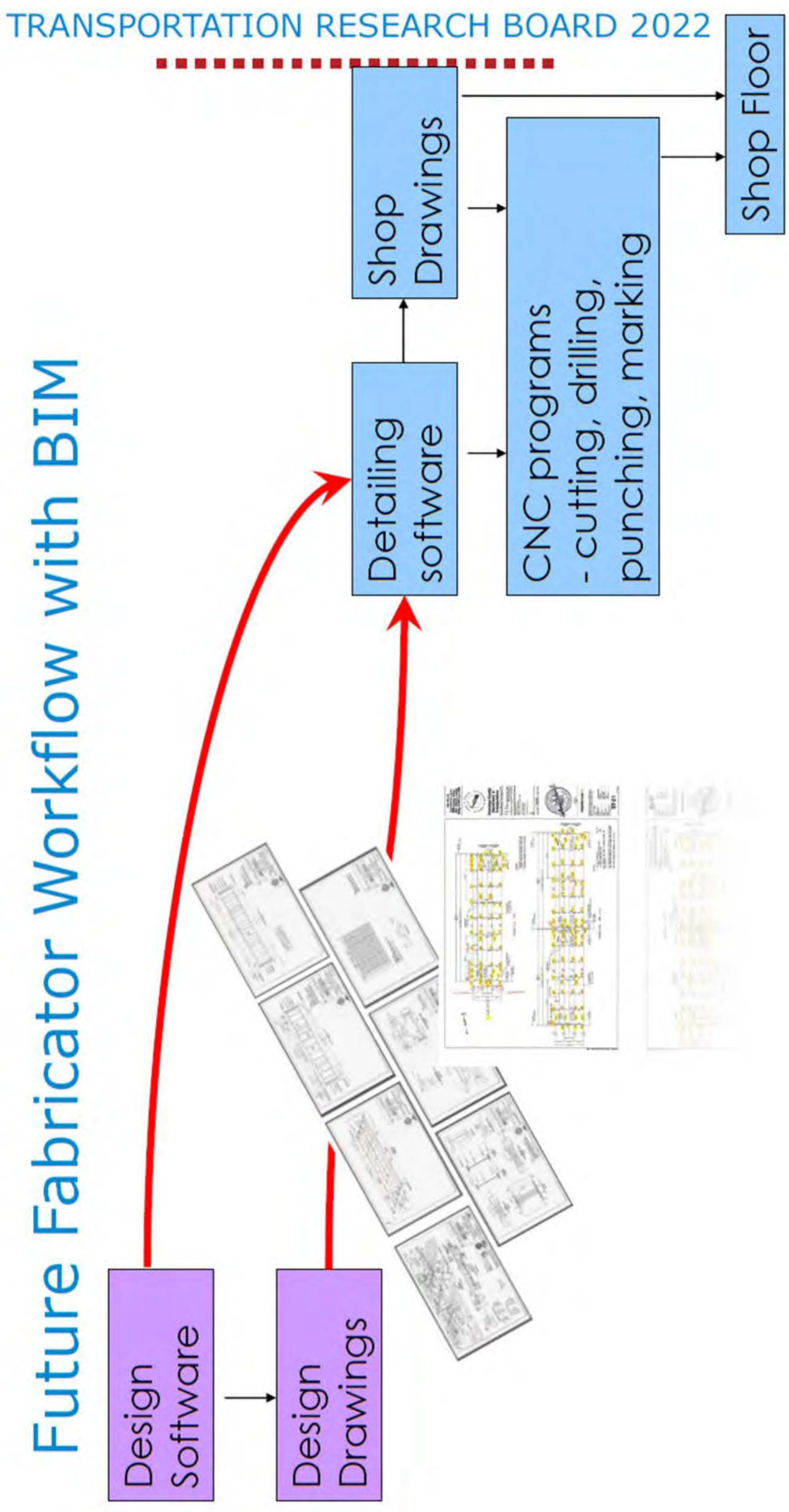

FIGURE 6 Future fabricator traditional workflow with BIM, with top red arrow shortcutting the 2D contract plans phase. Slide prepared by Brad Dillman.

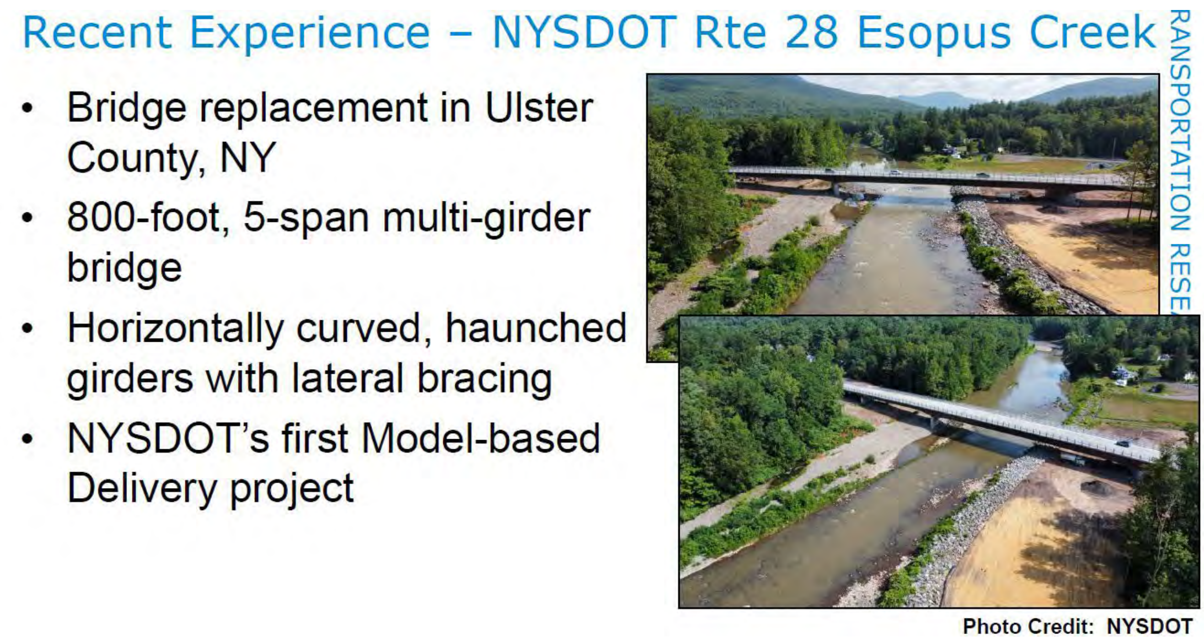

FIGURE 7 Project details for New York State DOT Rt. 28 bridge replacement over Esopus Creek. Slide prepared by Brad Dillman.

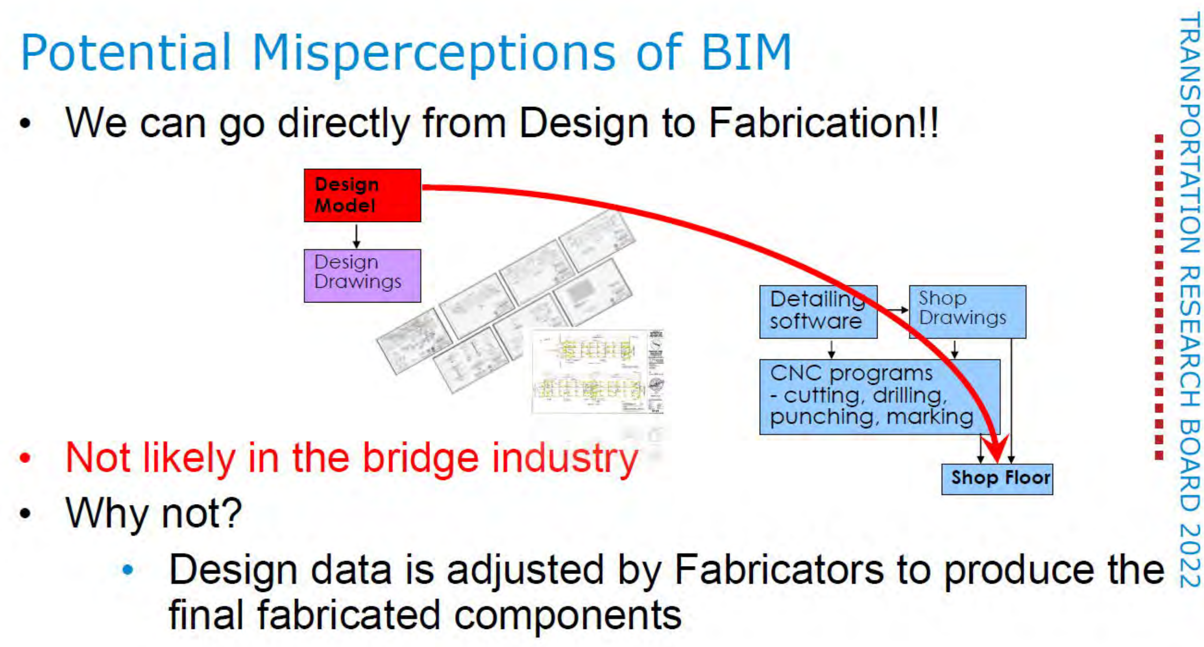

FIGURE 8 Misperception that fabricators can go from the delivered design directly to the shop floor. Slide prepared by Brad Dillman.

The final presented misconception was that the 3D model is the key in BIM. Dillman said that the 3D model was a great tool, but he maintained that the data driving the 3D graphical representation is the key, not the 3D model itself. He found that what everyone needs is the data, but stakeholders need different parts and pieces of the data to complete their part of the project.

These data can be contained within an .ifc file, which can be input in a software to generate a 3D visualization and representation, but the data itself is what is most needed.

BREAKOUT SESSION

The following limitations and future needs were identified from the breakout session for the group associated with this presentation:

Current Limitations

The main limitation addressed was the mixed formats in the digital exchange model (e.g., 3D model file with embedded .pdfs and Excel files) that fabricators had found challenging to navigate. A question asked was "What info was in the [embedded] .pdfs versus in the model?" Examples to answer this question were detail connections in the .pdf and camber tables in Excel. A resolution addressing this mixed format limitation was the .ifc model should include all data required by each partner software program that uses the file. Partner programs would only import–export data from the model that are pertinent to it, giving each stakeholder the information they need.

Future Needs

Several future needs were identified by participants, driving future directions of BIM for bridges. An area of future development that arose in the breakout session was "how to handle alternates in [the] model." This question ponders alternative designs and how to handle them in a 3D deliverable BIM model. Participants noted that the owner creating the model knows what data others would need and could use rule sets to accommodate alternates. They hypothesized that two different models would be needed for alternates (e.g., one for concrete versus steel bridge model). In terms of level of detail, the participants found a future need would be accommodating models that are only developed to 30%, which would be true of the 2D drawings as well in a 30% submission. Specifying what information is set (e.g., a specified dimension) and what is not yet determined (e.g., a member with a yet undefined plate size) would be a need in modeling. Another future need was a revision/audit history for the .ifc file. Participants asked if this was planned, and the presenters confirmed that it was.

Participants asked about the state of .ifc adoption and how it could progress as a future need. Producers of data and data users would be affected by this process. Participants noted that software vendors are on board, who could present only the data their users need in their software from the .ifc file. Leaders in the .ifc movement are still working on data mapping as it pertains to horizontal (bridge) design. The intent is to finalize .ifc and those future changes will happen in one's individual data dictionary. Participants noted that the adoption of the .ifc standard is largely driven by owners and oversight agencies, especially if it is included as a bid item; this would be a strategy on how to next incorporate .ifc in the bridge industry. A major step in this direction is AASHTO recently adopted .ifc, though participants noted that no one is leading the data dictionary efforts for AASHTO yet, so leaders in this area are needed.

Outstanding questions to be answered include: (1) Who will be the keeper or librarian of the data dictionary? Participants posited this may be the FHWA, AASHTO, another entity entirely, or state DOTs, noting that states tend to drive AASHTO standards that are adopted by the FHWA. (2) Is there need for an AASHTO data committee? Participants found that the process to adoption could be complicated and long, which can delay standard adoption. The AASHTO committee could have parallels drawn to the BuildingSMART Initiative, where established "agents" act on behalf of key parties to keep the data dictionary current. These questions and discussions showed the current state and future direction of data exchange for bridges.

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1. BIM for Bridges and Structures TPF-5(372) Roadmap. March 30, 2021. Available at https://bimforbridgesus.com/application/files/6116/1712/0056/AASHTO_BIM_Roadmap_20210330b.pdf. Accessed June 6, 2022.

PANEL SESSION 3

Structures Digital Delivery

Design Through Construction

DANIEL JENSEN
JOE BRENNER
Michael Baker International, Inc., Presenters

Daniel Jensen and Joe Brenner presented their findings on the digital delivery process of five bridges performed for Utah DOT. Jensen and Brenner covered information related to the utilization of the digital delivery process that require a 3D design for those five bridges. The presentation was divided into two parts. The first addressed the project overview and the second included the digital delivery process (from design to letting) utilized. An overview of each project follows.

PART 1:
PROJECT OVERVIEW

The first part introduced the bridge over I-80 over Union Pacific Railroad Tracks (UPRR). This bridge replaced two existing three span steel with single-span steel girder bridges over the UPRR track. The existing piers were skewed to the UPRR tracks. Figure 9 displays the elevation view of the existing bridges. The project was delivered through a construction management–general contracting contract. This is the first bridge project performed in Utah that utilizes a digital model as a legal document (MALD). The project was performed fully in 3D design. Sample views of structural details of the full 3D model are displayed in Figure 10.

The second bridge introduced was the bridge replacement of SR-36 over I-80. The elevation view of this design is presented in Figure 11. The new SR-36 over I-80 bridge replaced the existing four-span steel bridge with a three-span concrete girder superstructure built offline. The substructures are highly skewed to the SR-36 control line. This project required realigning the roadway and revising the profile grade. The final 3D design for this project is displayed in Figure 12.

The third bridge introduced was the 5600 W over UPRR. This project had a new bridge constructed over existing UPRR tracks changing from an at-grade intersection to a grade-separated rail crossing. The design included both curved horizontal and vertical alignments. Due to the complexity of the design, this project required considerable coordination with multiple disciplines to determine an optimized design that worked with the site and present constraints. The proposed final design for this project is displayed in Figure 13.

The fourth bridge was the replacement for I-84 over UPRR and Weber River. Given the project constraints, the task requires considerable manual modeling because of software limitations in parametric features. The modeling presented some unique topographic challenges

FIGURE 9 Side View of I-80 Blackrock project.
Slide prepared by Daniel Jensen and Joe Brenner.

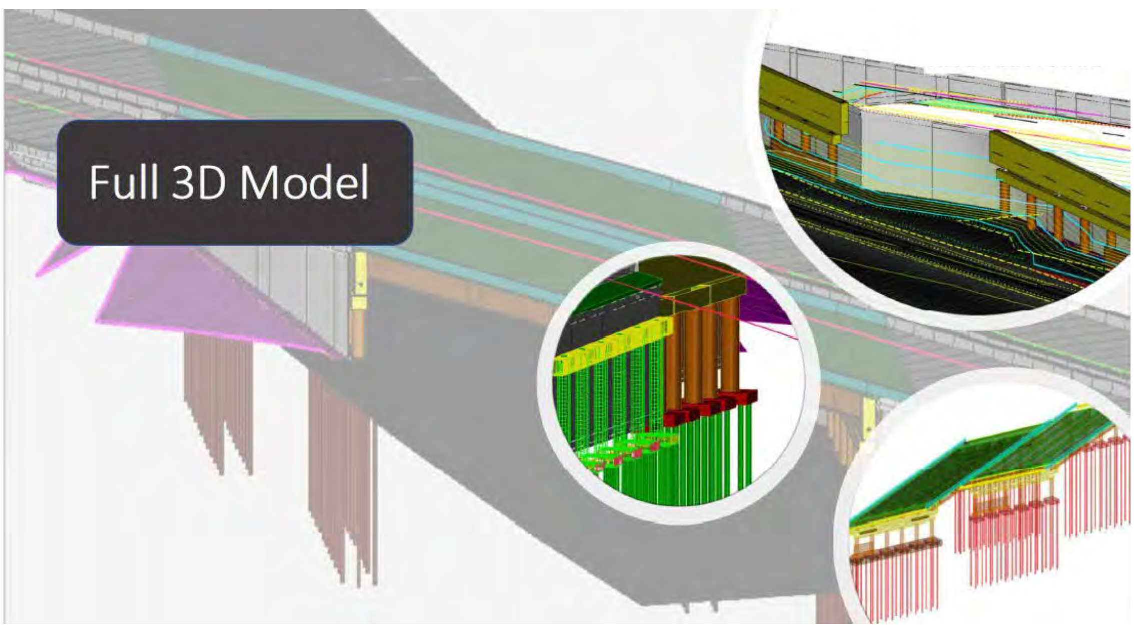


FIGURE 10 3D model for I-80 Blackrock project.
Slide prepared by Daniel Jensen and Joe Brenner.

FIGURE 11 Side view of SR-36 over I-80 project.
Slide prepared by Daniel Jensen and Joe Brenner.

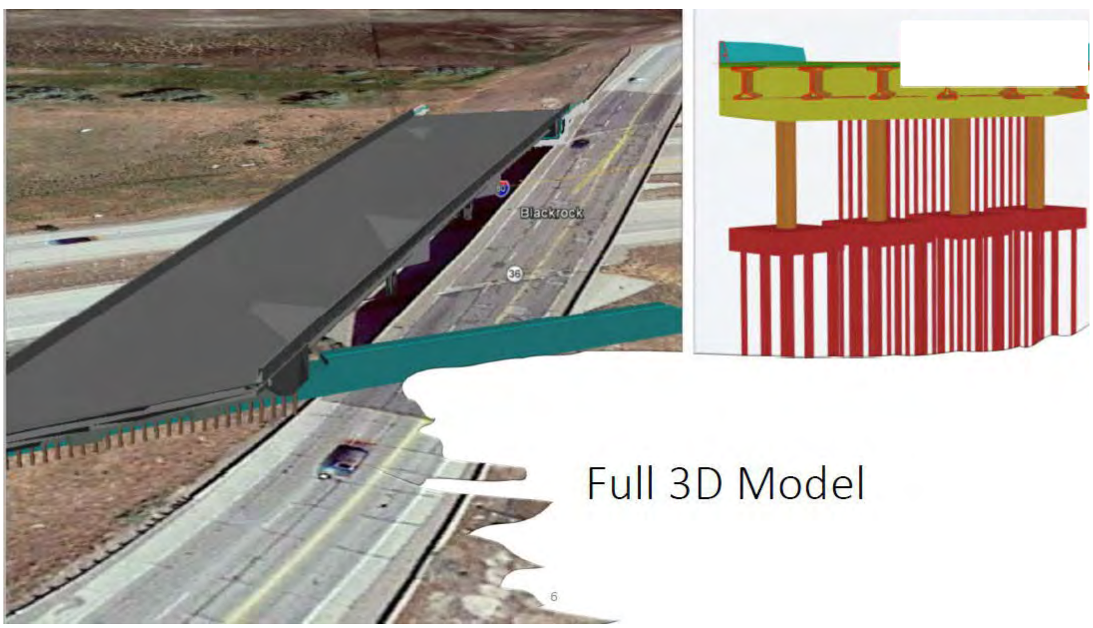


FIGURE 12 3D model for SR-36 over I-80 project.
Slide prepared by Daniel Jensen and Joe Brenner.

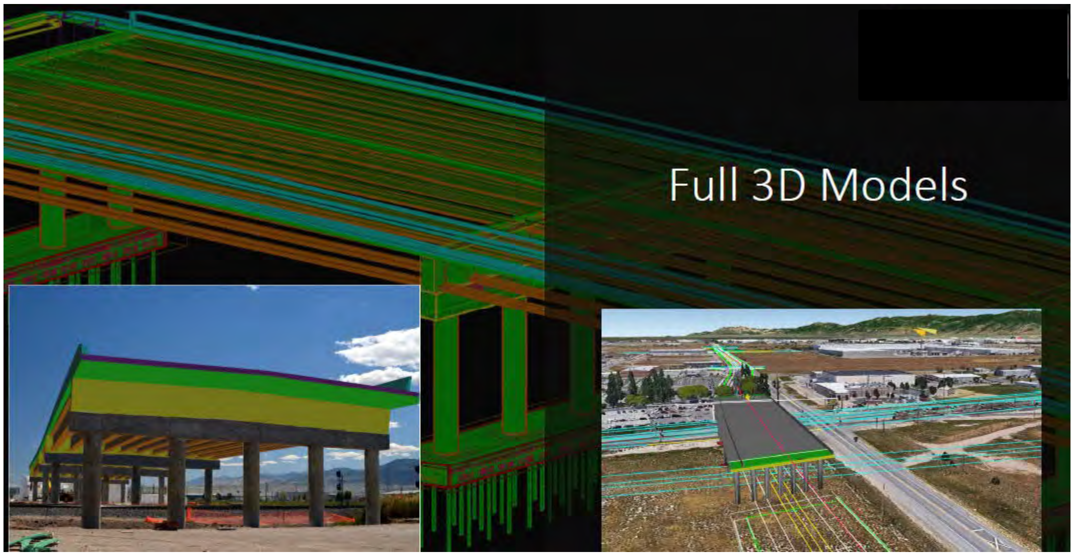


FIGURE 13 3D model for 5600 W over UPRR project.
Slide prepared by Daniel Jensen and Joe Brenner.

and due to the limitations of the software, the model needed to have hands-on modeling of some details. Hand modeling caused a very time-consuming process that complicated the BIM design. Figure 14 presents the 3D model for I-84 over UPRR and the Weber River project. As shown, the bridge geometry is constrained by the river and the adjacent railroad track. In addition to having to perform a manual model, the task requires intense coordination with railroad officials to ensure the construction is feasible, especially since the railroad operates over 40 trains per day and its operations cannot be disturbed.

The final bridge presented was the bridge design for I-696 over Rouge River. This project includes the design of two parallel bridges with splayed concrete girders with multiple phasing models. Similar to the I-84 over UPRR and Weber River project, due to the highly skewed alignment, the design of this bridge required the coordination of multiple stakeholders. Figure 15 presents the 3D model for I-696 over Rouge River.

PART 2: DIGITAL DELIVERY PROCESS

The second part of the presentation covered the digital delivery process utilized by Michael Baker International, Inc., on the three projects presented in Part 1. The discussion included an introduction to the efforts applied to facilitate DOTs in adopting 3D modeling.

The organization of the digital delivery process followed by Michael Baker International, Inc. included three main components.

1. The creation of a working environment.
2. The structure of data files, and
3. Additional information (i.e., notes, 2D details, supplemental data).

**FIGURE 14 3D model for I-84 over UPR and Weber River project.
Slide prepared by Daniel Jensen and Joe Brenner.**

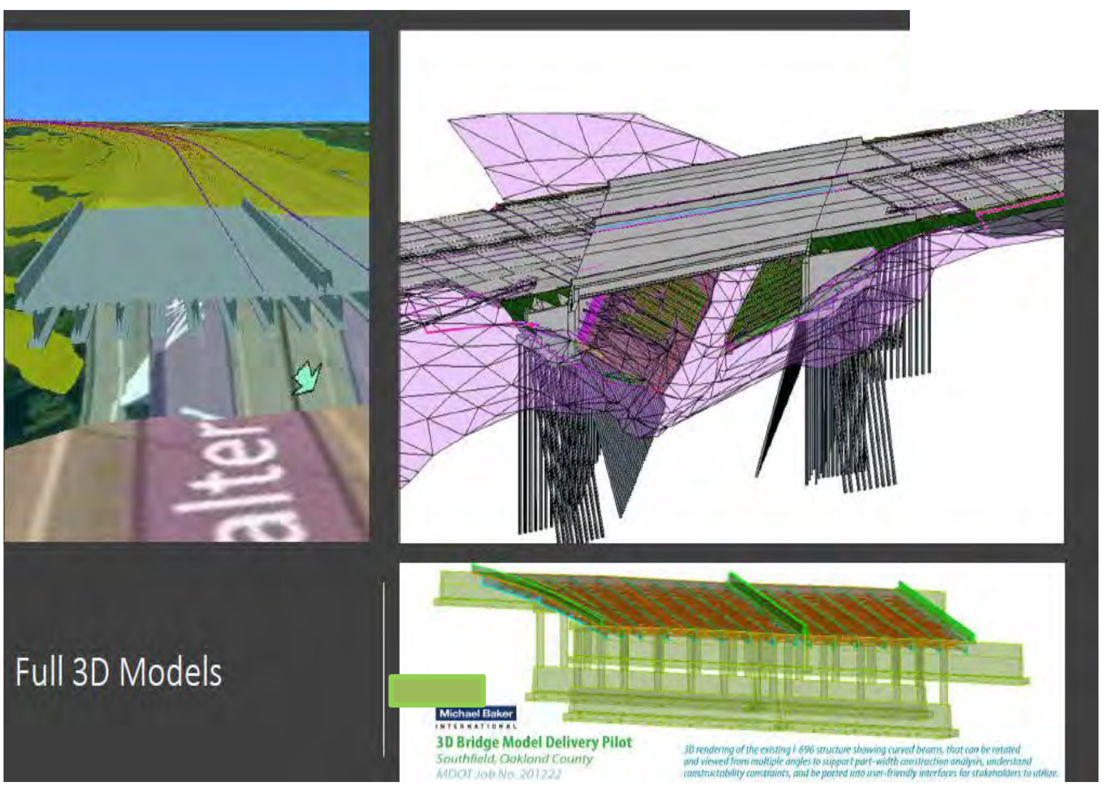


**FIGURE 15 3D model for I-696 over Rouge River project.
Slide prepared by Daniel Jensen and Joe Brenner.**

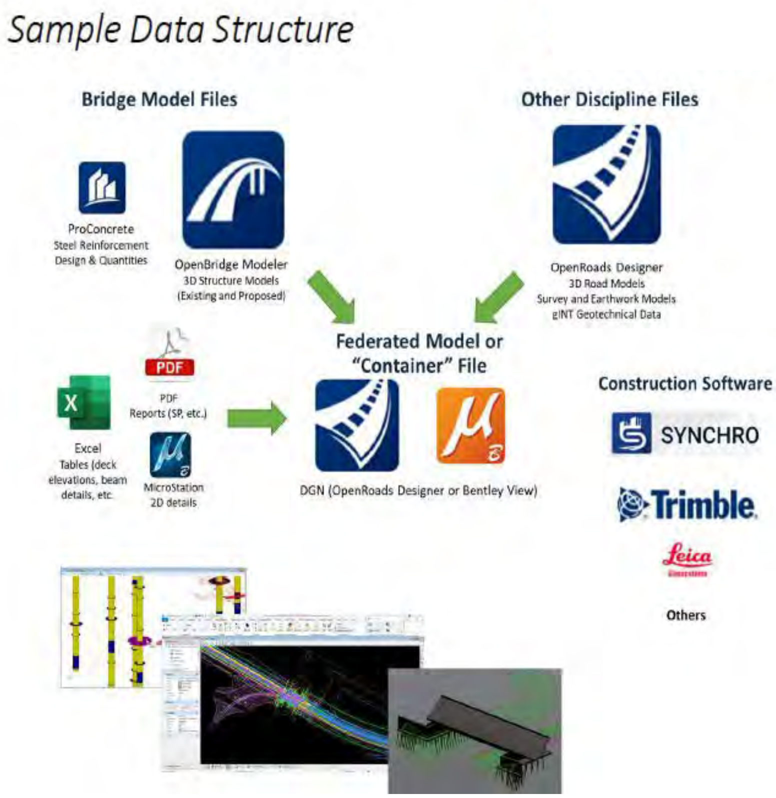


FIGURE 16 Sample data structure for digital delivery process. Slide prepared by Daniel Jensen and Joe Brenner.

A sample of the data structure is presented in Figure 16. In this figure, even though multiple disciplines (e.g., construction, bridge, and roadway design) utilize different software, the files have the same underlying format allowing for a standard format for models and the creation of layers/levels of the design fostering collaboration. Some common use formats include Excel, .pdf, and MicroStation 2D details. Using a standard format allows users to incorporate additional information such as notes, 2D details, and supplemental data.

In addition to having an organization for the digital delivery process, it is important to consider and define the level of modeling detail for the project. Jensen and Brenner recommended building the geometry of the bridge with 3D "solid" elements. This will allow for modifying elements to ensure correct geometry and not to model all elements of the design as detail modeling should be used only where such detail is necessary. It was recommended to first determine which details are useful for the design and plan the detailed models as such. If further specifications are needed for a model, it is recommended to utilize attributes and attachments.

The attributes and attachment features allow users to incorporate information that would not be included in the basic (solid) model. This information is considered useful to have available and easily accessible providing a broader description. Figure 17 is an example of how these attachments can be incorporated into a 3D model. These attachments contain details related to the concrete deck, beams, abutment stem, or other important topics of relevance to that particular part of the design. Attributes can be files of multiple types providing additional critical information, specifications for instance.

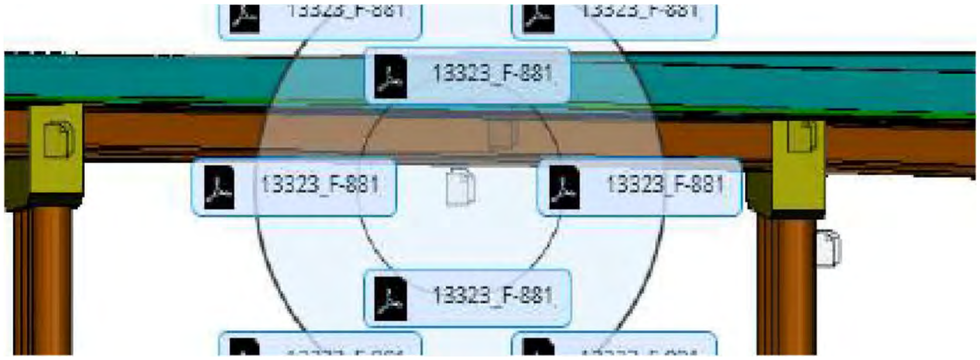


FIGURE 17 Sample of attributes and attachments in a 3D model. Slide prepared by Daniel Jensen and Joe Brenner.

Jensen and Brenner covered information related to saving views and reviews (or a summary) of the model. The discussions surrounding this topic focused on the limitations and attributes of the technology. This includes information related to elevation reports, quantity reports, geometric reports, and reinforcement bending schedules.

BREAKOUT SESSION

The following limitations and future needs were identified from the breakout session for the group associated with this presentation:

Current Limitations

The limitations identified in the breakout sections included concerns regarding the capability of the software. First, participants identified that 3D plans present a grid to ground distortion and overcoming this is important to create reliable documents. Second, a concern regarding the sealing of 3D documents was raised. As of today, not all states have implemented laws or policies regarding the authorization of sealing 3D models, therefore, it is suggested that users may want to consider looking for alternatives and document findings.

Lastly, participants mentioned that digital delivery may be limited by the design process of the project. For example, if a project is delivered through a design–bid–build contract, the compatibility with various contractor software packages must be addressed.

Future Needs

Several future needs to fully incorporate digital delivery for all DOTs were identified by participants. There is a need to produce National Standards for how to conduct surveying work with BIM models and how to create files that are compatible with any software.

Similarly, sealing 3D models possess legal and liability questions, therefore participants noted that it is essential to update specification requirements, including documents that clarify contractual files, and how these can be delivered. The concept of sealing documents in 3D and locking the modification features to prevent any changes was introduced. Future work on how to develop these files is needed. To do so, it is also important to maintain parallel standards for 2D and 3D models (for the next step in the future).

Another future need identified includes the importance of maintaining or developing files that will be accessible far into the future as asset management tools. Considering that DOTs' projects have a typical life span of 20 to 30 years, from planning to the actual construction of a project, it is important to ensure a file can be opened 10 to 20 years from creation. Because project-built assets can last more than 100 years, it is important to consider how a digital file from design and construction is maintained as a usable document far into the future.

PANEL SESSION 4

BIM Uses and Model-Based Reviews

ALEXA MITCHELL
HDR Inc., Presenter

Alexa Mitchell's presentation focused on examples of BIM applications on five DOT projects. Her presentation covered BIM use in the following applications:

- New York State DOT Kew Gardens Interchange Phase IV (Queens);
- Utah DOT I-84 over Weber River and UPRR Bridge Replacement (Weber County);
- Ohio DOT MRG-376-8.10 Emergency Landslide Repair (Morgan County);
- Ohio DOT Tru-46/82 Diverging Diamond Intersection (Trumbull County); and
- Montana DOT Salmon Lake Highway Reconstruction (Missoula County).

Mitchell's presentation was broken into three parts: project examples of 3D model-based uses, model-based review, and lessons learned.

PART 1: PROJECT EXAMPLES OF 3D MODEL USES

Mitchell's first example was the New York State DOT Kew Gardens Interchange Phase IV in Queens, which had several BIM requirements in the contract. These included

1. Creating 3D/4D/5D models and animations to illustrate planned and completed construction with associated costs;
2. Using 3D models for interdisciplinary design collaboration; and
3. Delivering as-built 3D CADD models and 3D GIS datasets at construction completion.

In this context, 4D was defined as including time schedule (e.g., critical path method) in the model, while 5D meant including cost as the 5th dimension. Level of development (LOD) requirements were specified in the request for proposals stage; LOD requirements tell BIM users what level of accuracy or completeness their models are required to be developed to (*1*), and they ranged from conceptual (LOD 100), to precise geometry (LOD 300) to as-built (LOD 500) for different aspects of the Kew Gardens project. The software tools used were Bentley Microstation, InRoads SS2, and ProjectWise for this design–build delivery type. Though these tools were not developed recently, the intent was to leverage the technology to meet engineers' needs. The design–build team worked with the contractor and the owner simultaneously, using the model to visualize unique details and to conduct geometry coordination engaging all parties. A model-based visual and summary of project details are shown in Figure 18.

The project model uses on the Kew Gardens Interchange Phase IV project are

FIGURE 18 Project details for New York State DOT Kew Gardens Interchange Phase IV. Slide prepared by Alexa Mitchell.

summarized in Figure 19. Major benefits of BIM included clearance checks and clash detection. On the Kew Gardens project, the use of BIM avoided a large change order when the proposed design was determined to clash with a viaduct. The use of BIM allowed the project team to revise the design and avoid a change order estimated in excess of $1 million. In this case, the benefits of using the BIM software outweighed the cost through change avoidance alone. The takeaway was to save on costs by using the tools available for their intended purposes.

The Kew Gardens Interchange Phase IV project showed that the 3D model could be used as a public information model to communicate project ideas to the public. The 3D models enabled visualizations and offered the capability to do field of vision studies—placing cameras in the model and presenting what the driver could expect to experience. Mitchell stressed the benefit of using BIM throughout the project delivery process. She emphasized the gained efficiency and broader capability creating visualizations from the schematic BIM model as opposed to creating standalone graphical visualizations.

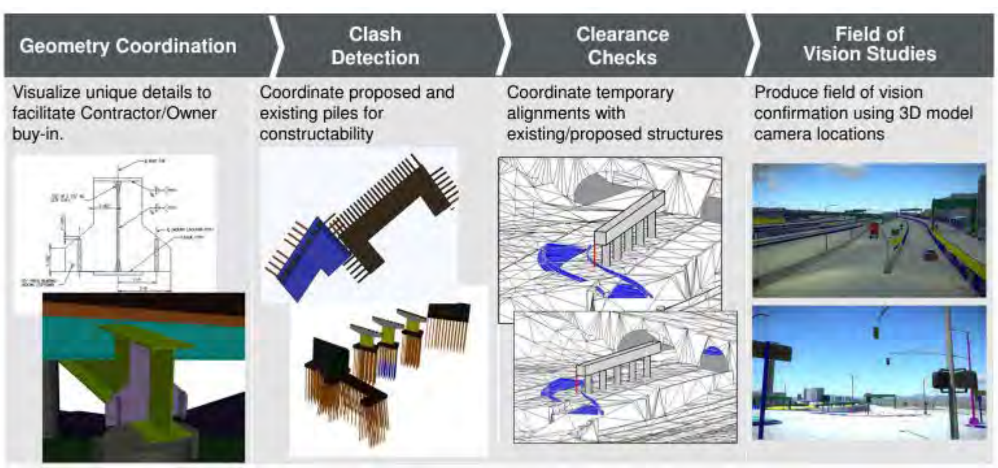


FIGURE 19 Project model uses on the New York State DOT Kew Garden Interchange Phase IV Project. Slide prepared by Alexa Mitchell.

The second project Mitchell covered was the Utah DOT I-84 over Weber River and UPRR Bridge Replacement in Weber County. This was an I-84 bridge replacement which incorporated the MALD requirement for roadway, structure, and drainage models, highlighting model use and delivery by different disciplines. The tools used were Bentley's ORD (OpenRoads Designer) Connect, OBM (OpenBridge Modeler) Connect, ProStructures, and iTwin Review. For this project, HDR and Michael Baker International used OBM for their structures and iTwin Review for model-based review and MALD. Limited traditional 2D sheets were used for UPRR coordination. Specific use cases included a contractual model and engineering coordination. The use of models encouraged more collaboration because the different project teams were viewing each other's designs earlier. This model-based design collaboration and review could be either real-time or not, depending on if a cloud-based service was used. Mitchell asserted that by using the modeling capabilities, the design team was able to better coordinate and make better decisions for the project. Project details and a model visual are shown in Figure 20.

On this Utah DOT project, the BIM model was a contract deliverable. Mitchell explained it is becoming standard practice for bridge and roadway models to be contract deliverables. This trend is expanding to drainage and utilities as well. The use of models across disciplines allowed designers to reference each other's work in coordinating design details and making needed adjustments. In this project, the engineers modeled construction staging for the purpose of facilitating construction (e.g., a model for Phase 1, a model for Phase 2), providing a clear workflow and avoiding conflicts, thus allowing the contractor to progress faster.

A main takeaway from Mitchell was not to increase the level of modeling detail "just because" or for the sake of modeling; there must be a concrete reason and need, preferably identified at the start of the modeling process. For example, if modeling at a refined level (e.g., LOD 300: precise geometry) saves the engineer time to produce quantities, then the modeling is worthwhile so the engineer can focus on more important tasks for design. Quantities can be derived directly from the model in these cases, and current software packages provide many tools to report the estimated quantities.

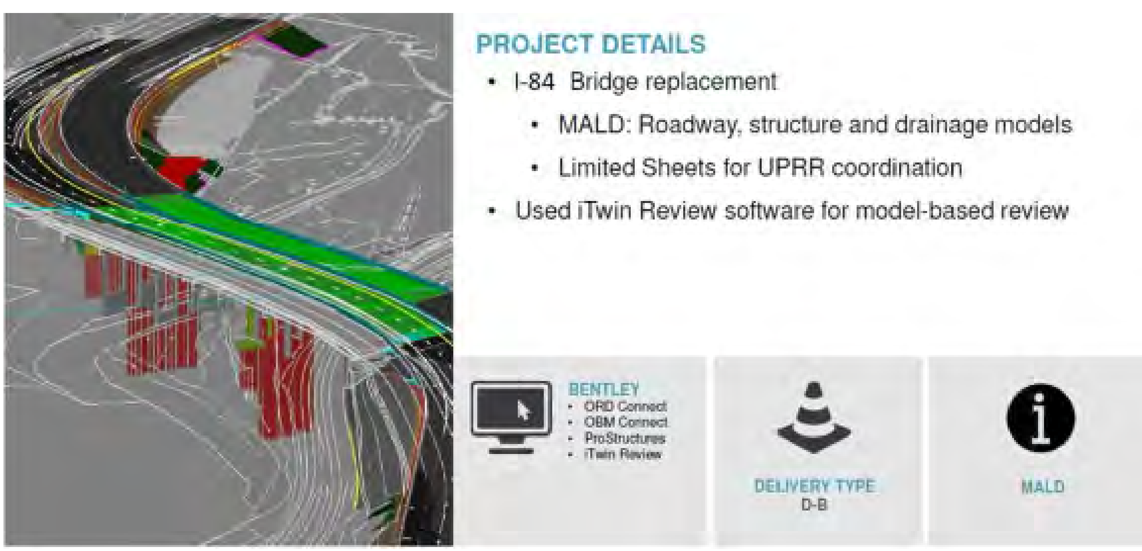


FIGURE 20 Project details for UDOT I-84 and UPRR Bridge Replacement. Slide prepared by Alexa Mitchell.

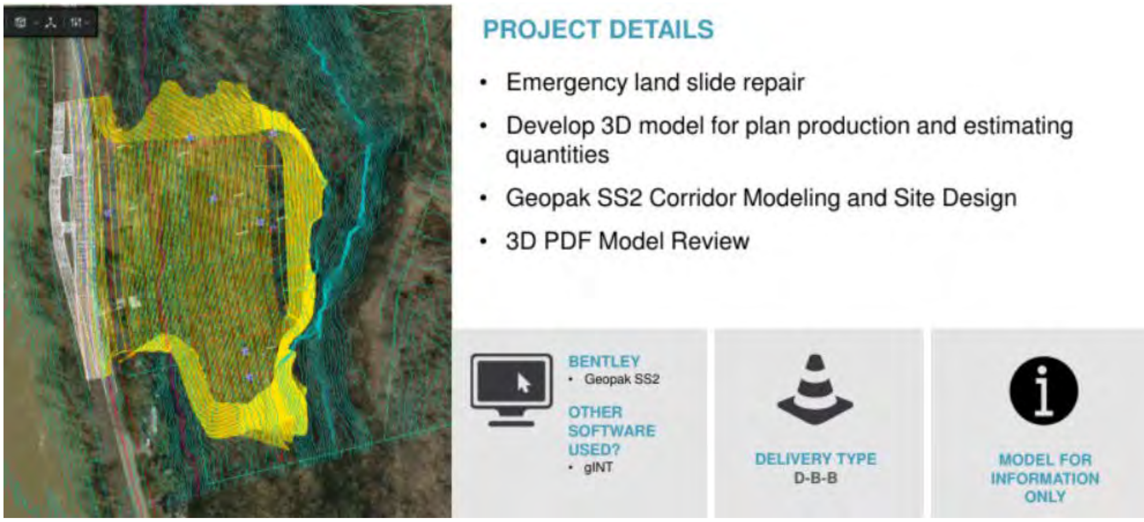


FIGURE 21 Project details for Ohio DOT, MRG-376.8.10 emergency landslide repair. Slide prepared by Alexa Mitchell.

Mitchell noted that applying BIM modeling is not just for large projects; it can be used on small projects as well. The Ohio DOT project, MRG-376-8.10 in Morgan County District 10 was presented as a case study, which was an emergency landslide repair as shown in Figure 21. There was no requirement to produce a model for this project. The design team created a model to better understand the slide condition and make decisions and then for plan production and estimating quantities. Using established software, the team elected to develop and deliver a model for information only, in addition to the other contractual deliverables. This model provided further clarifications and aided in expediting this emergency design–bid–build project.

The next case study Mitchell presented was the ODOT, Tru-46/82 Diverging Diamond Interchange (DDI) reconstruction in Trumbull County, Ohio. This was a large DDI Design-Bid-Build project that necessitated modeling. The project tools used were Bentley ORD Connect, Lumen RT, 3DS Max, and Blender. Plans on this job were developed directly from the model, streamlining plan production and allowing engineers to focus on design tasks. The 3D model was delivered "for information only" and was developed for the purpose of plan production and estimating quantities; these functions were automated through the model.

In the ODOT DDI project, the model served as a visualization tool as shown in Figure 22 and fostered collaboration with other disciplines. The project was the first DDI to be built in the area. Using visualization tools in the model, point of view videos were created for the public to better understand the traffic flow through the DDI and provide a simulated view of what drivers could expect. The visualization was used by the design team and informed where to place traffic cameras. The model facilitated design coordination among teams. Specifically, the deliverables to the utilities team were in the same format as traditionally used before 3D models. The 3D tool facilitated the design team's production of sheets, and the continuity of data provided avoided a loss in fidelity between disciplines. By taking the time to model accurately, designers had clear payoffs in the quality and time required to prepare deliverables.

As modeling tools advance, the software can recognize model components as features instead of lines on a layer. Automation is also a great benefit. For examine, in this ODOT DDI project, the deliverables to the utility coordinator were directly derived from the model,

FIGURE 22 ODOT model illustrates Diverging Diamond Intersection (DDI) and serves as starting tool for visualization products. Slide prepared by Alexa Mitchell.

automating population of tables and detailing. Traffic surveillance also started automating quantities using item types. Models can serve as a coordination tool for project teams, and subsurface utility engineering surveys can provide the information to improve model quality. The model does not always have to serve as the legal document, but the end goal is leveraging technology to make deliverables and better decisions.

PART 2: MODEL-BASED REVIEW

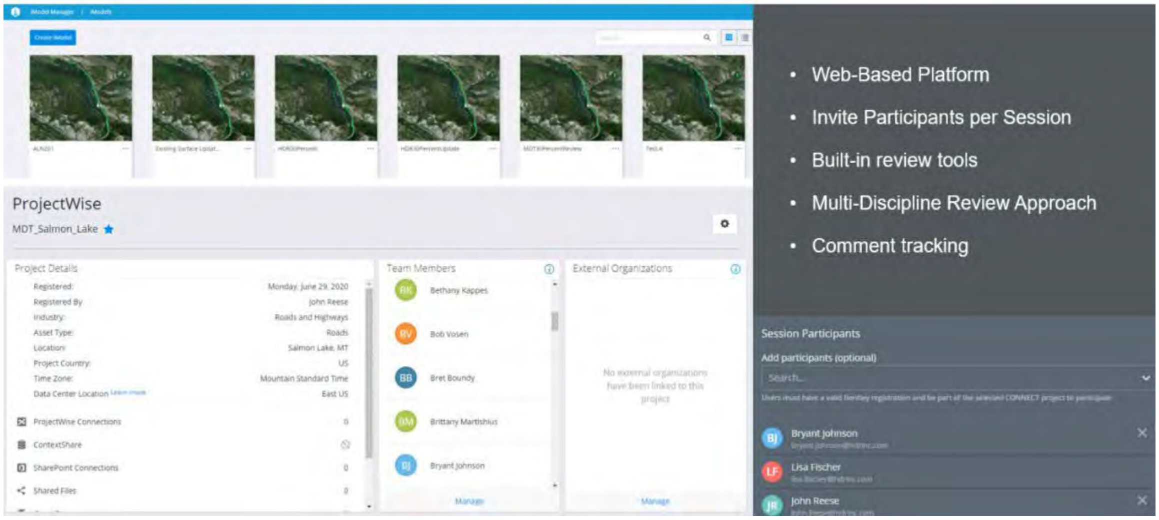
The second part of Mitchell's presentation focused on model-based review**.** The key takeaway was that models could be reviewed in a format similar to how Bluebeam Revu is used for 2D plan sets, using analogous review software like iTwin Review to conduct model-based review. The same quality control procedures applied in a traditional design approach such as checklists could be utilized to review a model.

An example of model-based review was a project in Missoula County, Montana which took place as part of the MDT Salmon Lake Highway Reconstruction. Software used included Bentley iTwin Design Review for model review, as well as ProjectWise and Geopak SS10 (OpenRoads technology). This project involved 4 miles of highway reconstruction. Digital delivery goals included utilizing model review software to document the design process through a 30% submittal with limited plans and 3D model review followed by the 60%, 90% and 100% submittals with standard plan deliverables. The project was delivered using CMCG (Construction Manager/General Contractor) contract methods with the BIM model provided for information only. The project provided an opportunity to test out model-based review and provide a proof of concept through a pilot study. Project details are summarized in Figure 23. The 3D model, plan sheets, and preliminary quantities were delivered.

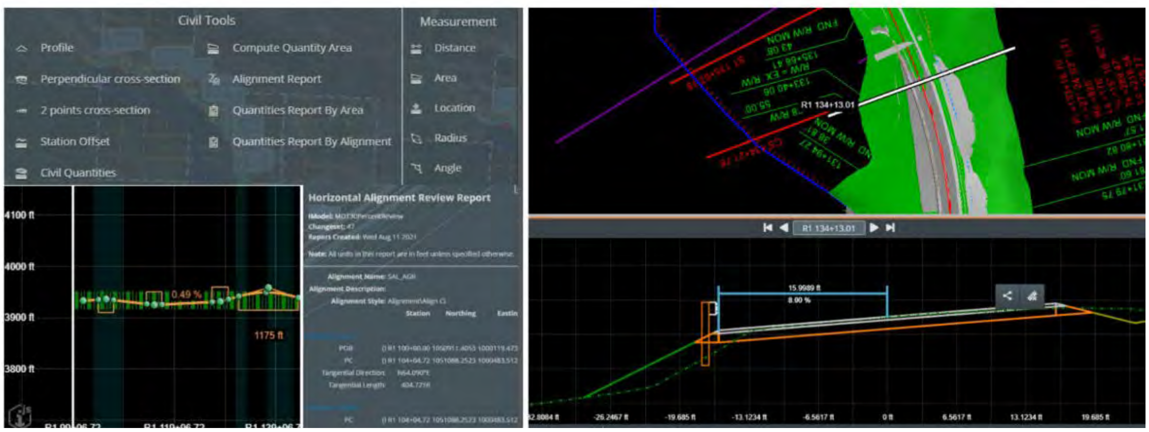
FIGURE 23 MDT Salmon Lake Highway Reconstruction. Slide prepared by Alexa Mitchell.

The iTwin Review tool for model-based review was web-based, where participants were invited to a review "Session" as shown in Figure 24(*a*). The tool can be summarized as "Bluebeam for 3D models." Like Bluebeam, iTwin Review has built-in review tools, a multi-discipline review approach, and real-time commenting and comment tracking in the 3D model, as shown in Figure 24(*c*). Comments can also be exported to Excel for documentation, as shown in Figure 24(*d*). The tool allows information to be viewed in an industry-familiar format, reducing initial learning curves. iTwin Review has the added benefit that the user does not need to be a computer-aided drawing (CAD) expert to utilize the software and review the model; it can provide cross sections and profiles that reviewers are used to seeing, as shown in Figure 24(*b*), making the review more accessible.

For the test session on the MDT project, 50 comments were tracked over five disciplines, with over 40 participants commenting on the model. Model review checklists were employed (similar to those used for plan sheets) to keep track of the comment status. Mitchell stressed that the design criteria and the project review requirements are not changing; what is changing is the means by which reviews are conducted. Mitchell also emphasized the ease at which comments were documented, streamlined, and exported together directly from the software instead of having all reviewers having a model open and creating their comments in separate Excel spreadsheets.

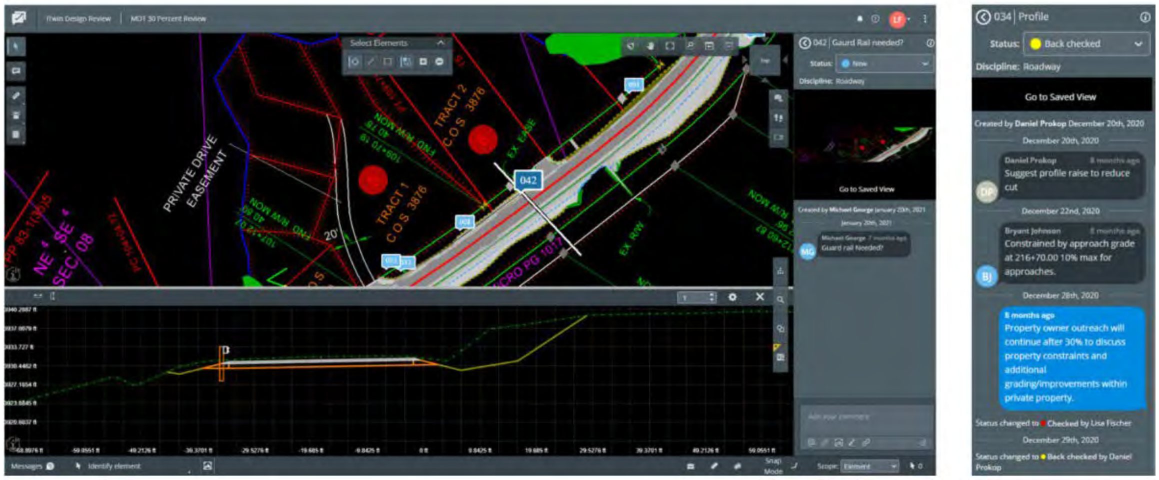


(a)

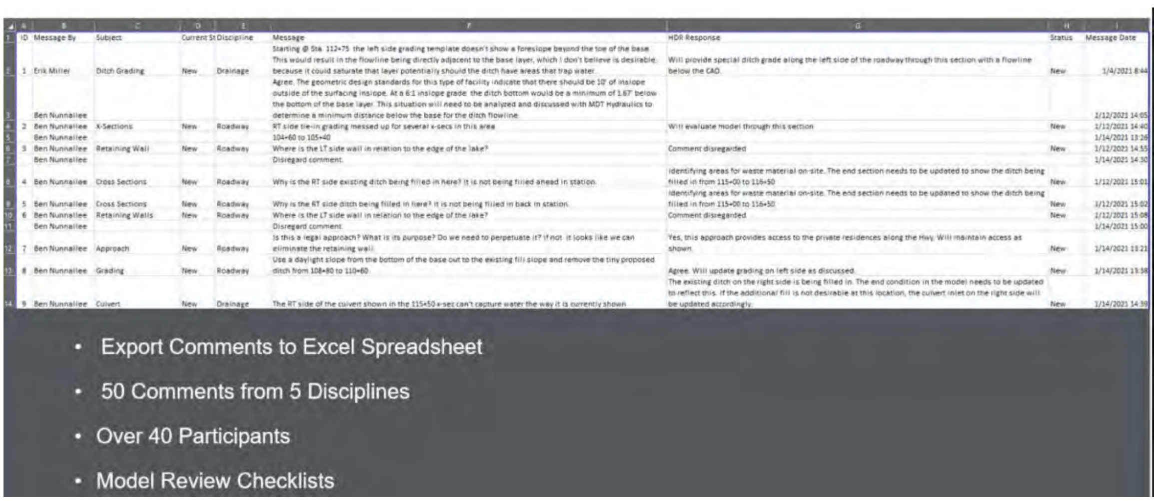


(b)

FIGURE 24 Example of Bentley iTwin Model Review: (*a*) iTwin Review Session and (*b*) Cross Sections Developed from Model. Slide prepared by Alexa Mitchell. **(Continued on next page)**



(c)



ID	Message By	Subject	Current St	Discipline	Message	HDR Response	Status	Message Date
1	Erik Miller	Ditch Grading	New	Drainage	Starting @ Sta. 112+75 the left side grading template doesn't show a foreslope beyond the toe of the base. This would result in the flowline being directly adjacent to the base layer, which I don't believe is desirable because it could saturate that layer potentially should the ditch have areas that trap water.	Will provide special ditch grade along the left side of the roadway through this section with a flowline below the CAD.	New	1/4/2021 8:44
	Ben Nunnallee				Agree. The geometric design standards for this type of facility indicate that there should be 10' of inslope outside of the surfacing inslope. At a 6:1 inslope grade the ditch bottom would be a minimum of 1.67' below the bottom of the base layer. This situation will need to be analyzed and discussed with MDT Hydraulics to determine a minimum distance below the base for the ditch flowline.			1/12/2021 14:05
2	Ben Nunnallee	X-Sections	New	Roadway	RT side tie-in grading messed up for several x-secs in this area	Will evaluate model through this section	New	1/12/2021 14:40
	Ben Nunnallee				104+60 to 105+40			1/14/2021 13:26
3	Ben Nunnallee	Retaining Wall	New	Roadway	Where is the LT side wall in relation to the edge of the lake?	Comment disregarded	New	1/12/2021 14:55
	Ben Nunnallee				Disregard comment.			1/14/2021 14:30
4	Ben Nunnallee	Cross Sections	New	Roadway	Why is the RT side existing ditch being filled in here? It is not being filled ahead in station.	Identifying areas for waste material on-site. The end section needs to be updated to show the ditch being filled in from 115+00 to 116+50	New	1/12/2021 15:01
5	Ben Nunnallee	Cross Sections	New	Roadway	Why is the RT side ditch being filled in here? It is not being filled in back in station.	Identifying areas for waste material on-site. The end section needs to be updated to show the ditch being filled in from 115+00 to 116+50	New	1/12/2021 15:02
6	Ben Nunnallee	Retaining Walls	New	Roadway	Where is the LT side wall in relation to the edge of the lake?	Comment disregarded	New	1/12/2021 15:08
	Ben Nunnallee				Disregard comment.			1/14/2021 15:00
7	Ben Nunnallee	Approach	New	Roadway	Is this a legal approach? What is its purpose? Do we need to perpetuate it? If not it looks like we can eliminate the retaining wall.	Yes, this approach provides access to the private residences along the Hwy. Will maintain access as shown.	New	1/14/2021 13:21
8	Ben Nunnallee	Grading	New	Roadway	Use a daylight slope from the bottom of the base out to the existing fill slope and remove the tiny proposed ditch from 108+80 to 110+60.	Agree. Will update grading on left side as discussed.	New	1/14/2021 13:38
9	Ben Nunnallee	Culvert	New	Drainage	The RT side of the culvert shown in the 115+50 x-sec can't capture water the way it is currently shown.	The existing ditch on the right side is being filled in. The end condition in the model needs to be updated to reflect this. If the additional fill is not desirable at this location, the culvert inlet on the right side will be updated accordingly.	New	1/14/2021 14:39

(d)

FIGURE 24 (*continued*) Example of Bentley iTwin Model Review: (*c*) Comment Tracking in iTwin review and (*d*) Exported Comments in Excel. Slide prepared by Alexa Mitchell.

PART 3:
LESSONS LEARNED

Mitchell emphasized defining the contractual deliverable requirements and desired outcomes for the use of 3D models early in the project in terms of what information is needed out of the model and for the planned model use. Mitchell also stressed the importance of developing a BIM digital delivery execution plan, detailing the “why, what, when, and who” of the process. In her experience, this happens at the pre-construction meeting, where there is an item on the agenda solely for the model to set forth the BIM execution plan that specifies, for instance, how changes will be made to the model, and who is responsible for making changes. Mitchell recommended that clients using the model should review it and conduct quality control early and on a regular basis, thus making plan production easier and more efficient.

Mitchell explained that utility modeling is only as good as the source information, so it is essential the client understands the risk regarding what information can be gained from the model, what information can be relied upon, and what cannot. She recommended that clients communicate and coordinate with all stakeholders as early as possible, stressing that using models facilitates the coordination.

In terms of modeling tools, Mitchell emphasized picking the right tools for the desired outcome, and in some cases leveraging existing tools. She pointed out the importance of expecting software updates and using workarounds in the meantime because there is no such thing as a perfect software. For expediting model development, Mitchell recommended requesting client workspaces and developing standard libraries that can be used on multiple projects for more consistent deliverables. Another important factor was to plan on providing training on the BIM process, not just the tools. In addition, providing technical support to construction staff by having the designer available during construction was important because the staff were not always familiar with using models.

Mitchell noted that bridge modeling software has improved significantly, and she summarized recent developments in modeling software. These included the development of parametric vs. single-use templates as well as functional components that allow for the use of parametric substructure elements. Mitchell upheld that a specific model authoring workflow is required if design integration tools are used, regardless of what software is used. She maintained that engineers should be trained on the overall process, not just the tools as was the experience in the Montana DOT project. There have been various updates to software to fix bugs and problems in the general user interface, leading to better tools altogether.

In conclusion, 3D model-based design for a deliverable does not always mean having a MALD. Rather, there are many ways that models can be utilized in the delivery process so long as the use cases are defined early in the project. Models can be used for many applications including development of plans and quantities. 3D models enhance communication, collaboration, and decision making for design teams, particularly for coordinating between multiple disciplines working together. Lastly, the same 3D models created for the project can serve as a great starting point for public information visualization products, resulting in both time and cost savings.

BREAKOUT SESSION

The following limitations and future needs were identified from the breakout session for the group associated with this presentation:

Current Limitations

The limitations identified by the participants included concerns regarding the simplicity of training on model-based review for non-CAD users. This concern is focused on the accessibility standpoint, considering that not all model-based review users would be CAD users or familiar with model software, which Mitchell addressed in her session on iTwin Review. Another limitation is the current lack of a discipline-specific education program based on the needs of each discipline as a means of getting more disciplines involved in using model-based tools. Mitchell noted that having multiple disciplines using these tools encouraged greater and earlier collaboration.

Future Needs

The participants discussed the need for an open data source for posterity and "future-proofing" of model-based tools and review. An opportunity enabled by model use and delivery was the consolidation of items for bidding. Lastly, the participants emphasized the need to establish modeling standards against deliverables, specifying the detail relevant to each stage LOD requirements. Four clear future directions that participants summarized are as follows:

- -Accessibility
- -Discipline-specific training
- -Open Data Source
- -Modeling Standards/LOD

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1. New York State Department of Transportation. Kew Gardens Interchange Infrastructure and Operational Improvement Project Grand Central Parkway. DB Contract Documents. Part 3 Project Requirements. March 16, 2018. Available at https://www.dot.ny.gov/main/business-center/designbuildproject43/repository/D900043%20-%20Part%203%20-%20Project%20Requirements_FINAL_2018.03.16.pdf.

Workshop Key Takeaways

The effectiveness of using 3D BIM models in the construction field was elaborated upon by **Use of 3D Models for Construction Inspection and Benefits to Owners**. The advantages of 3D plans include better understanding of the onsite clashes, dimension errors, control of as-built plans, material specifications, and live digital documentation of work progress. Additional areas of possible growth for 3D models include the use of augmented reality by overlapping 3D model details over the actual construction site to improve spatial and dimensional accuracy of placement.

The ability of BIM programs to be effective construction tools requires overcoming current limitations by providing better and effective internet connections on site, technically skilled staffs, and incentivizing program use to further encourage investment.

The necessity to create standards for design and fabrication digital exchange in the IFC file format was discussed in **Development of Building Information Modeling Exchange Standards in U.S. Bridge and Structures Industry: A Steel Bridge Fabricator's Perceptive on the Exchange Process**. The challenges faced by fabricators in applying model design data were discussed including varying data formats and multiple design data files. Suggestions for improvement included creating a neutral file enabling the multiple involved parties to extract needed information. The fabricator's perspective provided insight about misconceptions regarding BIM. The common idea of directly applying 3D models to shop drawings and fabrication on the shop floor is inaccurate. The fabricator must still create 2D shop drawings and develop CNC program input from the information contained in the 3D models. The effort required to extract information from 2D, or 3D models is similar. The fabricator must also adjust the data from the designer to create fabrication instructions and shop drawings, a process that remains unchanged with the use of BIM. However, by passing the design data in a usable digital format, data fidelity is maintained, and manual data entry is significantly reduced. There are multiple modifications suggested to address the issues of handling project phases, ownership of the data dictionary.

The experiences of using digital delivery process for Utah DOT were discussed in **Structures Digital Delivery: Design Through Construction**. Due to the highly skewed nature of the bridges and geographical locations, this project required time-consuming manual modeling. The three main components of digital delivery were discussed in the presentation.

These components help to understand the importance of using standard format of models by other disciplines to facilitate collaboration. For the digital delivery process, the presenters recommended defining the details which will need 3D solid element modeling and adding other details as attributes or attachments. The difficulty faced with digital delivery process include sealing 3D models, software compatibility issues with contractor's software in design–bid–build project and maintaining and developing files for future accessibility.

The five projects presented in **BIM Uses and Model-Based Reviews** provide a comprehensive overview of the advantages of 3D model-based design. The lessons from each project provided a wide variety of the BIM implications in project. From avoiding clashes by providing clearance checks to using the model as legal document and encouraging disciplines to work together to monitor the changes and implementing effective design changes. The 3D models were also used to produce visualization exhibits aiding in communication with the public. BIM models can be used for a large variety of applications, but to be successful it is crucial to establish and clarify the expectations for the model early in the design process. Plan sheets and material quantities can be extracted directly from the models, allowing for rapid understanding of design changes and potential costs, encouraging engineer to invest in developing the models.

NATIONAL ACADEMIES *Sciences Engineering Medicine*

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