

Lessons Learned: Implementing BIM for the Chiltern Tunnels for High Speed 2 in the UK

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ABSTRACT

High Speed 2 (HS2) mandated that Building Information Modelling (BIM) processes be implemented during design and construction. Gall Zeidler Consultants (GZ) was responsible for developing the BIM Models for the portals, tunnels, and cross passages of the of the 16 km-long Chiltern twin-bore Tunnel. In addition, GZ developed the GBR for the Chiltern Tunnels and incorporated the relevant information into the Project's BIM framework. This paper presents the implemented BIM framework, describes the modelling approach, and discusses the advantages and challenges of implementing BIM, particularly how BIM improved interface coordination and how BIM was used in feasibility assessments of different construction options.

INTRODUCTION

HS2 is a new high-speed rail line that will be the backbone of the UK's rail network. Phase One of this project will connect London to Birmingham between 2029–2033. In July 2017 the Align joint venture, consisting of Bouygues Travaux Publics, Sir Robert McAlpine, and Volker Fitzpatrick, was awarded the contract to complete the design and begin construction of the C1 package. The C1 package consists of 21.6 km (13.5 mi) of high-speed rail infrastructure that includes a 3.5 km (2.2 mi) viaduct, the 16 km (10 mi) twin-bored Chiltern tunnel, and five vent shafts accommodating both intervention and tunnel ventilation facilities.

The Chiltern Tunnel is the longest tunnel on the HS2 route between London and Crewe and will carry passengers under the Chiltern Hills. The Chiltern Tunnel consists of a twin TBM tunnel, 5 intermediate shafts, 40 Cross Passages (CPs) and 2 portals, one each at the South and North ends of the tunnels. The two Tunnel Boring Machines (TBMs), Florence and Cecilia, that are being used to create the twin bore Chiltern Tunnel were launched in the summer of 2021. As of the writing of the paper, tunneling under the Chiltern Hills is currently ongoing.

Gall Zeidler Consultants (GZ) is working on tunnel design and serving as a geotechnical specialist supporting Align's design partner Align D, consisting of Ingerop and Jacobs. GZ's main scope of works for the tunnels includes the design of 38 out of the 40 Cross Passages and the adits associated with each shaft.

Following the UK Government's Building Information Modelling (BIM) Mandate, HS2 is being delivered using BIM. BIM, as defined by the BS EN ISO 19650-1:2018 is the:

“use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions.”

In other words, BIM is a process that involves the generation and management of project and asset information using digital representations of physical and functional characteristics of structures and facilities over their entire life cycle. At the time of the commencement of the HS2 project, the UK BIM mandate required that all projects be implemented to a “BIM Level 2,” meaning (Innovative UK, 2017):

“Projects will use intelligent, data-rich objects in a managed 3D BIM environment. All parties working on a project are able to combine their BIM and design data to collaborate and share information through the use of a common data environment (CDE). The CDE enables users to carry out checks against data validation strategies to make sure they are on target.”

The definitions above are, however, necessarily vague, as they need to broadly describe BIM as a concept. They do not provide the average engineer, project manager, or CAD technician with a concrete understanding of how BIM is implemented in a tunneling project. In current practical international usage, BIM is often used as an umbrella term to describe the use of any number of digital tools, such as, but not limited to, 3D modelling, computational design, visualization, clash detection, 4D/5D modelling and information management used to improve design, project delivery, asset management, and collaboration (ITA WG 22, 2022). This contribution is therefore intended to provide a concrete example of BIM implementation for a tunneling project by giving an overview of how BIM was, and is being, implemented for HS2’s Chiltern Tunnel.

It should finally be noted that the implementation of BIM in tunneling differs somewhat internationally. Some countries have concrete standards regarding BIM while others do not. BIM in the UK is largely regulated by the BS EN ISO 19650 series as well as the PAS 1192 series of documents, and this contribution should be viewed with this frame of reference in mind.

CONTRACTUAL FRAMEWORK

Employer’s BIM Requirements

The Employer’s BIM Requirements form the basis of BIM implementation for the HS2 Project. The BIM requirements differentiate between a Project Information Model (PIM) and an Asset information Model (AIM). The PIM refers to the BIM implementation during the design and construction phases of the project and the AIM refers to the BIM framework in place after handover and during asset management. The BIM Requirements also state the goals of the PIM and AIM. These goals are for BIM to:

- Provide a consistent approach to the ways in which data requirements are defined and how data is procured,
- Provide a consistent data-driven approach to the production, management, and delivery of the Project Information Model (PIM) that is structured such that it can be efficiently shared and reused,
- Provide assurances and validation of the quality, integrity and completeness of the design and construction through the utilization of an up to date and validated PIM,
- Provide an improved assessment of health and safety and risk impacts through the utilization of an up to date and validated PIM,
- Provide greater value for cost planning, estimating and carbon management through the utilization within an up to date and validated PIM,

- Provide a validated and verified Asset Information Model (AIM) for operational use,
- Achieve target capital delivery during design and construction by eliminating waste,
- Enable information governance and information security, and
- Deliver best value through innovation.

The Employer's BIM requirements further constrains the JV to internal HS2 standards (CAD, Health & Safety, Sustainability, etc.).

BIM Execution Plan

While the Employer's BIM requirements define which BIM goals are to be met by the project, they do not define how these goals are to be met. The BIM implementation, therefore, falls under the purview of the JV, provided that HS2 standards are followed. The Employer's BIM requirements dictate that the actual tools and methods used are to be set forth in a BIM Execution Plan (BEP). While the BEP is seen as a "living document," and may be modified due to changes in the Employer's BIM requirements, the BEP forms the contractual framework that describes the BIM implementation process for the PIM as well as AIM.

Among other items, the BEP describes the information delivery plan, the management of the modeling process the Common Data Environment (CDE) used to store and transfer the project/asset information, and a description of the BIM deliverables.

Digital Delivery of the Design Information

An integral part of BIM is the data management process. Specifically, to ensure conformance to ISO 19650, all data should be stored, exchanged, and managed within a Common Data Environment (CDE). A CDE is, per the ISO 19650 Series an:

agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process.

With the additional following note being provided for clarification:

A CDE workflow describes the processes to be used and a CDE solution can provide the technology to support those processes.

At its core, a CDE is often a cloud-based file storage system, and many software programs used to develop a CDE allowing an owner to define workflows which regulate when information is uploaded, edited, checked, or approved (ITA WG 22, 2022). For the HS2 C1 project, ProjectWise was used as CDE to store and manage all project information, including all models, drawings, design reports, specifications, and geo-technical information. It was also used as a tool for configuration management and deliverable submission.

To ensure a coordinated workflow for the delivery of all the BIM models, each model and drawing uploaded to the CDE were assigned to a unique reference number and added to the Task Information Delivery Plan (TIDP) and Master Information Delivery Plan (MIDP) by the Project Manager. Essential attribute information such as Seed file, Primary Asset and Sub Asset ID were stored/assigned to ensure uniqueness. A unique script was developed to import the information from TIDP and MIDP and generate the placeholders on CDE. This ensured the proposed deliverables created on

ProjectWise being consistent with the logs on TIDP and MIDP. It also eliminated the risk of creating redundancy and losing control of the CDE.

The workflow (shown in Figure 1) for this project was based on requirements presented in BS 1192:2007+A2:2016. Establishing this concrete workflow streamlined document/model/submittal management and distribution and ensured a minimum quality of design information. Every placeholder has an embedded property called “state” and can be approved by person with appropriate authority to move it to next state. The first state was always “Work in Progress” and it was used to produce the design work. After the work was done the placeholder was approved by the originator which triggered an automatic background process called CAD-QA to ensure the placeholder was compliant with project standard. When successful, the placeholder was moved to state ‘Checking’. At this state the next person in the design process, a discipline engineer, was responsible to check the design. Once the design was successfully checked and approved, the placeholder then moved to the state ‘Package Shared’, where it became visible to other disciplines in the design. This ensured that only checked designs were shared with others. This checking loop was performed on a weekly basis. The next State for the placeholder was “Reviewed.” Only the project manager or other individuals with “Reviewer” authority were able to approve the “Package Shared” placeholder. The last state of the process was either Team Shared or “Client Shared.” “Team Shared” was used for those submissions which were only submitted to the Contractor, i.e., the Align JV, while Client Shared included the submission to HS2.

The workflow process included built in automatic procedures. In the “Package Shared” state incorporated an automatic model creation of 3D models, and in the “Approved for Team Shared/Client Shared” state PDF renditions of the drawings were automatically created.

CREATION OF 3D MODELS

A 3D model was created for each structure of the Chiltern Tunnel system. In contrast to simple 3D models, these BIM objects included metadata or information beyond the simple 3D geometry of the object. The metadata includes information such as asset IDs, materials, design life, etc, that allow the user/Asset Manager to query the BIM model much more effectively. An example of a BIM model showing the 3D model including the metadata stored on the object is provided in Figure 2.

Before creating the 3D models, 2D cross sections were developed to ensure that all spaceproofing requirements were met. The 2D Models were also used as a basis for all structural calculations to ensure that the base structural concept was sound before beginning modeling. Finally, the 2D sections were additionally used to verify the 3D models as part of the QA process by comparing cut sections in the 3D model with the original 2D concepts.

To effectively and efficiently create the BIM models for the Chiltern tunnels and define HS2 metadata for each element, several techniques were used. The following sections provide a description of three of the primary techniques to do so: DataGroup Catalog Profiles, Feature Modelling, and Generative Components.

DataGroup Catalog Profiles

To model all the components more easily along the Chiltern Tunnel alignment, a Catalog of elements was created for each space proofed 2D cross section. This allowed implementation of HS2 Metadata before creating models, as much of this data

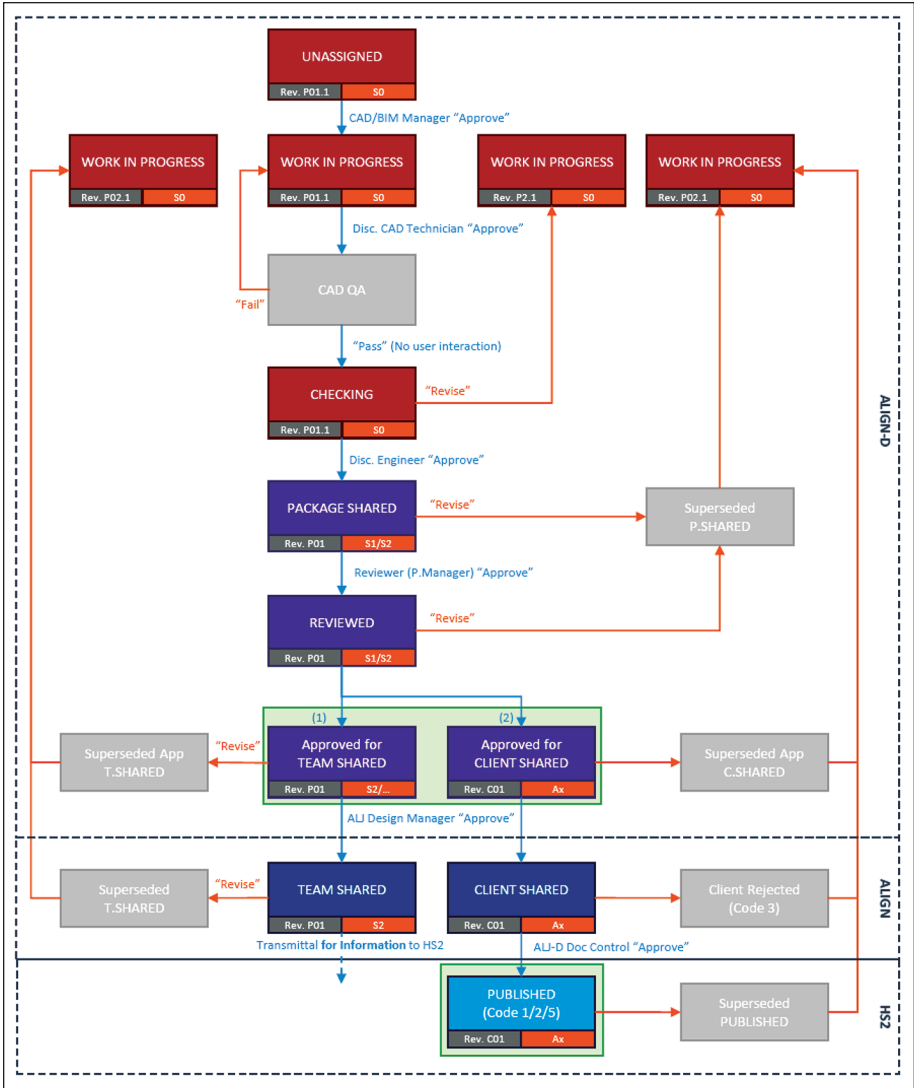


Figure 1. Document workflow for HS2 C1

was standardized. This allowed a modeler to simply pick up a required shape from the Place Profile library and extrude it along either the alignment or any predefined setting out line. Not only does this technique simplify the modelling process, but it minimizes mistakes made from manual creation/insertion objects along 3D setting out lines that may follow complex 3D paths. Even if the BIM object required further modification of its Metadata, any Metadata could be easily edited from inside the model after the model was created.

Feature Modelling

Feature modelling is an AECOSim modelling technique that is used to create complicated 3D objects while maintaining a detailed history of the changes made to the

model. This technique was used for the Cross Passage collar transition and TBM tunnel walkway transition at door frame locations (Figure 3). The disadvantage of feature modeling is, however, that no properties from the DataGroup Catalog as discussed above are implicitly embedded into the objects. Hence HS2 metadata must be added to objects in a different way. To simplify and expedite this process, HS2 metadata were added to feature elements by Boolean operation. Boolean operations allow the user to combine objects, create differences between two objects, or create an intersection between two objects that can inherit the properties of both objects. By intersecting a feature modelling object with a DataGroup Catalog object, such a wall or slab, which both contain metadata, the feature object was able to inherit the required properties.

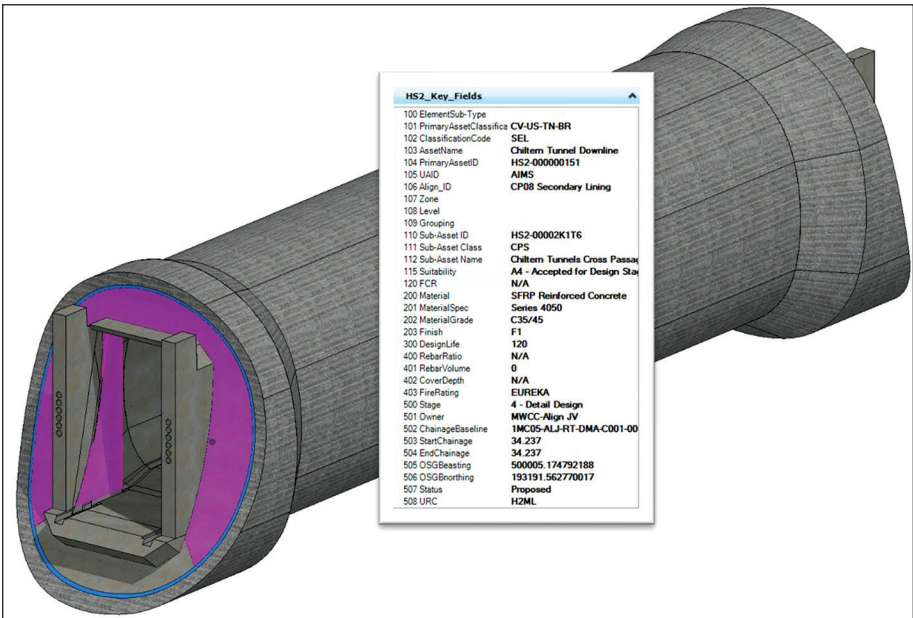


Figure 2. HS2 metadata attached to highlighted element

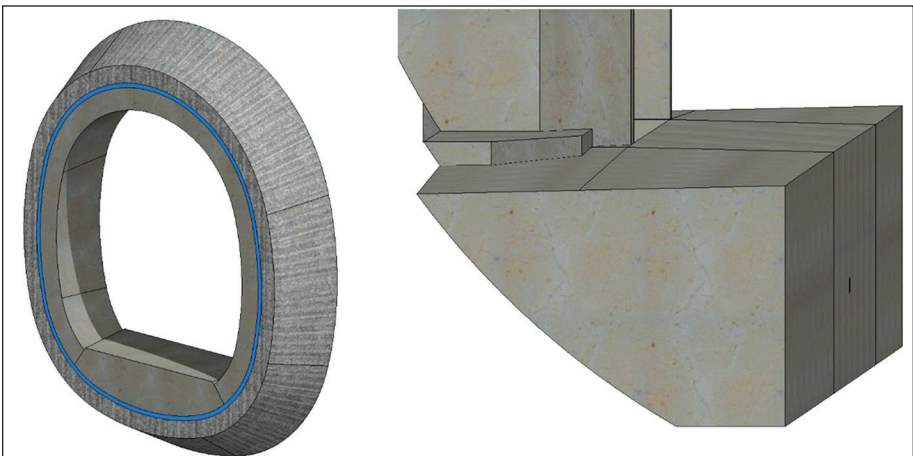


Figure 3. Cross passage collar transition and TBM walkway transition at door frame

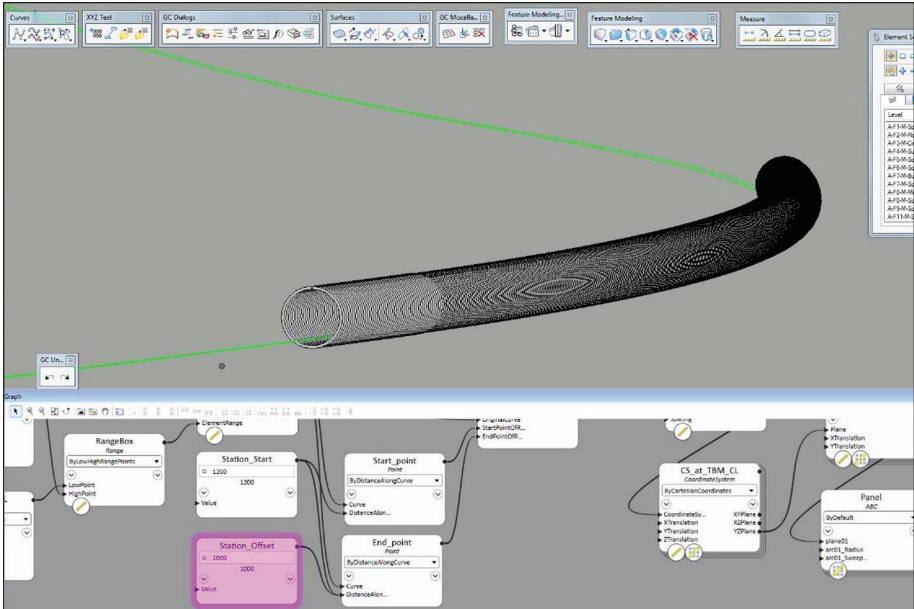


Figure 4. Computation of tunnel ring element along alignment for station 1200 to 2200

Generative Components for TBM Ring Model

Modelling a 16 km long twin-tube TBM tunnel provided a set of unique modeling challenges. The DataGroup technique only proved useful in creating an extruded element to a maximum length of 200 m, such as for the CPs. After 200 m, the extrusion function no longer functioned properly. As such, to model the main TBM tunnel with the DataGroup technique, the tunnel alignment would have had to be divided into a series of 200 m long sections with individual setting out lines to extrude longitudinal elements like walkways, slabs, or the tunnel lining.

The TBM tunnel lining is/will be comprised of 2 m wide pre-cast concrete segmental rings. To create more than 8,000 segmental rings over the entire length of tunnels more efficiently, the Generative Components (GC) software was used to build the TBM model. This technique allowed for the creation of a set of rules, which govern the automatic model creation. In doing so, the full 16 km length of alignment could be used as setting out line, and a pre-defined set of rules was used to replicate a single ring object to create the 8,000+ rings with precision and control. This process is shown in Figure 4.

Another benefit of GC was the ability to automatically input data into each element. It should be noted, however, that this software feature did not perform as anticipated, as data cannot be replicated into reporting schedules. Nevertheless, feedback was provided to the Software developer who is now working on resolving this issue.

BIM USE CASES

The following sections describe some of the BIM use cases that were implemented in the HS2 C1 project.

Design Interface Coordination

One of the biggest advantages of using 3D models is to coordinate the design between several disciplines. For example, the Chiltern Tunnel structural design has interfaces with shafts, portals, utilities, and mechanical and electrical design packages. As per the BIM requirements, each discipline developed their own 3D models for the design. The design coordination models could then be easily prepared by bringing different 3D models from different disciplines into a “federated model.” A federated model is described in the ISO 19650 Series as a model that “...comprises information models from different lead appointed parties, delivery teams or task teams.” By sharing these federated models across all packages on ProjectWise, engineers were able to study the coordination models and identify interface issues. With the aid of the federated models, the interface issues could be visualized and discussed in the regular interface meetings as mandated in the BEP.

One very powerful example of interface coordination is the utilities passing through the cross passages. The design of the Cross Passages adopted innovative design approach of using Reinforced Concrete (RC) door frames inside the TBM tunnels to provide support to the opening on the TBM segmental linings. With the door frames structurally connected to the TBM linings at each CP location, the route of the services and utilities running along the TBM tunnels needed to by-pass the door frames or feed into the CPs per another method.

After the 3D models of the TBM and CPs had been created, they were shared with the tunnel M&E team and drainage team for design coordination. The other designers could use them to create their own 3D models for their design elements such as cable ducts, fire mains, drainage channels etc. All 3D models were then shared and referenced in a federated design coordination model (Figure 5). Thus, designers could always see the latest design developments from other design disciplines and conduct necessary design coordination. The responsibility was also clear as each discipline was responsible to keep its own model correct and updated. When design coordination required recesses and openings to be modelled on the tunnel structures, solid blocks were modelled by the proposing party to represent cut-out in the concrete. The tunnel designer would then use the solid blocks to cut their structure models

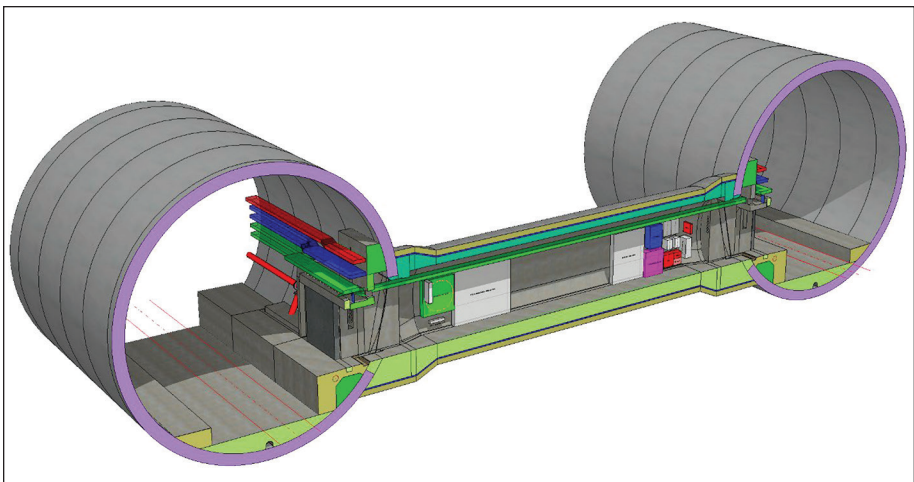


Figure 5. Federated interface model for CP8

upon the agreement between the designers. To ensure the coordination was carried out smoothly, it was important that a RACI (Responsible, Accountable, Consulted, Informed) chart was agreed upon between different parties on their modelling scopes.

Use of 3D Model for Construction Method Assessment

The designers used BIM to help the contractor select suitable construction methods. Benefitting from the ECI (Early Contractor Involvement) approach, the contractor had been involved in the design development from an early stage. As an integrated design team, 3D design models were available to the contractors to help them understand the design approach and assess the feasibility of different construction methods.

In the Scheme design stage, the proposed pre-support design for CP excavation was to install pipe arch canopy tubes (as shown in Figure 6) from the TBM tunnel and provide crown support throughout the excavation of the CP. After adopting the door frame support approach, a 3D federated model of the TBM tunnel, CP and door frame was jointly reviewed by the designer and the contractor. It was identified that the pipe arch canopy tubes approach was no longer desirable due to the heavily reinforced RC frame around the opening. An alternative design of grouted pre-support spiles was therefor considered. Although 3D modelling of temporary works was not required by the Client, a full 3D model of the pre-support spiles system was conducted for space proofing and feasibility study purpose (Figure 7). The proposal was reviewed and subsequently accepted by the contractor, benefiting from 3D model.

Use of 3D Model to Produce Design Drawings

3D models were used to prepare the design drawings. Sections and views on the drawings were generated by creating dynamic views (D-views) at the specific locations

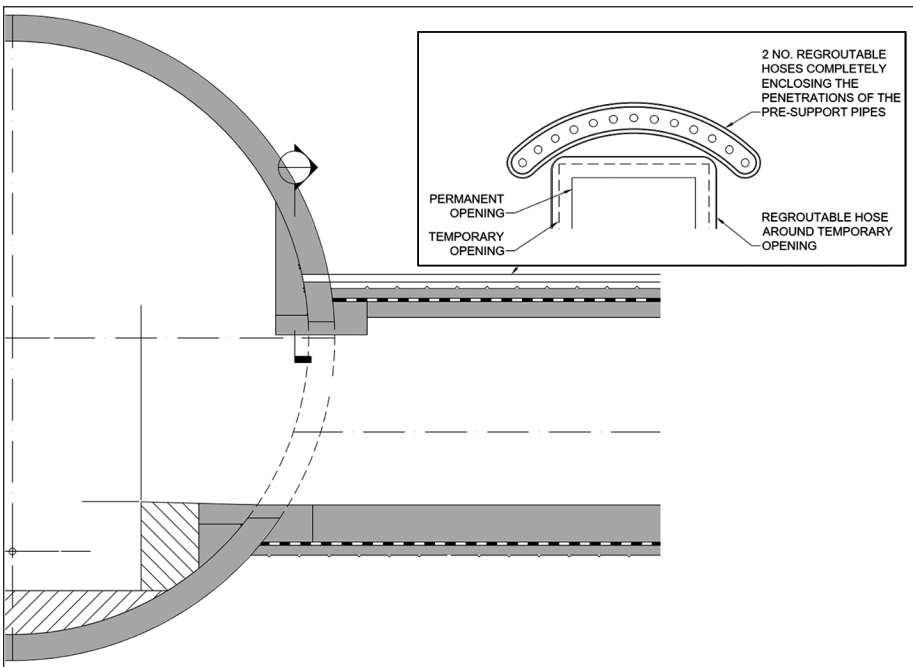


Figure 6. Scheme design pipe arch canopy tube concept

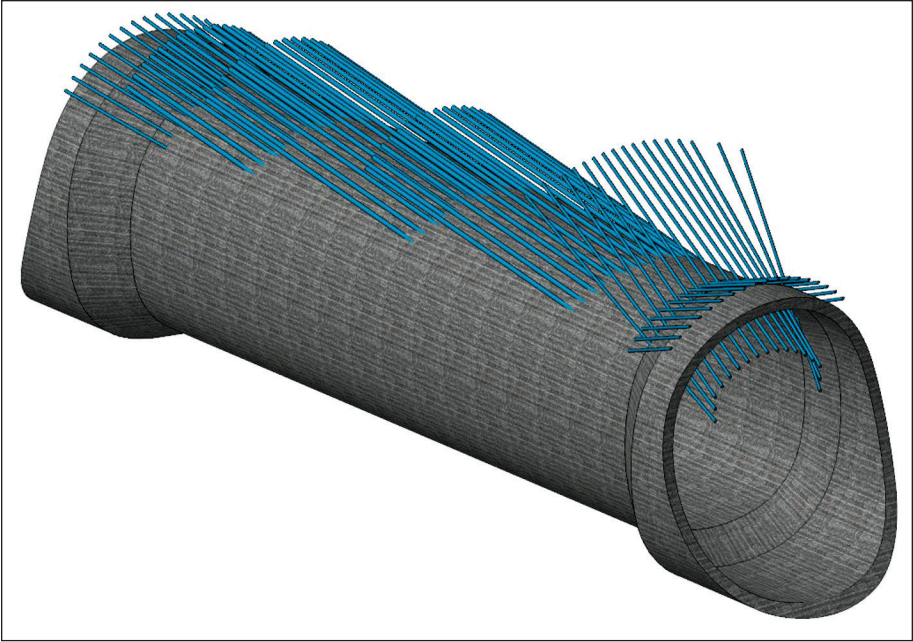


Figure 7. 3D model of grouted pre-support spiles

on the 3D models. These D-views were saved in a separate D-view model and referenced to the drawing sheet with annotations and notes required to complete the drawings. Figure 8 shows the D-views set up in a CP 3D model with the highlighted D-view displayed in the small window.

Sometimes line types and hatchings needed to be manually adjusted at the D-views to improve the clarity of the drawings. An element from D-views could be selectively shown to fit the drawing purpose. For example, only the primary lining was shown in the excavation sequence drawings while the secondary lining was turned off from the D-view as it was not relevant for an excavation sequence drawing.

Once the drawings were set up with the correct D-views, it was much more efficient to update the drawings when the 3D model was updated as the design developed. CAD technicians only needed to refresh the D-view model to pick up D-views from the most up to date 3D model, and the sections and views in the drawing were updated accordingly. While this was very helpful in producing design drawings, the number of D-views increased as more drawings were produced. This led to issues with locating the correct D-views. Draftsmen spent too much time to find the correct D-view for a drawing which subsequently affected the efficiency of drawing production. Had a coherent naming system for the D-views been used from beginning, this issue could have been avoided. Superseded or unused D-views should have been deleted or renamed accordingly to avoid the development of too many D-views. A good D-view name should contain detailed location information and which drawing it was used to help the draftsmen select the correct the D-view during drawing production.

Although 3D models should have enough details so that the correct details were reflected on the 2D drawings, it was important that a balance between insufficient details and too many details was maintained during the production of 3D models.

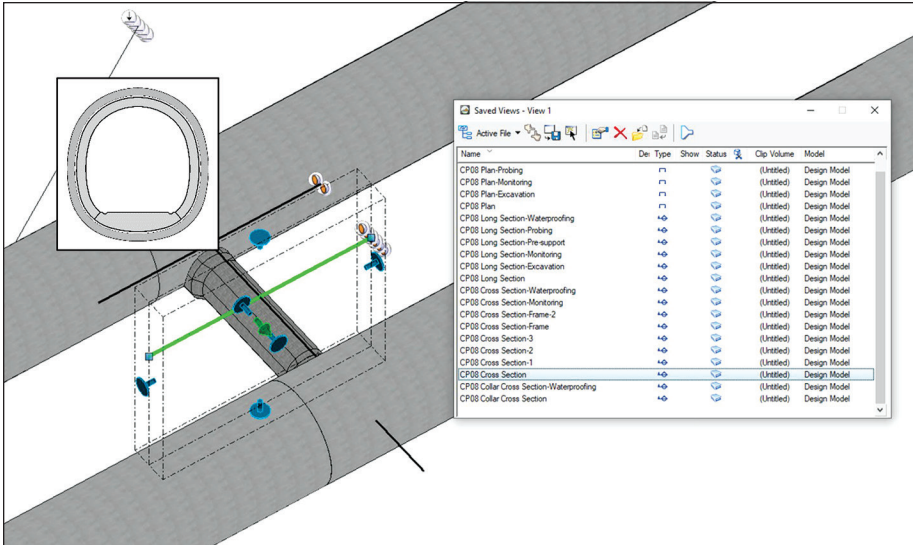


Figure 8. Dynamic view of CP cross section

Models with insufficient details would not provide the contractor enough information to understand the designer's intent. Models with too many details were slow to model and could be confusing and distracting from the focus subject

One of the design requirements from the drainage team was to provide 1:100 transverse slopes across the invert slab of shaft adits to drain any surface water into the side channels. Including this feature in the model would not add any additional value to the model, instead it would increase the complexity of the 3D model. In the end it was decided that invert slab was modelled as flat, not including the slope feature. A note was added to the cross section drawing to highlight the 1:100 fall design requirement rather than include this in the 3D Model.

Use of 3D model to Store As-Built Information

As discussed in the introduction, the Chiltern tunnel is currently in construction. To this end, BIM implementation has progressed from the BIM setup through modelling, and the existing models are currently being updated with as-built information. The current stage of the project requires the CAD/BIM team to support the construction team. The Site survey team is providing precise coordinates of CP positions, and CPs are remodeled using the new coordinates. Laser scanning and cloud modeling is being used to assess the accuracy of constructed structures, as well as forming the basis for updating the as-built models. This contribution will provide a description and lessons learned of the initial stages of the BIM implementation through to the current as-built model updating phase.

CONCLUSION AND LESSONS LEARNED

The use of full-scale BIM for a large scale and complex multidisciplinary tunneling project has been pioneered on the HS2 Chiltern Tunnels Project in the UK. While there were many challenges throughout the different design stages which required collaboration between the developer and the designer, many lessons were learned, and the BIM system evolved and improved as the project progressed. Nevertheless, the BIM

implementation for HS2 has proven that a mature BIM system can increase design production efficiency, reduce construction risks and project cost, and add value to a large tunneling project.

In addition to the topics discussed in this contribution above in detail, the following are a few additional key lessons learned during the BIM implementation in the HS2 C1 project:

- Contractor involvement at early stage is important to allow design to be suited to used construction method and to avoid costly or unnecessary changes on later part of the project.
- The established workflow needs to be taken seriously and maintained during the project.
- The CDE needs to be used by all involved parties (e.g., design files should not be allowed to be sent via email)
- MIDP and TIDP are the only source of truth and should be used to create placeholders on CDE.
- A neutral platform/file format (e.g., IFC) should be used as an output to allow all involved on the project to have access to design regardless of software used.
- 3D Modeling needs to be overviewed by design engineer to make sure the design is represented correctly. This requires Engineering staff to learn new review tools.
- Metadata input into models needs to be correctly understood and input with overview by design engineer.
- When a project consist large number of 3D models, which are used also for drawing production, it is important to setup section cut systems from the 3D model in a way, it allows the efficient introduction of changes.
- All 3D models need to be developed to the same coordinate system to allow for smooth coordination.

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