Development of the ITA "BIM in Tunneling—Guideline for Bored Tunnels"

Vojtech Ernst Gall
Gall Zeidler Consultants

Wolfgang Angerer
Jacobs

Jacob Grasmick
Maxwell GeoSystems

Jurij Karlovšek
The University of Queensland

ABSTRACT: The International Tunneling Association (ITA) Working Group (WG) 22 "Information Modelling in Tunneling" has developed a guideline for the implementation of Building Information Modeling (BIM) concepts for Bored Tunneling Projects. The guideline primarily covers the use of BIM during the conceptual and delivery phases of a project. It provides Owners with an introduction to BIM, an overview of the current capabilities of BIM, and a guide for implementation for a Bored Tunnel. The document will be officially published at the World Tunnel Congress (WTC) in Copenhagen in 2022. This paper describes the need for the guideline and provides a preview of its contents.

INTRODUCTION

Building Information Modelling (BIM) is becoming an increasingly important aspect of tunnel projects worldwide. Due to the rapid development of new technology, software, data management tools, and data management concepts, BIM has the capacity to fundamentally change how tunnels, or more generally, underground infrastructure, is designed, built, and maintained. While the rapid development of BIM within the past decade has certainly led to improvement in tunneling projects, is has also led to a certain degree of ambiguity concerning the core concepts behind BIM and their implementation. This ambiguity can be further exacerbated by the differences in goals of BIM implementation between project partners, i.e., between owners, engineers, and contractors within a tunnelling project.

To address these issues, the International Tunnelling Association (ITA) Working Group (WG) 22 has developed a guideline for the implementation of BIM within a bored tunnel project. This Guideline intends to support the tunnelling industry by presenting international "best practice" solutions for owners, engineers and contractors. Rather than competing with existing owner's BIM guidelines, the ITA guideline is intended to provide a reference framework for the implementation of BIM for tunnel projects for which there are no pre-existing standards. The guideline provides recommendations for selected important elements to be included in a project BIM Execution Plan (BEP) or similar contractual documents in which an owner's BIM requirements are set forth.

Because BIM is such a broad topic, the ITA guideline is specifically focused on the implementation of BIM for the heavy civil works of segmentally lined bored tunnels. Additional structures, such as stations, and additional disciplines, such as systems, are not directly covered by the guideline, as these are assumed to be addressed via general civil/MEP standards. Nonetheless, it is the intent of WG 22 to develop further specific guidelines for different tunnel methodologies (e.g., mined tunnelling) and to include non-tunnel components (e.g., cross passages) into future editions of the guideline.

The ITA guideline will be officially published at the World Tunnel Congress (WTC) in Copenhagen in 2022. This paper provides an overview of the guideline's and an excerpt of its contents

BUILDING INFORMATION MODELLING

The ITA WG 22 has adopted the following definition for BIM:

> **Building Information Modelling (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. This process is supported by various digital tools and software as well as by contractual information management agreements. In current practical 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 project delivery, asset management, and collaboration.

While the ITA WG 22 does not purport to have the authority to provide a definitive definition of BIM, the above definition has been developed to address two common issues. First, in describing BIM as a process, rather than as a single software, program, model, or data structure, the definition provides a technically accurate description of BIM. In contrast, the final portion of the definition addresses the reality of the usage of the term "BIM" in the tunneling industry. While experienced BIM professionals may consider BIM to be primarily an information management process supported by tools such as 3D modelling, less experienced BIM users tend to refer to the 3D models or 3D modelling tools themselves as BIM. The definition above aims to reconcile this divergence in perception.

To differentiate between BIM as a process and the various models used when implementing BIM for a project, the following definition will be employed in this paper.

> **Building information models (BIMs)** are digital files or models that store information regarding a built asset.

When fully implemented, BIM involves the creation of a central storage location for all digital information of the project/asset during its lifecycle, from design to operation and maintenance. This information is stored within a multitude of BIMs that accurately capture the desired project/asset information at each project phase. The BIMs together with the information management/storage system with which they are connected make up the "digital assets" of a project.

GUIDELINE FOR BORED TUNNELS

The Guideline addresses the following core concepts that are necessary for BIM to be successfully implemented in a project:

- BIM Uses
- The Information Management Process and Responsibilities
- Model Interoperability and Data Environments
- Exchange Data Formats
- Classification systems
- Level of Definition
- Asset Definition
- Ground Modelling
- Sustainability

Finally, the ITA guideline provides a list of endorsed BIM documents, such as the DAUB BIM guidelines [DAUB, 2019; DAUB, 2020] or the ISO19650 series [ISO, 2018(1); ISO 2018(2)], as well as providing a list of reference projects, and a list of otherwise relevant standards to provide a set of reference documents for further education.

The following sections provide a more detailed description of the contents of the sections discussed above.

BIM Uses

Before BIM can be used on project, the goal of its application (e.g., BIM for spaceproofing, for cost calculation, for construction scheduling, etc.) should be clearly defined and outlined. These goals are referred to as BIM Uses in the ITA Guideline. It should be noted, however, that other terminology, e.g., Use Cases, as employed by buildingSMART [buildingSMART, 2020], is often used to refer to the same concept.

BIM Uses are the tasks or processes for which BIMs are used. In order to give each project participant the information they need, it is vital to know in which way various BIMs are engaged and how they are interrelated. A BIM Use will determine the necessary software or information storage environment required to develop a BIM and at which project stage the BIM information must be provided. Within the ITA BIM guideline, the determination of BIM Uses before design is strongly encouraged.

To aid the determination of BIM Uses, the WG22 has developed a summary of common examples. The BIM Uses provided by the WG22 are largely based on the existing literature, with several cases being adapted from the DAUB [DAUB, 2019] and buildingSMART [buildingSMART, 2020]. To provide more transparency for the project participants, the examples provided by the WG 22 have been sorted by applicability to different project stages. An excerpt of the BIM Uses is provided in Figure 1.

USE CASE	DESCRIPTION	Source	STRATEGIC DEFINITION	PREPARATION & BRIEFING	CONCEPT/PRELIM DESIGN	BASELINE/REF DESIGN	DETAILED/ CONTRACTOR DESIGN				CONSTRUCTION	COMMISSIONING & HANDOVER	USE/OPERATION
							30%	60%	90%	100%			
Design variants investigation	Variant investigation based on 3D models of the existing condition including conflict analysis	DAUB	X	X	X	X	X						
Visualisation (public relations work)	Visualisation of the design including existing buildings and infrastructure	DAUB		X	X	X	X	X	X	X	X	X	X
Cost estimation and cost calculation	Model-based and structured quantity determination; Linking of the 3D model with cost data	DAUB		X	X	X	X	X	X	X	X		
BIM/structural/FE model co-ordination	Co-ordination of domain-specific sub-models by combining models in coordination software for detecting interferences	IFC		X	X	X	X	X	X	X	X		
Sustainability	Incorporation of sustainability parameters in the BIM model with the target to support quantifications 'for EG, carbon content' and provide data for variant investigation	WG22		X	X	X	X	X	X	X	X		
3D ground modelling	Provision of all geotechnically relevant data over the entire course of the project; Use of the data as input quantities for further use cases; Constant updating of the model as knowledge is gained	DAUB			X	X	X	X	X	X	X		
GIS	Integration of GIS data into the BIM environment to improve design co-ordination and clash analysis	WG22			X	X	X	X	X	X	X		
Change management	Handling of deviations identified in construction progress controls … as well as changes during the design process	DAUB			X	X	X	X	X	X	X		
Geological documentation	Assessment of geotechnical risk along tunnel route	IFC			X	X	X	X	X	X	X		
Spaceproofing	Interface document / agreement between discplines to determine the space requirements for each individual design component - classified as design basis	WG22				X	X	To be replaced with design development					
Bill of quantities, tendering, award	Use of the 3D models produced in the preliminary design phase and updated for the process of tendering the works in underground construction; Standardisation of the tendering process	DAUB				X							
Digital Twin (in the design stage)*	Creation of a coordinated workflow to set a single source of truth between digital models in the design development, e.g., between the Structural model and BIM model, Hydraulic model and BIM model	WG22				X	X	X	X	X	X		
Construction Scheduling	Model-based scheduling of construction; Linking of individual construction elements from the structure model with the associated activities in the schedule; Representation of the project structure in the schedule structure and the BOQ structure	DAUB					X	X	X	X	X		
Quantity determination	Basis for cost estimation, tendering, billing, logistics, planning as well as during construction for billing and payment purpose	IFC					X	X	X	X	X		
Invoicing of construction works	Use of the model, which is promptly updated with the on-site excavation classes and any additional and/or reduced quantities of supportmeasures, as the basis for the payment of excavation works, taking into account the associated time-related costs; Use of the „construction time model" in BIM	DAUB									X		
Monitoring	Monitoring of ground deformations during tunnelling	IFC									X		
Digital Twins (Asset Management)	Advanced asset management is expected to leverage a Digital Twin of a tunnel, in the form of a continuously updated digital mirror of the current conditions.	IFC										X	X
Use for operation and maintenance	Provision of a facility model with all relevant data for operation; Data administration and updating at a central location (database)	DAUB											X

Figure 1. Excerpt of BIM Use list as provided in the ITA WG 22 Document "BIM in Tunnelling—Guideline for Bored Tunnels

It should be noted that the ITA BIM Use table is necessarily non-exhaustive. BIM uses vary with the project needs. In addition, the continuous development of BIM software leads to the continuous expansion of potential BIM Uses within a project.

Information Management Process and Responsibilities

A clear information management framework is required to successfully adopt, integrate, and apply BIM processes within a project. Such a framework must regulate and define the workflow which governs the process of creation, modification and verification of digital project information within a project. In doing so, it should be determined which project participant (i.e. client, engineer, contractor, etc) is responsible for which task (e.g., creation, modification or verification of information) at each stage of a project or asset's life cycle. Once such a framework is developed, it is further recommended to adopt a contractual agreement between participants that codifies the information management process. This agreement can, for example, be made in the form of a BEP.

The ISO 19650 series [ISO, 2018(1); ISO, 2018(2)] provides a standard framework for information management of built assets using information modelling processes applicable throughout the asset life cycle. As the ISO 19650 series is already frequently adopted by the tunneling industry, the ITA WG 22 has chosen to endorse the adoption of the ISO 19650 series, rather than developing an independent guideline. To support this process, the ITA WG 22 has developed a companion document to the ITA BIM guideline regarding the adoption of the ISO 19650 series. This companion document is titled "ITA-AITES Recommendations for the Application of ISO 19650 Series during the Delivery of Underground Projects and Assets—Information Management Process and Responsibility Matrix." These ITA recommendations are intended to provide a guideline for the for the adoption of the ISO principles in the underground construction industry. The ITA recommendations for the application of ISO 19650 Series will be officially published at the WTC in Copenhagen in 2022.

Model Interoperability and Data Environment

It is often falsely believed by non-BIM experts that all digital project information can be stored within a single BIM. This is largely impossible, as computing power and software capabilities are not yet sufficient to do so. Rather, several BIMs (e.g., separate geotechnical, structural, and systems models) according to the selected BIM Uses are typically developed for a Tunneling project. Although not all BIMs interact with one another, all BIMs should be stored in a centralized location, referred to as the Common Data Environment (CDE), which is subject to the information exchange requirements set forth in the BEP or by ISO 19650. A CDE can be, for example, a ProjectWise environment (or similar in another platform, e.g., Autodesk BIM360) in which the file structure as well as the uploading, editing and approval process is strictly controlled.

CDE's are well defined in ISO 19650 and may be directly adopted in the field of tunneling. The WG 22 therefore recommends that the ISO 19650 standard be followed for the creation of a CDE in tunneling projects.

Exchange Data Formats

BIMs within a project often need to exchange and share information. Importing, exporting, creating, or editing data, may, however, require software specific exchange formats. These formats may have limited interoperability with other software used in the BIM environment. Consequently, data requirements and file formats for data interactions between BIMs must be pre-selected and codified in a contract document (e.g., BEP or similar) before use. If data between BIMs cannot be directly transferred through native file formats, interfaces modifying the export or import information must be manually created using specialized coding tools.

File formats for BIM programs are typically proprietary and often unique to a specific program or software family. To increase transparency and compatibility between BIM programs, the ITA WG 22 guideline supports the adoption of the Industry Foundation Class (IFC) format. The IFC format presents a vendor-independent format for the exchange of information between BIMs. Tunneling specific objects classes (titled IFCTunnel), have been in development by Building Smart International [buildingSMART, 2020] since 2019. Although significant progress has been made towards the adoption of IFC in commercial BIM software, the IFC format may not be available in all commercial programs.

In lieu of the IFC format, it is generally advantageous to combine software packages from one developer to improve interoperability between disciplines and tasks. In doing so, the ITA guideline provides the following additional recommendations:

- Tunnels are linear structures, and not all software are capable of handling chainages. Care should be taken in determining the right software to provide the ideal working environment for tunnels.
- In contrast to the above, local structures (e.g., Shafts or Stations), may require different modelling software than the primary tunnel alignment.

- Generally, the adoption of fewer software platforms leads to better integration between BIMs as the number of interfaces is minimized.
- All tunnel and other project models should share the same co-ordinate system from commencement of modelling.
- A federation strategy to transmit information containers or models should consider the maximum file size that is practical for upload and download with the specified IT infrastructure (e.g., 250MB, 1 GB, 10 GB, etc.). The information model should be subdivided such that no single information container exceeds these limits. These limits are typically set forth in a project Master Information Delivery Plan (MIDP) and Tas Information Delivery Plans (TIDP).

Classification Systems

Objects within BIMs (i.e. the tunnel lining or tunnel segments) should be properly named or labelled so that a model may be properly queried. Classification systems are used within a BIM context to achieve this purpose. These systems provide a naming hierarchy which allows all objects within a BIM to be named in a consistent but unique manner.

Classification systems may be project specific or may be dictated by pre-existing Owner's requirements. In the absence of Owner's requirements, the ITA recommends the adoption of existing classification systems. Examples are the Uniclass [NBS, 2021] or DAUB [DAUB, 2020] classification systems. The DAUB standard is tunnelling focused and provides an extensive naming convention for BIM objects within both TBM and conventional tunnelling frameworks. The DAUB standard is, however, complex and results in long object names that adopt local national conventions. The NBS Uniclass 2015 system is has been more broadly developed for the entire construction industry. In being broader, the Uniclass system provides less direct guidance on naming conventions for specific tunnel-based objects, but is therefore also easier to manipulate. A schematic of the Uniclass structure is provided in Figure 2. An example of named objects using the Uniclass convention are provided in Table 1.

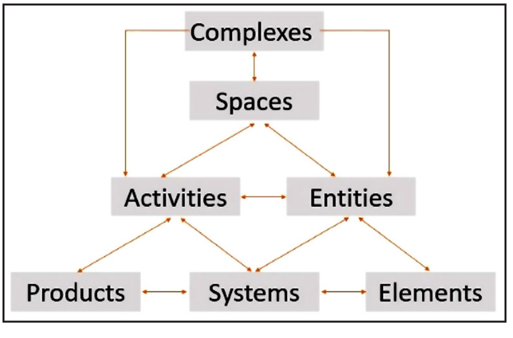

Figure 2. Uniclass object hierarchy

Level of Definition

Within the context of the ITA BIM Guideline, The level of definition (LOD) describes the level of geometrical information associated with an object within a BIM. For example, a tunnel segment can be modeled to a LOD incorporating only its inner radius, outer radius, and faces, or a tunnel segment can be modelled such that is accounts for all the geometrical details such as the gasket groove, contact area for the longitudinal joint, etc. The LOD of each object within a BIM develops throughout the life of a tunneling project. To simplify this concept for easier inclusion into a tunnelling BIM environment, the ITA guideline provides a simplified table that accounts for most of the objects found in a tunnel and provides recommendations at which stage which object or detail should be included. An excerpt is provided in Figure 5.

To account for the complexities in the delivery process, the WG 22 guideline proposes to split the bored tunnel BIM into two models: a ring model and a tunnel/alignment model. The ring model is included as a reference within the tunnel model through the tunnel model's Level of Information (LOI). The LOI describes semantic, i.e. non-geometrical, information associated with objects in a BIM. A schematic of the interaction between the tunnel and ring model is provided in Figure 3.

The Tunnel Model is a tube model that defines the location of tunnel in the three-dimensional space. The tunnel model also includes all information

Table 1. Tunnel specific examples of Uniclass object naming structure

Uniclass Element	Object	Uniclass Code
Complex	N/A	
Spaces	Tunnel and shaft spaces	SL_80_96
Entities	Lined tunnels	En_80_96_49
Systems	Tunnel structure systems	Ss_37_50_92
	Cementitious grout systems (i.e., annular grout)	Ss_20_05_80_12

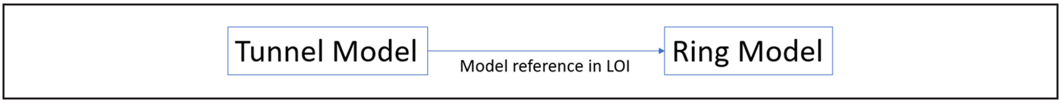

Figure 3. Schematic of the relationship between tunnel and ring model in a BIM for a bored tunnel

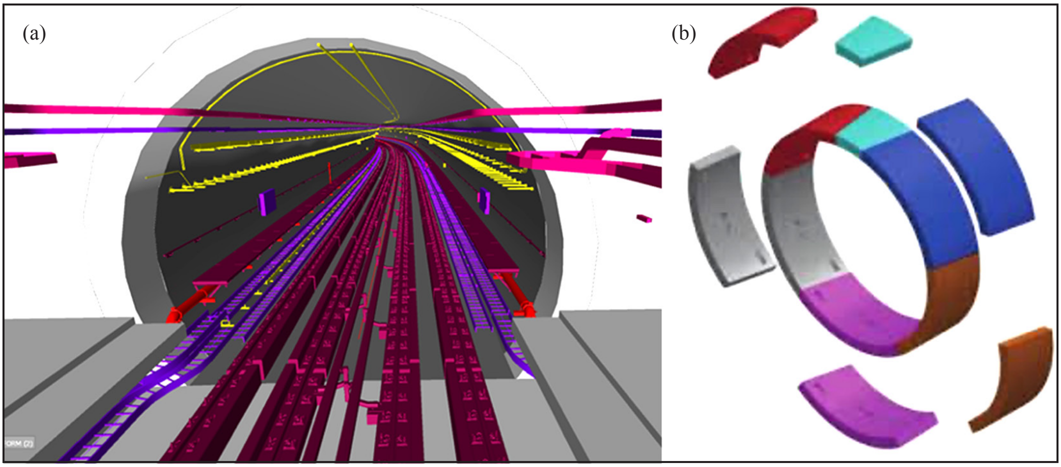

Figure 4. (a) Tunnel model including interior systems; (b) ring model including segments

generalizable to the tunnel as a whole (clearance envelopes, linear internal structures, etc.). It does not contain the location of the ring segments, as the achieved construction tolerances, and corresponding segment location, are unknown during the design process. The segmentation information is contained in the ring model. During design, only a single ring of each ring type generally needs to be modelled. In addition to the segmentation, the ring model should contain all relevant information needed to define the segmental lining, i.e., exact geometry, number and location of embedded items, reinforcement content, etc. The Ring Model is intended to form the basis of the segmental lining drawings and can be used at a later date by the Contractor to generate the as-built tunnel models with the exact known ring orientation and locations. The as built models, in contrast to the design models, should contain the as-built location of the individual ring segments. An image of an exemplary tunnel model is shown in Figure 4 (a), whereas a schematic of a ring model is shown in Figure 4 (b).

Asset Definition

The ITA guideline is focused primarily on the project delivery phase of a tunnel project. Owners, however, often desire that the digital assets developed during a project used for asset management purposes after handover. The ITA guideline therefore provides a short introduction into BIM for Asset management. This introduction covers the differing terminology involved when discussion asset management, i.e., Project Information Models (PIMs) and Asset Information Models (AIMs) and describes important aspects to consider when transferring information between a PIM and an AIM. In addition, the guideline provides a reference to ISO 55000 which specifically covers the primary aspects of asset management.

Ground Modelling

The inclusion of ground information (e.g., borehole data, geophysical data, geological models) in a BIM environment is often hindered due to a variety of reasons, with some being:

- The development of a full geological database of all available ground information is often difficult due to the large volume of geological information available.
- In contrast to a civil design, ground information cannot be largely determined a-priori.
- Ground information changes during tunneling, and previous assumptions concerning geological layering are updated or replaced as the project progresses (e.g., borehole vs face map records, latest readings from I&M, etc.).
- Much available geological information is not factual, and is a result of specialist interpretation.

ISO 19650	STRATEGIC PLANNING	PROJECT DELIVERY									OPERATION PHASE
ITA WG22	STRATEGIC DEFINITION	PREPARATION & BRIEFING	CONCEPT & PRELIM DESIGN	BASELINE REFERENCE DESIGN	DETAILED/ CONTRACTOR DESIGN 30%	60%	90%	100%	CONSTRUCTION	COMMISSIONING & HANDOVE	USE/OPERATION
Level of Detail											
Object											
Alignment	NR	NR	X	X	X	X	X	X	X	X	By Asset Owner
Clearance Envelope	NR	NR	NR	NR	X	X	X	X	X	X	
Tunnel Intrados	NR	NR	X	X	X	X	X	X	X	X	
Concrete Outline	NR	NR	NR	X	X	X	X	X	X	X	
Annular Grout	NR	NR	NR	NR	X	X	X	X	X	X	
Segmentation	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
HDPE Lining	NR	NR	NR	NR	NR	X	X	X	X	X	
Reinforcement content	NR	NR	NR	NR	NR	X	X	X	X	X	
Openings	NR	NR	NR	NR	NR	X	X	X	X	X	
Opening Tolerances	NR	NR	NR	NR	NR	X	X	X	X	X	
As-built Object											
Lipping	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	By Asset Owner
Stepping	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Alignment deviations	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Ovalisation	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Ring Roll	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Structural Defects	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Non Structural Defects	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
3D Survey Model	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Level of Information											
Ring Model	NR	NR	NR	X	X	X	X	X	X	X	By Asset Owner
Basis of Design	NR	NR	NR	X	X	X	X	X	X	X	
Design Report	NR	NR	NR	NR	X	X	X	X	X	X	
Geotechnical Report	NR	NR	NR	X	X	X	X	X	X	X	
Durability Report	NR	NR	NR	NR	NR	X	X	X	X	X	
Coating Specification	NR	NR	NR	NR	NR	X	X	X	X	X	
Related Specifications	NR	NR	NR	NR	X	X	X	X	X	X	
Defect Report	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Repair Report	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Future Loading	NR	NR	NR	NR	NR	X	X	X	X	X	
As built Survey	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Carbon Coefficient	NR	NR	X	X	X	X	X	X	X	X	
Ring Type	NR	NR	NR	NR	X	X	X	X	X	X	
Concrete Grade	NR	NR	NR	NR	X	X	X	X	X	X	
Rebar Grade	NR	NR	NR	NR	X	X	X	X	X	X	
Fiber Content	NR	NR	NR	NR	X	X	X	X	X	X	
Exposure Classification	NR	NR	NR	NR	NR	X	X	X	X	X	
Fire Rating	NR	NR	NR	X	X	X	X	X	X	X	
Water Retaining (Y/N)	NR	NR	NR	NR	NR	X	X	X	X	X	
Water tightness Critera	NR	NR	NR	X	X	X	X	X	X	X	

Figure 5. Excerpt of the LOD/LOI table developed by the ITA WG 22. NR signifies "Not Required."

Despite the complexities surrounding the subject, ground information is a vital component of underground construction, as many of the risks and successes of a project hinge on the correct interpretation of its geology. The ITA guideline strongly encourages the inclusion of ground information within a BIM environment.

Integration of Geological & Geotechnical Data Within a BIM Context

Ground information in a geotechnical "BIM" environment often follows a different data structure than structural or architectural data included within BIM models. For this reason, the ITA guideline recommends that the geotechnical/geological model be kept separate from the main tunnel model. This also supports the practicality of reducing model sizes in line with software/hardware limitations. Furthermore, the inclusion of different types of information will be dependent on the stage of a project. Some examples of information to include in geotechnical BIMs at different project stages are:

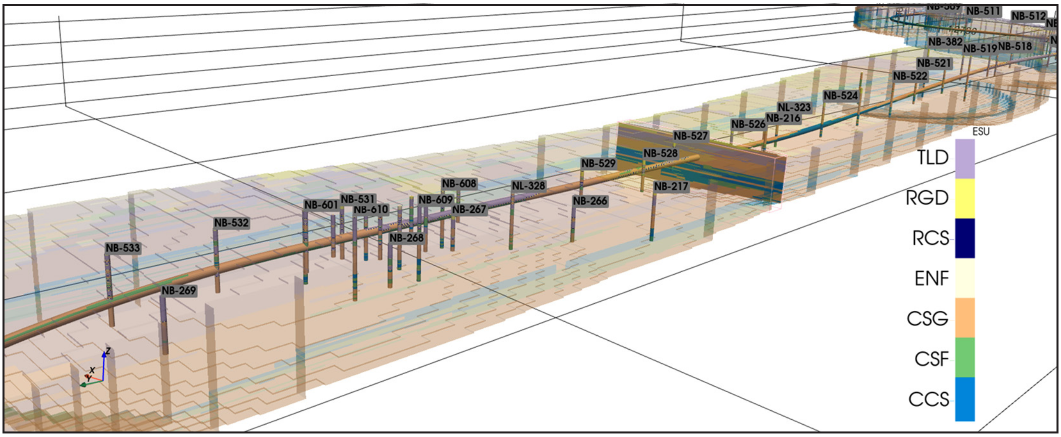

Figure 6. Geotechnical BIM showing positions of boreholes along a tunnel alignment

- Conceptual & Preliminary Design Model—Historical borehole data
- Baseline Reference Design Model—borehole data (with links to relevant reports), initial geotechnical/geological models and sections
- Detailed/Contractor Design Model—borehole data, geotechnical/geological models and sections, baseline I&M readings
- Construction Model—Borehole data, I&M (real-time or not), updated models and sections
- Handover/Operational Model—The Asset management Model is assumed to be the construction model as often no further information is created after completion of construction. The asset stage is, however, outside of the scope of this work as it needs to be defined by the Asset Owner suitable to their systems.

An example of a BIM showing borehole data is provided in Figure 6.

Factual vs. Non-Factual (or Contractual vs Non-Contractual)

Ground information can be factual or non-factual (i.e., interpreted data). It is recommended to include factual data (examples outlined above) in project-wide BIM models.

Non-factual data include interpolations for geological models and sections, recommended baseline parameters or interpretations from geophysics. The inclusion of non-factual data should be carefully considered since this information may impact risk sharing arrangements within a project. The inclusion of non-factual data within a project wide geological BIM Model does, however, carry significant benefits. Interpretive data, such as the in-situ stratigraphy, and other actual ground conditions can be very useful to make informed engineering decisions, and provide direct comparisons to the baseline or refence model, especially in projects with complex geology. In addition, such data included within a BIM model can significantly streamline future engineering decisions, as future engineers may use past interpretations as basis for their own assumptions or interpretations. This is especially true with regards to BIM models intended to be used as Asset management aids during USE/OPERATION phase.

If non-factual data is to be included in the BIM, it should be explicitly evident that this information is an interpretation from factual data. Uncertainties in this interpretation should be quantified and reported. Methods for clear classification of factual vs. non-factual data vary based on projects and are owner dependent. One example of how to distinguish geotechnical data is that provided by Building Smart International [buildingSMART, 2020] in which geotechnical data is stored as "Factual Data," "Interpreted Data," and "Conception (Design) Data." In addition to correctly identifying non-factual geotechnical data, the source of interpretive information should be traceable. Traceability within a BIM model can be achieved by, e.g., consistently tracking author information within a BIM object.

Sustainability

BIM can facilitate the early tracking of sustainability parameters and quantify the emissions associated with geometrical objects. The ITA WG 22 guideline recommends to track equivalent carbon emissions as a primary sustainability marker of a project. This approach supports informed decision making by clients and consultants. Other life cycle analysis design tools specific to tunnelling projects that include geology, structural design options and alignment can additionally provide early embodied carbon calculations for best practice results.

CONCLUSION

The field of BIM is continuously changing due to the ever-increasing number of tools available to architects and engineers. Nevertheless, some core concepts, such as organized data management and workflows or centralized data structures, have established themselves as necessary for the successful integration of BIM into a tunneling project. The ITA "guideline for the implementation of Building Information Modeling concepts for Bored Tunneling Projects" aims to clearly depict these core concepts to both owners and engineers and therewith support the continued adoption of BIM within the tunneling industry.

ACKNOWLEDGMENTS

The authors would like to thank the all the members of the ITA WG 22 for their assistance in developing the guideline. In addition, we would like to thank the UCA of SME Working group on interaction modelling in tunneling for their review on the applicability of the guideline for the US market. The UCA of SME WG consists of Anthony Bauer, Jacob Grasmick, Ivan Hee, Mark Johnson, Jay Mezher, Foteini Vasilikou, and is chaired by Vojtech Ernst Gall. The authors also thank Hichem Zammit for his contribution to this paper.

REFERENCES

Building Smart International (buildingSMART). 2020. IFC-Tunnel Project Report WP2: Requirements analysis report (RAR). Retrieved from: https://www.buildingsmart.org/the-final-draft-of-the-ifc-tunnel-requirements-analysis-report-is-now-available/.

German Tunneling Committee (DAUB). 2019. Digital Design, Building and Operation of Underground Structures BIM in Tunnelling. DAUB e.V.: Cologne, Germany.

German Tunneling Committee (DAUB). 2020. Digital Design, Building and Operation of Underground Structure Model requirements—Part 1: Object definition, coding and properties. DAUB e.V.: Cologne, Germany.

International Organization for Standardization (ISO). 2018. ISO 19650-1:2018—Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling Part I: Concepts and Principles. ISO: Geneva, Switzerland.

International Organization for Standardization (ISO). 2018. ISO 19650-2:2018—Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling Part 2: Delivery phase of the assets. ISO: Geneva, Switzerland.