BIM in Tunnelling
Guideline for Bored Tunnels - Vol 1

ITA Working Group 22
Information Modelling in Tunnelling

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1 >> Introduction

This guideline has been initiated by the International Tunnelling Association (ITA) Working Group (WG) 22 to support BIM implementation in the tunnelling industry. It provides recommendations which are to be adapted according to the availability of corresponding best practice experiences for all project parties in order to support the adoption of BIM within a tunnelling project.

This guideline is intended to be used by all engineers and owners to provide a reference framework for the implementation of BIM for tunnel projects. This guideline is specifically focused on the implementation of BIM for a segmentally lined bored tunnel as it pertains to heavy civil works. It is the intent of ITA WG 22 to develop further specific guidelines for different tunnel methodologies (e.g., conventional tunnelling) in the future. For more general information concerning BIM and its use in underground construction, the reader is referred to more general guidelines such as The German Tunnelling Committee's (DAUB's) "Building and Operation of Underground Structures – BIM in Tunnelling" or similar documents as provided in Section 12.

Specific recommendations concerning the modelling of non-civil works, e.g., mechanical, electrical, automation, or control systems, or project-specific internal structures, e.g., concrete infills, plenum walls, duct-banks, smoke ducts, etc. are not provided.

This guideline is not intended to contest Employer's Information Requirements (EIR) or local best practise. It is only intended to alleviate ambiguity that may exist due to general definitions in the Employer's Information Requirements or provide reference to owners for the development of their Employer's Information Requirements.

It is expected that the BIM's capabilities will continue to expand as new BIM technology is developed. This version of this guideline is, however, based on a review of current international practise of BIM in tunnelling. As such, this document is subject to up-dates in consequent versions.

2 >> BIM

Building Information Modelling (BIM) is defined by 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 1: Concepts and principles: as: *"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. Moreover, this process is supported by various digital tools and software as well as by contractual information management agreements. For this reason, 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 design, project delivery, asset management, and collaboration.

While the ITA WG 22 does not purport to have the authority to provide a definitive description of BIM, the text above addresses 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 line with ISO 19650. In contrast, the final sentence of the paragraph above addresses the reality of the usage of the term 'BIM' in the tunnelling 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 text above aims to reconcile this divergence in perception.

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 BIM Models that accurately capture the desired project/asset information at each project phase. The BIM Models together with the information management/storage system with which they are connected make up the 'digital assets' of a project.

2.1. BIM FOR BORED TUNNELS

The successful implementation of BIM for a bored tunnel project does not significantly diverge in concept from the implementation of BIM in other Architecture, Engineering, or Construction fields. In all fields, successful implementation of BIM is based around organizing information/data workflows (i.e., who edits/creates which data/information at which time, and who this data is shared with/reviewed by). Different fields only diverge in which type of information is modelled, as different construction or asset information is relevant for different types of projects and/or assets. Some information such as 3D/4D structural or architectural information may be common among all major infrastructure projects, but other information, such as the logging or tracking of TBM process Data, is specific to TBM projects. In particular, geotechnical, geological, or ground data (discussed in detail in Section 10) is of great importance to tunnelling projects, and care must be taken in its incorporation into a BIM framework. For this reason, as stated in the introduction, this guideline provides a general introduction to BIM concepts, as well as providing best practise guidelines for the implementation of BIM for tunnelling projects. The specific information relevant for a Bored Tunnel Project (e.g., machine data, ground data, monitoring data, etc.), and when to collect or model this information, is addressed in the Use Case descriptions in Section 4.

3 >> Assets

The parties involved with the design and construction of the tunnel project often differ from those involved through operation and maintenance. Similarly, the information relevant to design and construction differs from the information required during operation and maintenance. Consequently, the information stored within a BIM model should be tailored to the asset cycle. For this reason, the BIM models used during construction may be referred to as Project Information Models (often abbreviated as PIMs) and those used during asset life are often referred to as Asset Information Models (often abbreviated as AIMs). Correspondingly, information included required for a PIM are referred to as the Project Information Requirements (PIR), whereas Asset information required by an owner to be included in an AIM are referred to as Asset Information Requirements (AIR). The AIR & PIR may differ, but, as much design and construction information are relevant during the asset management phase, the information transfer between these two models should be well coordinated. This information management loop (with additional sources of information) is depicted schematically in ISO 19650-1 and reproduced herein in Figure 1.

Information required for asset management during the operational phase is built-up through the whole asset life cycle including the early project stages. At the project definition stage, the owner defines Asset Information Requirements which specify the uses of Asset Information Models during operation and the information required to be included in the model to fulfil its function.

The Asset Information Requirements provide input to the Project Information Requirements which are used to develop the Project Information Model during the project stages. At the end of construction, during commissioning, the Project Information Model is used by the Contractor to develop the Asset Information Model and hand it over to the Asset Manager. As such, the Asset Information evolves continuously during the project phases and becomes a crucial part of the management of the information requirements.

It is critically important for owners to identify at an early stage which asset information is required in order to ensure that the Project Information Model is populated adequately during each project phase.

ISO 55000:2014 "Asset Management, Overview, Principles and Terminology" provides an overview on the subject. For reference, the definition of assets and benefits of asset management are reproduced herein to provide an overview of the potential benefits with proper asset management:

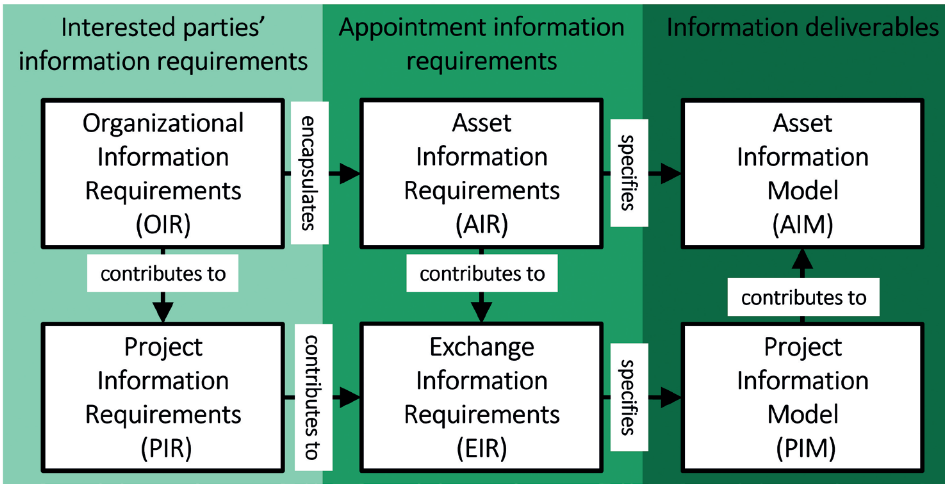

Figure 1: Hierarchy of information requirements as exerted from ISO 19560-1.

3.2 BENEFITS OF ASSET MANAGEMENT (REPRODUCED FROM ISO 55000:2014)

Asset management enables an organization to realize value from assets in the achievement of its organizational objectives. What constitutes value will depend on these objectives, the nature and purpose of the organization and the needs and expectations of its stakeholders. Asset management supports the realization of value while balancing financial, environmental and social costs, risk, quality of service and performance related to assets. The benefits of asset management can include, but are not limited to the following:

a) improved financial performance: improving the return on investments and reducing costs can be achieved, while preserving asset value and without sacrificing the short or long-term realization of organizational objectives;

b) informed asset investment decisions: enabling the organization to improve its decision making and effectively balance costs, risks, opportunities and performance;

c) managed risk: reducing financial losses, improving health and safety, good will and reputation, minimizing environmental and social impact, can result in reduced liabilities such as insurance premiums, fines and penalties;

d) improved services and outputs: assuring the performance of assets can lead to improved services or products that consistently meet or exceed the expectations of customers and stakeholders;

e) demonstrated social responsibility: improving the organization's ability to, for example, reduce emissions, conserve resources and adapt to climate change, enables it to demonstrate socially responsible and ethical business practices and stewardship;

f) demonstrated compliance: transparently conforming with legal, statutory and regulatory requirements, as well as adhering to asset management standards, policies and processes, can enable demonstration of compliance;

g) enhanced reputation: through improved customer satisfaction, stakeholder awareness and confidence;

h) improved organizational sustainability: effectively managing short and long-term effects, expenditures and performance, can improve the sustainability of operations and the organization;

i) improved efficiency and effectiveness: reviewing and improving processes, procedures and asset performance can improve efficiency and effectiveness, and the achievement of organizational objectives

3.3 ASSETS (REPRODUCED FROM ISO 55000:2014)

An asset is an item, thing or entity that has potential or actual value to an organization. The value will vary between different organizations and their stakeholders, and can be tangible or intangible, financial or non-financial. The period from the creation of an asset to the end of its life is the asset life. An asset's life does not necessarily coincide with the period over which any one organization holds responsibility for it; instead, an asset can provide potential or actual value to one or more organizations over its asset life, and the value of the asset to an organization can change over its asset life. An organization may choose to manage its assets as a group, rather than individually, according to its needs, and to achieve additional benefits. Such groupings of assets may be by asset types, asset systems, or asset portfolios."

4 >> BIM Use Cases

Before BIM is implemented within a project, the goal of its application should be clearly defined and outlined in order support the build-up of the Employers Requirements for BIM. In this guideline, these goals are referred to as BIM Use Cases, in alignment with the terminology as employed by buildingSMART International). A priori identification of these BIM Use Cases is of utmost importance for a successful application of BIM as the specific BIM Use Cases will define the BIM infrastructure / software environment as well as the information needed.

BIM Use Cases are, as is suggested by the name itself, the tasks or processes for which a BIM model is used. In order to give each participant in a project the information they need, it is vital to know in which way the BIM Use Cases are engaged and how they are interrelated. As such the BIM Use will not only determine the necessary software required, but also at which project stage the BIM modelling information should be provided.

Information needs vary greatly between different BIM Use Cases. BIM can be used in all stages of a project for several purposes ranging from the development of architectural models for public outreach to the development of 5D scheduling and budget models for better construction coordination. The information required for drawing production, for instance, will be quite different from that required for prefabrication, asset management, or other tasks. Identifying and understanding the BIM Use in each case is therefore key for optimising data and information flows.

In this document, the ITA WG 22 has developed a summary of common BIM Use Cases, which is presented in Appendix A. The table is based on various sources, mainly the German Tunnelling Committee (DAUB) and buildingSMART International (see to section 12 for references), as these organization have already developed Tunnelling-specific BIM Use Cases. Several other Use Cases have, however, been added by the ITA WG 22. The list in Appendix A is not intended to be an exhaustive list of BIM Use Cases as they greatly vary with the project needs. Furthermore, potential BIM Use Cases are continuously being expanded due to the development of new software and processes. Finally, the definition of an Employers Requirement of a BIM Use Case may have an impact both in schedule and cost on the project delivery. As such, the initial definition of the role of BIM in the project should be clearly defined by the owner.

5 >> Information Management Process & Responsibilities

A clear information management framework forms the basis of the integration and application of BIM processes. The information management framework defines the workflows which govern the creation, modification and verification of digital project information at any given stage during a project or asst's life cycle, as well as which party, i.e., client, designer, contractor, delivery team, etc. is responsible to do so. The ISO 19650 series regulates this information exchange by proposing a standard framework for information management of built assets using information modelling processes applicable throughout the asset life cycle.

It has become common practise in the tunnelling industry to use the ISO 19650 series as the information management standard that is followed in a tunnelling project, and it is therefore recommended to adopt the ISO 19650 series as an information management standard. In implementing the ISO 19650 series, the following the following should be considered:

- The ISO 19650 is inherently best suited for use in traditional Design-Bid-Build delivery processes with minor modification being needed for a Design-Build delivery. If alternative delivery approaches are implemented within a project, e.g., Contract Management at Risk (CMAR) or Progressive Design Build (PDB), the information flows as per ISO 19650 may need to be more significantly adjusted.
- The Information Management and Responsibility Matrix should be established at the earliest possible stage of a project. It is recommended that the information management process and responsibilities are recorded within the project's BIM Execution Plan (BEP) or similar document depending on local customs.
- The workflow and delivery strategy should be developed to suit BIM delivery.

6 >> Model Interoperability & Data Environment

Data environments used within a BIM process should be structured in such a way as to be conducive to the flow of data between project partners, to allow easy access to data across parties, and to be as compatible as possible with the software used to reach a project's BIM goals. To facilitate such a software environment, a Common Data Environment (CDE) is often defined within a BIM project strategy. A CDE is a central repository for all project information that is not only used to transfer and store data, but also to define the single base source of information for all digital data within a project. At its core, a CDE is often a cloud-based file storage system, but many software programs used to develop a CDE, such as Autodesk BIM 360 or Bentley ProjectWise, often allow an owner to define workflows which regulate when information is uploaded, edited, checked, or approved. Common Data Environments (CDE) are defined in ISO 19650 and this standard is recommended to be applied in the build-up of the CDE. There is no need for an adaptation of the CDE for work in underground construction, as the same data management principles as used for civil engineering may be applied.

In addition to developing a well-structured CDE, a project's BIM strategy should ensure that the software used to achieve a project's BIM goals are as compatible as possible. More specifically, if interaction or information exchange between two or more separate software systems is required to achieve a project's BIM goal, it should be ensured that the software systems

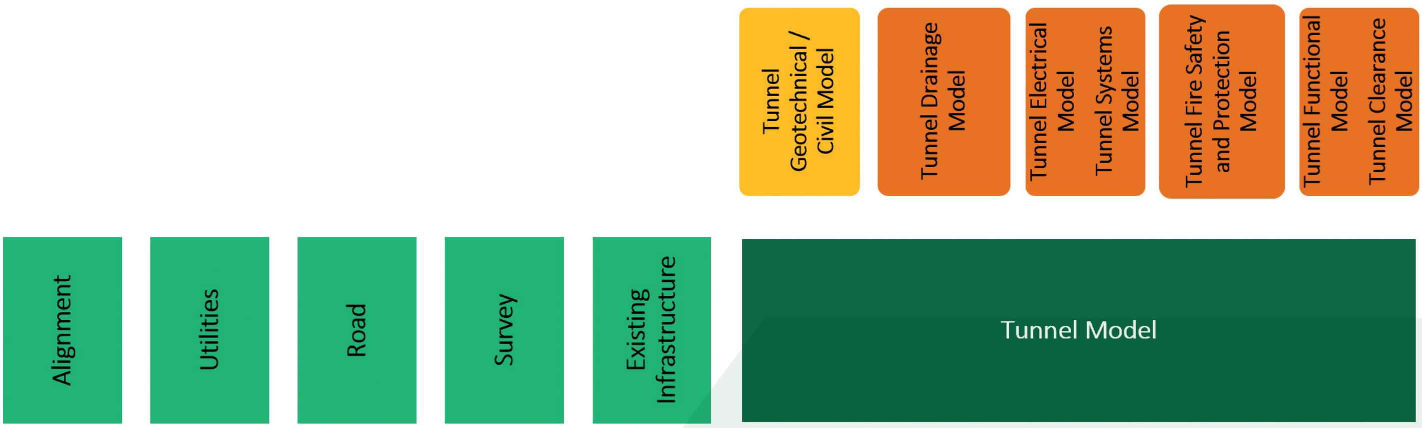

Figure 2: Potential Model build up strategy (Yellow and Orange showing scope of this Document).

can interact in the desired fashion, i.e., that the file exchange formats are compatible. More information concerning this topic is provided in Section 9 of this document.

In the context of the above, the following considerations and recommendations may be considered when setting up a software environment for a project's BIM implementation:

- Emphasis should be placed on choosing a set of tools for the project that are best suited for collaboration and model interoperability.
- The use of fewer software platforms leads to better integration between separate BIM models, as the number of interfaces is minimized.
- Not all software packages can handle chainages and providing the ideal working environment for tunnels or similar horizontal structures. Care should be taken that the software package for the alignment and tunnel model can do so.
- Local underground structures such as shafts and stations are typically suitable to be modelled in a standard BIM software.
- All tunnel and other project models should share the same co-ordinate system from the commencement of modelling (See Note Below).

Note: For projects spread over a large physical area, it can be useful to have different reference coordinates or "zero points" during the modelling stage. To generate correctly geo-located federate models, it can be useful to insert a simple easily identifiable coordination object (e.g., a double pyramid that points to the reference/zero point) in the BIM models that contains all information about the used coordination system and can be used to check the location for all models.

A project's CDE and software environment should support a project's federation strategy. A federation strategy is the strategy defined within a project to successfully develop composite information models, i.e., federated models, which consist of information developed from different project participants or disciplines. Successful federation strategies allow multiple parties and/or disciplines to work together efficiently and to independently develop project-wide BIM models without interference. One such a federation strategy is shown Figure 2, in which the separate drainage models, systems models, architectural models, etc. are combined into a single federated "tunnel model." An alternate federation strategy is provided in ISO 19650 Annex A, section A.4, in which the federated model is split into different models by geometric location in the cross section. This is shown in Figure 3.

As discussed in ISO 19650 Annex A, a federation strategy to assist the transmission of information containers or models within a delivery team or to and from an appointing party should consider the maximum file size that is practical for upload and download with the specified IT infrastructure. The information model should be subdivided so that no single information container exceeds the limits and allows for design development in parallel. More information concerning the file formats used in federated models is provided in Section 9.

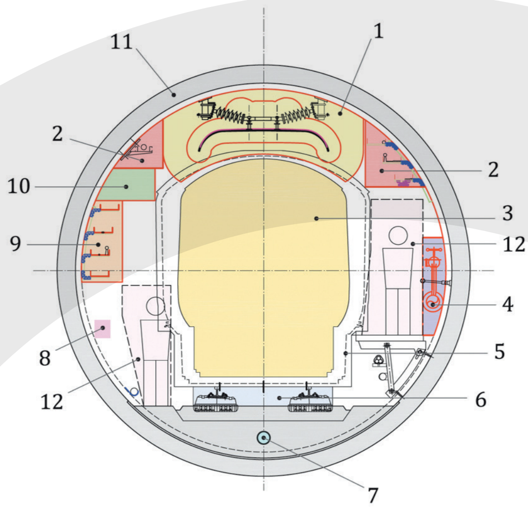

Figure 3: Illustration of federation of tunnel cross-section systems in a rail project as provided in ISO 19650 (Key: 1 overhead line electrification, 2 electrical system, 3 train, 4 water system, 5 kinetic envelop, 6 track system, 7 drainage system, 8 communications system, 9 signalling system, 10 signage, 11 tunnel structure, 12 emergency walkway).

7 >> Level of Definition

BIM models must be developed to varying degrees of complexity in order to fulfil the Use Cases for which they are created. For example, if it is desired to use a BIM model to perform a quantity take-off of the amount of concrete to be used in the construction of a Bored Tunnel Lining during Detailed Design, the BIM model must contain the required information (i.e., the volume of the tunnel lining) to do so. Similarly, if the equivalent carbon emissions produced by the production of the concrete lining are to be calculated, the tunnel lining in the BIM model must include information on the material type, its geometry, its density, and the equivalent carbon content per kg of concrete produced. In contrast, other information, such as the exact ring segmentation, may not be required.

This level of complexity to which a BIM model is developed is referred to as the Level of Definition within this document. This terminology is borrowed from the PAS 1192-2:2013, within which it was introduced. In PAS 1192-2:2013, the Level of Definition is further subdivided into the Level of Detail (LOD), which defines the level of geometrical detail to which a BIM object is developed, and the Level of Information (LOI), which is used to refer to non-geometrical information (i.e., material type, volume price, equivalent C0^2 output per kg, etc.).

While the Level of Detail/Level of Information terminology is used in this document, it should be noted that various organizations have developed differing terminology to refer to similar concepts. For example, BIM Forum, which is supported by the American Institution of Architects (AIA), uses the term Level of Development (also using the LOD acronym). BIM Forum provides strict guidelines for which information is to be included at separate level of development levels and does not further subdivide the Level of Development into smaller categories. The DAUB, in contrast, refers to a model of granularity (LoX), which is further subdivided into a Level of Geometry (LoG), Level of Information (LoI), Level of Detail (LoD) and, like the BIM forum, a level of Development (also referred to as LOD). Finally, the ISO 19650 series, which has replaced the PAS 1192 as a BIM standard, forgoes any complex terminology

Figure 4: Tunnel Model build-up.

and simply employs the term Level of Information Need (without an acronym). Nevertheless, as the original PAS level of Definition subdivision into LOI & LOD (no-geometric and geometric information, respectively) is inherently intuitive, it is continued to be used in this document.

All relevant documents (PAS, ISO & DAUB) are provided in Section 12

The definition of the required level of development, i.e., LOD & LOI, at different project stages should be coordinated with the specified BIM Use Cases for a project. As a project progresses, and as a project's BIM models become more detailed, the LOD & LOI increase. In order to control the development of a project's digital assets, it is recommended that an Employer's Information Requirements set forth the LOD & LOI to which a tunnel BIM model should be developed at which project stage in, e.g., a BIM Execution Plan (BEP).

7.1. BORED TUNNEL LOD & LOI

Many of the existing schemes for the standardization of the Level of Definition are quite complex, such as that proposed by the BIM forum, and are often too granular for a typical tunnelling project's BIM needs. As such, the ITA WG 22 has developed a Level of Definition proposal for a bored tunnel model that can be found in Appendix B. The Level of Detail (LOD) & Level of Information (LOI) provided in Appendix B is organized along typical project stages

Within the LOD/LOI scheme in Appendix B, it is proposed to split the Tunnel BIM model into two models for the design phase to account for the unknown position of the segmental lining. The two models are referred to as the Tunnel Model and the Ring Model, with the ring model being referenced as information in the tunnel model (see Figure 4).

The Tunnel Model is an extruded tube, which defines the location of tunnel in the three-dimensional space as well as information generalizable to the tunnel as a whole. It does not contain the segmentation, as the achieved tolerances (i.e., the exact position of the segments), are unknown during the design process. A full definition of the Tunnel Model can be found in the matrix presented in Appendix B, and a depiction of the interior of such a tunnel model is provided in Figure 5.

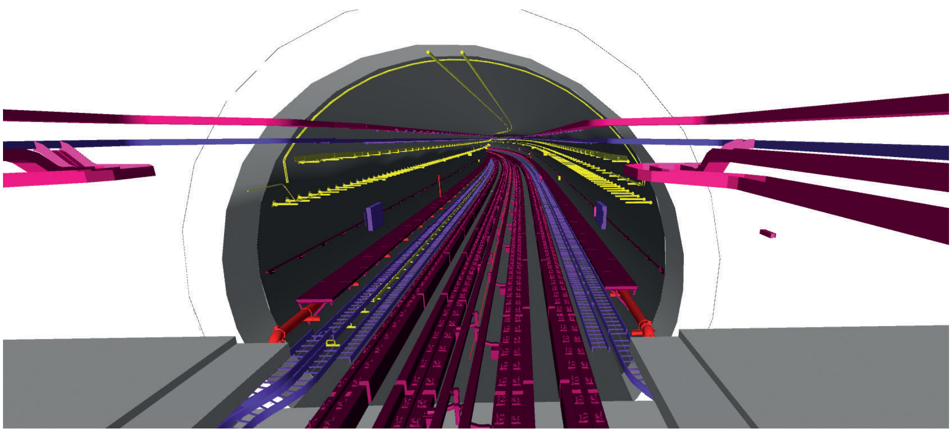

Figure 5: Tunnel Model.

The Ring Model contains information specific to the segmental lining. Only a single ring of each ring type is required to be modelled, containing all relevant information to define the segmental lining, i.e., segmentation, exact geometry, embedded items, etc. The Ring Model is intended to form the basis of the segmental lining drawings and can be used by the Contractor to generate the as-built tunnel models, which will contain the as-built location of the individual ring segments under consideration of construction tolerances. A full definition of the Ring Model can be found in the matrix presented in Appendix B, and a schematic representation can be found in Figure 6.

8 >> Classification systems

BIM models are inherently object-based, and a single BIM model may have hundreds or thousands of objects. As such it is important to develop a structured naming convention in which each object has a name which classifies it as a part of a larger whole to which it belongs (i.e., grout systems are part of the tunnel systems). The naming convention for these objects is referred to as a classification system. The goal of a classification system is to define a logical structure for the created data that allow for its efficient analysis and management. This classification system applies to modelled objects in BIM models and helps the user to query the models. Typically, the classification system to be used is set forth by an owner in the Employers Information Requirements.

Several different classification systems exist worldwide. In the absence of an employer defined classification system, pre-existing classification systems developed by national or international organisations may be used. One such example is the NBS Uniclass system, which can be easily adopted for use on tunnelling projects. The Uniclass system introduced tunnel elements in 2015 and provides several tables which identify how typical objects should be classified.

The Uniclass is structured as shown in figure 7.

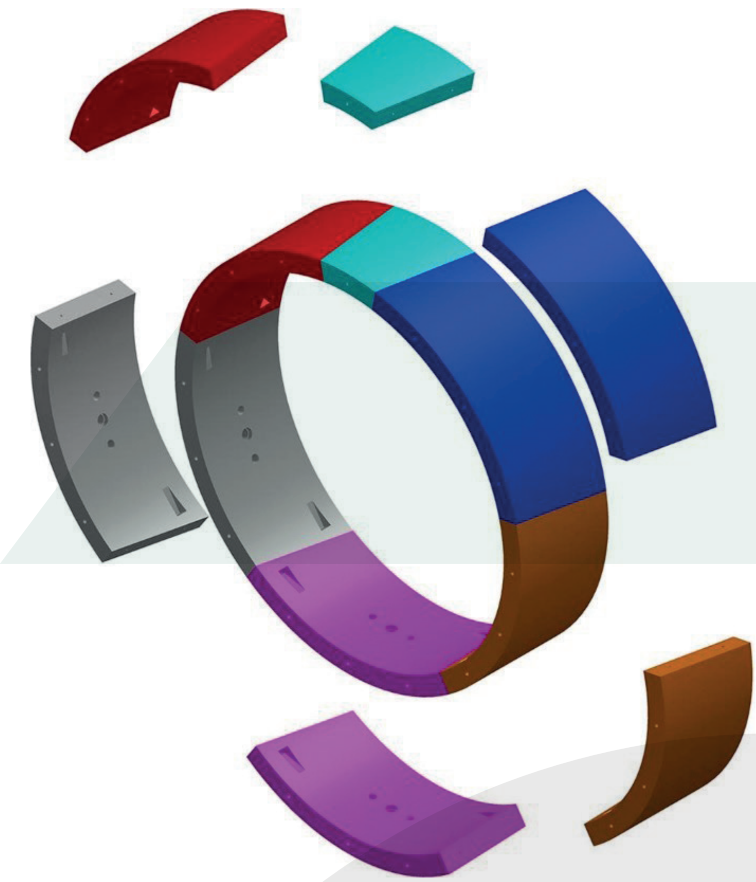

Figure 6: Ring Model as exerted from ITA-AITES Guideline for the Design of Segmental Tunnel Linings.

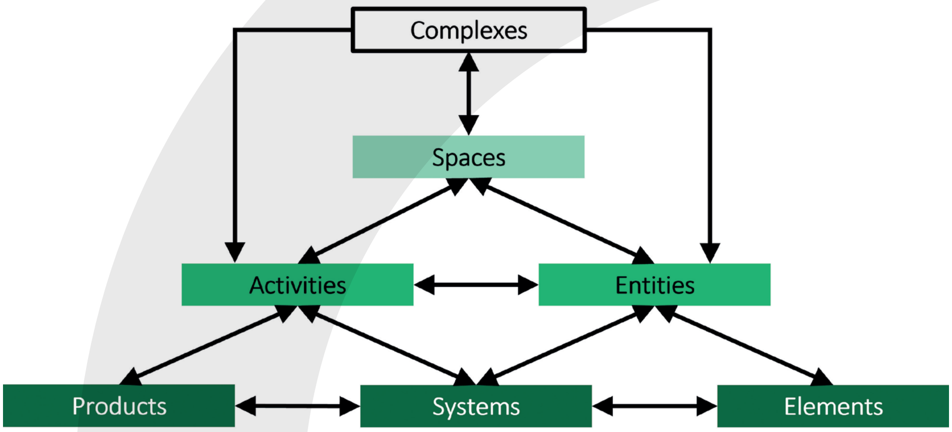

Figure 7: Uniclass Hierarchy as exerted from NBS integrated global platform.

For the Tunnel Model, Table 1 provides a representative classification scheme:

If it is beneficial to assign different classification to individual embedded items, individual subgroups to the product code can be developed on a project specific basis.
Further references to international classification systems, such as the classification system proposed by the DAUB, can be found in the section 12 Standards and Guidelines.

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

Table 1: Uniclass Tunnel Model

UNICLASS ELEMENT	OBJECT	UNICLASS CODE
Products	Concrete tunnel-lining segments	Pr_20_93_90_15
	Tunnel segment connectors (or other embedded items)	Pr_20_93_90_90

Table 2: Uniclass Ring Model

9 >> Exchange Data Formats

9.1. NATIVE FILES AND SOFTWARE SPECIFIC EXCHANGE FORMATS

All BIM software has native file formats for importing, exporting, exchanging, creating, or modifying information. These formats are, however, often proprietary and may have limited interoperability with other software packages. As such, it is important to understand the file formats which are used across a project's BIM environment to ensure that all the used programs are compatible. For this reason, it is often seen as advantageous to combine software packages from one developer to improve interoperability of disciplines and tasks.

9.2. FEDERATED MODELS

Every software has its limitations and is potentially not able to import all the native project models directly into the delivery platform. As such, interface management, general co-ordination, and clash detection needs be carried out via a federated model.

A Federated Model is a combined building information model that has been compiled by amalgamating several different models into one. A federated model enables the user to view all the project models together and to compare differences. Several tools are currently available on the market that allow the construction of a federated model. Some of these tools are provided as specific software packages, whereas others are web-based systems.

Regardless of which software is used, the federated model software should be defined in the project wide BIM Execution Plan (BEP).

9.3. IFC

As discussed above, several BIM software systems work primarily with proprietary data formats and therefore have limited interoperability with other software packages from other developers. Specifically, attributes or other object information in a BIM model may be lost when transferring information between two programs from different developers. For this reason, there is a need for BIM software, simulation software, geotechnical software, and asset management solutions used for tunnelling to be able to exchange rich information with each other in a neutral, vendor-independent, standard format. This is especially true for asset management as the format of data stored in an asset management model should be openly documented in case modifications need to be made to ensure compatibility with future software or hardware.

To address this issue, buildingSMART International (bSI; www.buildingsmart.org), a non-profit, independent organisation aimed at promoting openBIM and the digital transformation of the construction industry, has been working since 2019 on extending its Industry Foundation Class (IFC) format (standardized in ISO 16739) to cover tunnel structures. The IFC format will be extended through a set of domain specific object classes, together referred to as "IFC Tunnel", that will cover objects typically used in underground structures, their construction methods, and the geotechnical situations encountered in a tunnelling project.

The IFC tunnel project has so far been split into two phases. The first phase of the IFC tunnel project led to the release of a tunnelling specific Requirement Analysis Report (RAR) in August of 2020, which was consolidated out of 30 Use Cases (i.e., BIM Use Cases) submitted to the review of ITA experts. The second phase of the bSI IFC Tunnel Team launched in October 2020, with the goal of developing technical IFC specifications that address the requirements determined in the first phase. These specifications for object structures will be developed as extensions to bSI's existing IFC4.3 CommonSchema for infrastructure objects and/or be developed as free standing new IFCTunnel specific objects.

The IFCTunnel project objects classes will include information regarding:

- Geopositioning (projection & coordinate systems, and linear positioning

- 3D geometries (punctual, linear, surface, solid)
- Geotechnical situations, their uncertainties, and associated risks
- Excavation method, being Drill-&-Blast, road-header, TBM-based or Cut-&-Cover
- Support, reinforcement measures, waterproofing & lining
- Operational systems, being ventilation, lighting, fire-protection, drainage, evacuation.

In addition to bored tunnel projects, The IFC Tunnel object classes will be extended so as to be applicable to several types of tunnels as well as tunnel construction methods. A schematic of the scope of IFC Tunnel is shown in Figure 8.

The IFC Tunnel object classes will include 4 main characteristics: geopositioning, 3D geometries, properties, and functional relationships. These will be integrated into the basic IFC data structure which is shown in Figure 9.

This comprehensive data schema will allow IFC tunnel object classes to be used to exchange detailed information during the development of underground structures, specifically in between the following stages:

- program planning,
- design and simulation,
- tendering,
- sequencing of operation,
- realization methods & machine guidance,
- recollection of as-built (civil engineering) and as-encountered (geotechnics),
- reception and handover,
- monitoring and maintenance in nominal operational conditions.

This IFC format will be released as an ISO norm and is planned to become the recommended standard to be used once its first specification release candidate has been made available, which is planned for early 2022. In parallel, bSI will provide IFC technical support services to help software vendors speed up the implementation of import/export capabilities in their commercially available solutions.

The ITA WG 22 recognises that buildingSMART is invested in the tunnelling industry and actively supports the development of an open-source data exchange format.

9.4. MMS / CAFM SPECIFIC FORMATS

MMS stands for Maintenance Management systems. CAFM is another term utilised for the same and stands for Computer Aided Facility Management. These systems define the Maintenance, Inspection and Replacement intervals for assets and provides the operator with information regarding

- What is required
- When it is required
- What is required to carry out a specific task and record the actions taken for future reference.

The transfer of data from the construction / design phase of a project into MMS / CAFM is often achieved via utilisation of COBIE (Construction Operations Building Information Exchange). This format is used to export asset information from the construction and commissioning stage and transfer them into the operational database i.e., MMS / CAFM. The COBIE format has limitations with regards to the use in underground construction, as it is developed with Building Management in mind. There are commonly three types of assets:

- Maintainable
- Replaceable
- Static

Tunnel civil works are generally considered static assets that mainly require action through inspection, often with limited planned and predefined maintenance. As such, a COBIE information transfer does not necessarily add value for asset management. The use of the COBIE requires a considerable amount of information to be documented that is not required for tunnel civil works. As such it is recommended that the Operation and Maintenance Plan for the Tunnel Civil Works is populated in the System or Network Level LOI with clear references, allowing the Asset Owner to populate his MMS / CAFM directly with the required Inspection intervals.

If there is no system specified by the project for the handover, a good solution is to follow the guidance set forth in ISO 21597, as it captures not only the records required for asset management, but also the relations in between them. It describes Information containers for linked document delivery and provides exchange specifications. The ISO 21597 series has been developed in response to a recognized need within the construction industry to be able to handle multiple documents as one information delivery.

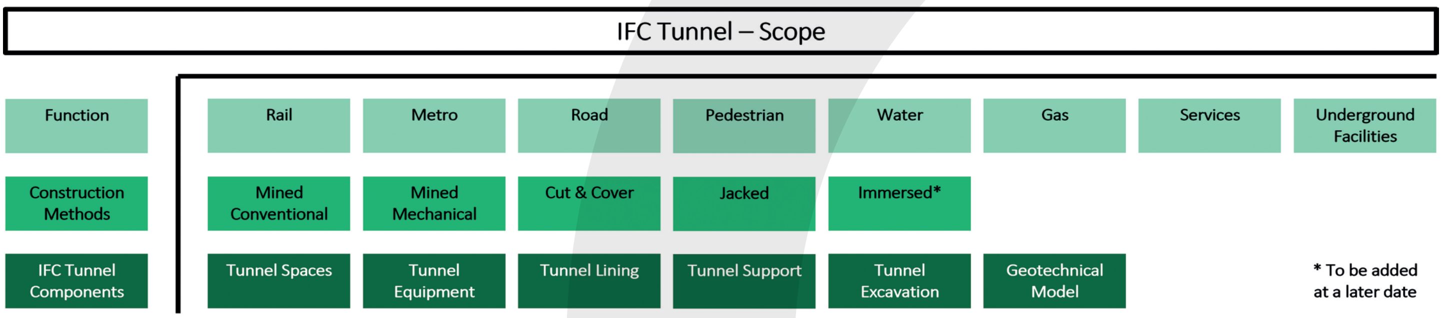

Figure 8: IFC Tunnel Scope as provided by buildingSMART International.

Information deliveries are often a combination of drawings, information models (representing built or natural assets in the physical world), text documents, spreadsheets, photos, videos, audio files, etc. Increasingly, this may also include datasets based on any ontology. An ability to specify relationships using links between information elements in those separate documents can significantly contribute to an information delivery value. The composition of such a package arises both from the process's requirements, e.g., delivery of as-built information, and from the specific functional purpose, e.g. performing a quantity take-off or communication about issues in 3D models.

A key feature is that the container can include information about the relationships between the documents. It is also software independent, as it is based on W3C industry standard RDF (Resource Description Framework). This way it can be reused in any given system.

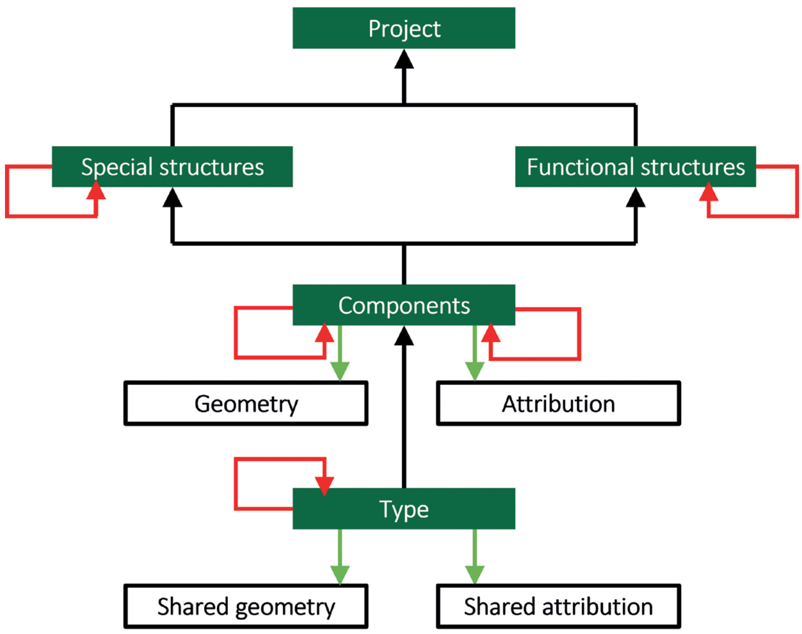

Figure 9: IFC Data Structure as provided by buildingSMART International.

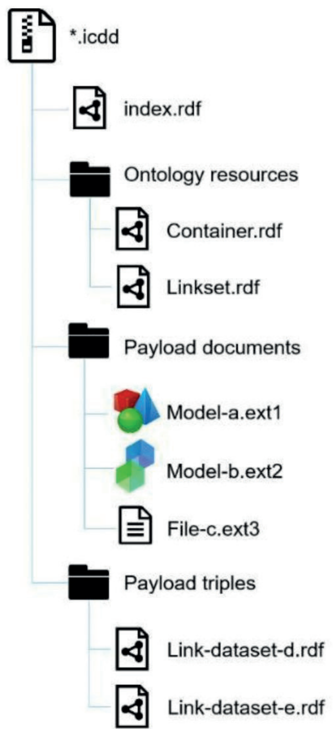

Figure 10: Minimum structure of the root of a container.

An example of an information container is provided in Figure 10. The general setup/structure of such a container is quite simple. The container is a file that shall have an extension ".icdd" also known as ZIP. Each container includes a header file in the top-level folder as Index.rdf. In addition to the .rdf file, as a minimum, a container shall have at least three folders:

- The "Ontology resources" folder can be used to store the Linkset.rdf and Container.rdf ontologies that together provide the object classes and properties that shall be used to specify the contents of and links between the documents within the container.
- The "Payload documents" folder shall be used to store all the documents included in the container (referred to as the payload).
- The "Payload triples" folder shall be used for storing Linkset files.

10 >> Ground Modelling

10.1. BACKGROUND

The inclusion of ground information (e.g., borehole data, geophysical data, geological models) in a BIM model is not always specified. However, ground information is a vital component of underground construction, and it is highly encouraged to include such information in BIM when feasible. This section provides recommendations for types and formats of ground information to include ways to integrate this information with traditional BIM objects, and when to present this information in BIM in the project life cycle.

10.2. DATA TYPES/SOURCES

Borehole logs contain geological and geotechnical data pertaining to stratigraphy, lithology, and geotechnical testing and groundwater. Other types include geophysical and geochemical data. This data is obtained from site investigations undertaken at any design stage prior to construction, and in some cases during construction. In many cases, historical data from previous projects at or near the project may also be available.

Geological models and sections are based on factual data sources, such as mapping, interpretation of outcrops, and borehole data, typically with respect to stratigraphy. These models and sections are generally developed during the conceptional and preliminary design, baseline reference design and detailed / contractor design stages.

Instrumentation and monitoring data are collected using physical instruments as well as remote sensing techniques to monitor movements of the ground and structures, groundwater levels, and any other relevant environmental parameters such as construction induced vibrations. This data may be recorded throughout the life cycle of the project including baseline readings, active monitoring during construction and long-term performance monitoring.

Other ground information collected during construction include face mapping and probing. These records provide further details of the ground conditions as encountered while unnelling and can be used to update the geological models.

10.3. DATA FORMAT

Borehole data should be made available in digital format, with a clear data structure for easy processing. There are several standard data formats for site investigation borehole data adopted throughout the civil engineering community. A typical format in which borehole data is provided is in Extensible Markup Language (XML). Some examples of these formats include:

- Association of Geotechnical & Geoenvironmental Specialists (AGS)
- Borehole Markup Language (BoreholeML)
- Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS)
- Canadian Well Logging System (LAS)

For geological models and sections data formats will often differ depending on the program used to develop them. However, these programs will typically have multiple data export options and conversion tools. Common programs used in practice include:

- Civil3D (Autodesk)
- gINT (Bentley)
- Groundhog (British Geological Survey)
- Leapfrog (Seequent / Bentley)

The above software packages have distinct capabilities, and the owner/consultants should be aware of the strengths (and potential weaknesses) of each before selecting which software should be used for a specific project. It should be noted that the above list is not exhaustive and that, upon publication of this document, the capabilities of the above listed programs may have expanded or otherwise have been modified.

Instrumentation and Monitoring data is often stored in data management systems, which typically provide export of time series data and georeferencing information in comma delimited (csv) or other delimited text file format. Some example programs used in unnelling practice include:

- Geoscope (Sixsense)
- Kronos (Geodata)
- MissionOS (Maxwell GeoSystems)
- PROCON II (Maidl Tunnelconsultants)
- Tunnel Process Control (TunnelSoft)

Face mapping records often consist of hand drawings or photographs. These can be digitized to spatial data for updating geological models and it is encouraged to do so. Probing records consist of measurement while drilling (MWD) logs and core sample records.

10.4. INTEGRATION INCLUSION OF GEOLOGICAL & GEOTECHNICAL DATA WITHIN A BIM CONTEXT

The full implementation of ground information in BIM is often not considered due to the volume of information required for full representation. In addition, ground information is frequently updated or replaced as the project progresses (e.g., borehole vs face map records, latest readings from I&M, etc.). Lastly, much of the ground information requires some specialist interpretation.

Integration of any ground information in BIM should be for the purpose of added value, not added complexity.

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, it is common practice to keep the geotechnical / geological separate from the main tunnel model. This also supports the practicality to reduce model size in line with software / hardware limitations.

Considerations for the purpose of the BIM model should be taken when deciding which ground information to include:

- 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.

10.5. 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 within a project wide geological BIM Model does carry significant benefits. Interpretive data, such as the in-situ stratigraphy, can be very useful to make informed engineering decisions, 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 the use / operation phase of a project.

It is noted however, that the inclusion of non-factual data may impact risk sharing arrangements within a project which are set forth during the negotiations stage prior to award.

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 buildingSMART International in the IFC-Tunnel Project Report WP2: Requirements Analysis Report (RAR), in which geotechnical data is stored as “Factual Data,” “Interpreted Data,” and “Conception (Design) Data.” In addition to correctly identify 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.

As with all geotechnical interpretative information the representation often forms the basis for contractual risk sharing models. These risk allocation approaches differ significantly throughout the global markets.
As such inclusion or exclusion and definition of the non-factual data and their representation should be a conscious decision by the Owner that needs to be specified explicitly in the Employers Requirements together with the data formats in which the factual and/or non-factual data needs to be provided. The Owner also has to define which model (and based on which data) need to be provided at the beginning of different stages when new participants are introduced (i.e., tender stage) to provide the Minimum Contractual Requirements.

11 >> Sustainability

Climate change and the associated trends towards resource efficiency and alternative energy exert a significant influence on modern construction practices worldwide. A major contributor to the climate change impact associated with construction is cement production, which is responsible for approximately 8% of global greenhouse gas (GHG) emissions. Significant reductions in global warming potential (GWP) can therefore be achieved in Construction projects by minimization of the total volume of concrete needed and optimization of the concrete mix-design.

Tunnels are typically designed for a life expectancy of 100+ years of service. Although considerable attention in tunnel design generally lies within the construction phase, the contributions to GHG emissions can vary significantly based not only on construction methods, but also on materials used for repair during operation. As such, there is a principal need for the owner and eventual operator to provide guidance in managing embodied carbon in the early design of tunnels.

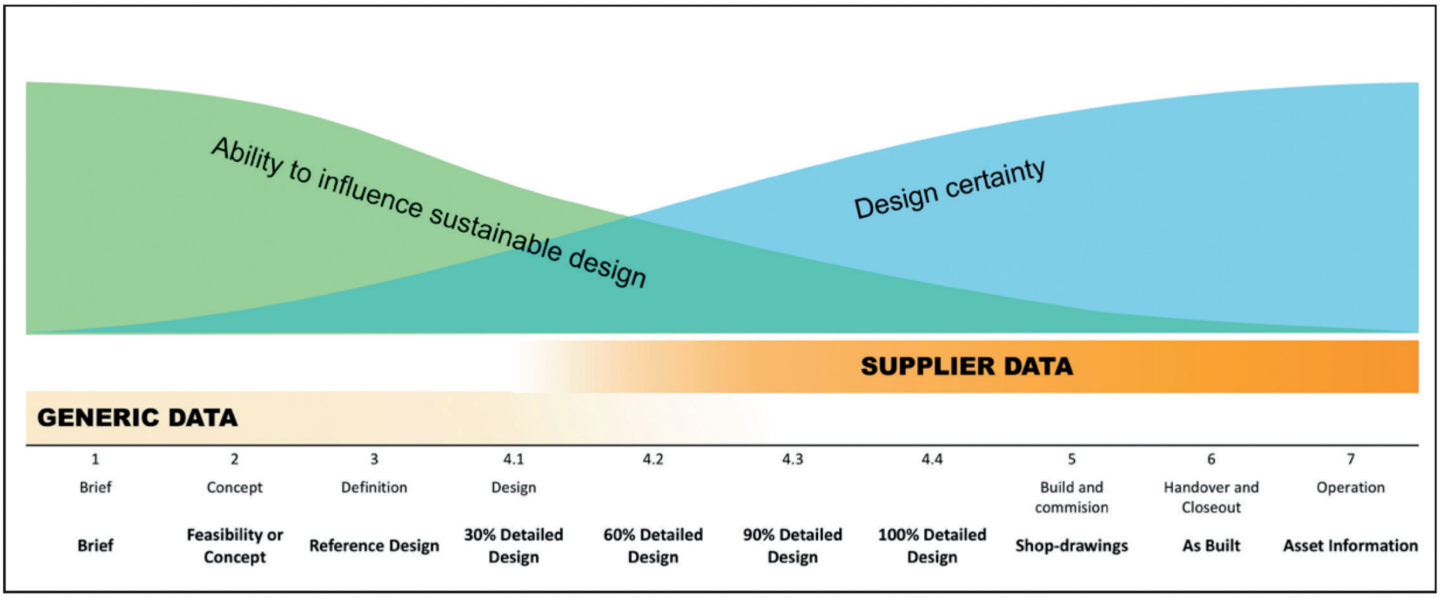

Figure 11: Early decisions to allow for a sustainable design. (Image Courtesy of Master Builders Solutions).

Figure 11 shows that the greatest impact to a tunnel's carbon footprint can be achieved with early design decisions. Some important early design decisions in a tunnel project include, but are not limited to, alignment variations, twin tunnels vs. a single larger tunnel, excavation via TBM vs. conventional tunnelling and lining considerations, such as the use of single-shelled tunnels vs. double shells or composite linings. The outcomes of these decisions determine the total concrete volume needed as well as the concrete quality and mix designs required to meet engineering and placement demands. To support the process of CO2 or Equivalent $C0_2$ (CO_2e) reduction throughout a tunnel's lifetime ($C0_2e$ being the sum global warming potential of all emitted greenhouse gases expressed as an equivalent CO_2 amount), the project owner should be technically involved at an early stage and include GWP targeted reductions (most often in the form of CO_2e savings) in signed contracts.

11.1. BIM MODELLING FOR UNDERGROUND CONSTRUCTION

BIM is especially useful for tracking sustainability parameters and quantifying the GWP of a tunnel project. By storing the CO2e produced per quantity of a material as object data in a BIM model, the model can be easily queried to calculate, i.e., to perform a quantity take-off of, the expected GWP in total $C0_2e$ output of a tunnel project. Due to modern product declaration requirements, the CO_2e data per product can be easily found in Environmental Product Declarations (EPD's), some of which are provided in Table 3. It should, however, be noted that the values in Table 3 represent the C02e data at the time of publishing of this document and are subject to change.

Tracking sustainability parameters is useful throughout a project's lifetime, but, as discussed above, the greatest impact to a project's overall GWP can be made in the early project stages (ca. Stages 1-3 in Figure 11). In these early project stages, project planning can be adjusted to find not only the most economical design, but to find the most sustainable design. BIM can be used in early project stages to analyze the GWP associated with different project/tunnel variants. In doing so, it should be recognized that not all project information is available in early project stages. Therefore, the following recommendations may be considered to simplify the process:

- Concrete and steel related CO_2e generally dominate the overall project GWP. The total concrete and steel GWP estimation represents roughly 60–80% of the total construction CO_2e. As such, for basic tunnel and alignment considerations, relevant early stage $C0_2e$ comparisons can generally be performed by only evaluating the total mounts of steel and concrete of any large structures or portions of structures in which concrete, steel, or other cementitious materials are used in significant volumes. Important quantities to consider in a tunnelling project typically are:
  - Segmental lining concrete (in total m³)
  - Annulus grout (in total m³)
  - Primary reinforcement (rebar or fibers), (in total tonnes of steel)
  - Major internal concrete structures, if known (in total m³)
  - Major internal steel structures, if known (in total tonnes of steel)

Note: reinforcement steel calculations are typically done much later in the GWP estimation process.

- If early project comparisons include only alignments, standard cross-sections or tunnel designs taken from comparable projects can be used in addition to the alignments to arrive at the necessary quantities/volumes needed for a comparison.
  - To this end, it may be helpful to generate a generic BIM model that contains the basic site and tunnel type information.
- several $C0_2e$ contributors, such as transportation costs, may not be known at early project stages. As such it is recommended to focus on early life-cycle stages in the evaluation of $C0_2e$ contributions, i.e., evaluation of the $C0_2e$ of products at the "factory door" without the consideration for outbound transportation, application, use, and potential demolition. Some typical values are given in Table 3. $C0_2e$ information taken from locally accepted/used mix designs & grouts meeting basic design considerations may also be used for more precise estimates.
- Use generic, regional EPDs (Environmental Product Declaration) as accepted input for mix-designs and multiply the mass (can be done in EXCEL) with the respective EPD GWP total.
- For structural steel tonnage calculations, attention must be paid to the recycled content in the steel EPDs since recycled content can significantly lower embodied carbon from steel production.

To aid in the assessment of $C0_2e$, ISO published ISO 22057:2022 Sustainability in buildings and civil engineering works – Data templates for environmental product declarations (EPDs) for construction products in building information modelling (BIM) in April of 2022. This document provides the principles and requirements needed to enable environmental and technical data provided in EPDs for construction products and services, construction elements, and integrated technical systems to be used in BIM to assess the environmental performance of construction works over their life cycle. A general schematic of the relationship between Sustainability Data and BIM as provided in the ISO standard can be found in Figure 12.

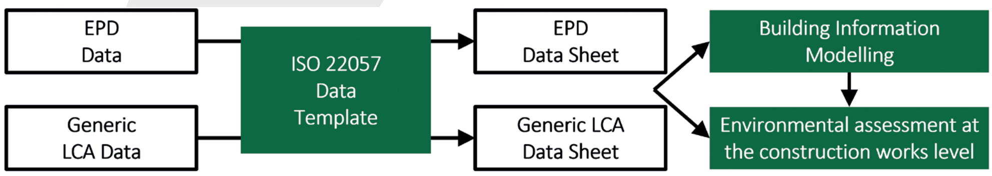

Figure 12: Relationship between Data, Data templates, Data sheets, BIM and Environmental assessment at the construction works level.

MATERIAL GROUP	PRODUCT	DESCRIPTION	GWP per KG*	REGION	SOURCE
Cement	Portland cement	Cement production portland	0.89	USA	Ecoinvent 3.6
		Portland cement, generic	0.94	Slovenia	One click LSA
	CEM II 32.5	CEM II 32.5	0.78	Germany	Oekobau.dat 2020-II
	CEM II 42.5	CEM II 42.5	0.8	Germany	Oekobau.dat 2020-II
	CEM II 52.5	CEM II 52.5	0.81	Germany	Oekobau.dat 2020-II
	CEM III 42.5	CEM III 42.5	0.38	Germany	Oekobau.dat 2020-II
	CEM III 52.5	CEM III 52.5	0.39	Germany	Oekobau.dat 2020-II
Blended cement	Slag cement	CEM II/B 42.5 30% GGBFS, 64.45% clincker	0.57	Germany	EPD Spenner CEM II/B-S 42.5 N
		CEM II/B 31.4% GGBFS, 64.26% clincker	0.56	Germany	EPD Spenner CEM II/B-S 52.5 N
		CEM II/B 25% GGBFS, 70.7% clincker	0.62	Germany	EPD Spenner CEM II/B-S 42.5 R
SCM	Fly Ash	Hard coal fly ask for use as concrete additive	2.0E-04	Germany	EPD EFA-Fuller BauMineral GmbH
		Fly ash	1.9E-03	Denmark	EPD Emineral A/S
Aggregates	Sand	Gravel and sand quarry operation (sand)	0.0042	Global	Ecoinvent 3.6
	Aggregates	Gravel and sand quarry operation (gravel, round)	0.0042	Global	Ecoinvent 3.6
	Aggregates	Gravel production, crushed	0.0086	Global	Ecoinvent 3.6
Water	Water	Market for tap water	3.0E-04	Europe	Ecoinvent 3.6
Acrylic	Acrylic resin	Methacrylate resin products	4.09	Germany/Belgium	EPD-DBC 20190116-1BE1-EN
Reinforcement	Steel rebar	Reinforcement for concrete (rebar)	0.24	Germany	EPD-BS-10.2
	Steel fiber	Steel fibers for concrete reinforcement	0.77	Poland	064/2017
	Welded wire	Stretched coil electrowelded mesh	0.66	Italy	EPDITALY0016 rev.1
	Welded wire	Reinforcement steel mesh	0.3	Germany	EPD-BMG-10.2
	Polypropylene fiber	Polypropylene fiber for concrete reinforcement	2.49	Norway	NEPD-1382-447-NO
Admixtures	Hardening accelerator	Master X-Seed	0.68	Germany	EPD-BAS-2017089-IBC1-EN
	Hardening accelerator	Concrete admixtures - Hardening accelerators	1.79	Europe	EPD-EFC-20210196-IBG1-EN
	Superpasticizer	Concrete admixtures - Plasticizers and superpasticizers	1.53	Europe	EPD-EFC-20210198-IBG1-EN
	Air entrainer	Concrete admixtures - Air entrainers	0.439	Europe	EPD-EFC-20210193-IBG1-EN
	Retarder	Concrete admixtures - Retarders	1.23	Europe	EPD-EFC-20210195-IBG1-EN
	Set accelerator	Concrete admixtures - Set accelerators	1.34	Europe	EPD-EFC-20210194-IBG1-EN
	Water resistance	Concrete admixtures - Water resisting	2.67	Europe	EPD-EFC-20210197-IBG1-EN

Table 3: Embodied carbon (kg CO2e per kg) approximations for concrete materials. Table Courtesy of Master Builders Solutions.

12 >> BIM & GIS

CAD and BIM programs often organize projects along Cartesian coordinate systems, i.e. along x,y,z axes (or similar). Such coordinate systems are coherent with most tasks in structural engineering, as it allows the positions of structural or architectural members (e.g., façades or columns) to be easily determined and referenced. In tunnelling, it is often more practical to arrange projects relative to 'geodetic' georeferenced coordinates (resulting from projecting latitude/longitude/elevation onto an x,y,z system) and/or a central axis corresponding to the project alignment (linear referencing). This difference in referencing information (CAD coordinates vs projected coordinates) can lead to difficulties and/or errors in the proper geo-positioning of a tunnel alignment, especially in very long projects in which elevation changes along the axis due to the curvature of the earth need to be properly considered.

One method with which to reconcile this problem is to reference data using the same conventions as employed in Geographical Information Systems (GIS). Such GIS applications provide capture, storage, and analysis features and modification tools for properly referenced spatial and geographic data, often in the form of latitude/longitude/elevations (GPS) as well in projected coordinates. In doing so, local coordinates used within a Cartesian based BIM environment can be mapped (or properly referenced) onto a global coordinate system.
The Import/export of data between GIS and BIM programs, is however, not always straightforward. While current state-of-the-art BIM or GIS tools enable data exchange between systems, correct data transfer often requires a thorough understanding of both systems and their functionalities. The integration tools and current standards lack the ability to help the user convey information (e.g. flags), that can be easily interpreted by both construction project participants as well as BIM and GIS tools. Furthermore, the quality of GIS databases varies considerably worldwide, and, depending on project location, may not be available.

Currently, significant efforts are being undertaken to address compatibility issues between BIM and GIS and develop corresponding norms (e.g. ISO) to improve standardisation. An example of progress being made in this field is the cooperation between the Open Geospatial Consortium (OGC) and buildingSMART International (bSI). Due to this cooperation, the latest official IFC version (IFC4.3) supports a deposit of a Coordinate Reference System (CRS) by referencing a corresponding identifier of the European Petroleum Survey Group (EPSG) database to relate spatial model data unambiguously.

A project team needs to understand the capabilities and limitations of both GIS and BIM to handle them wisely in a project. The current state of the art requires the user to define a project specific CRS to integrate GIS within BIM, which, in turn requires significant effort and resources. For this reason, GIS data is often only integrated in large projects, with an example being the Brenner Base Tunnel, Switzerland. The integration of GIS has major benefits to tunnelling projects. As such the owners are encouraged to ensure that GIS quality is such, that an integration is possible with reasonable effort. For such integration it is recommended to engage experts with experience in doing so.

13 >> Standards, Guidelines and References

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Contributors (first edition):

The development of the first edition was led by the WG22 task force supported by the following contributors & reviewers:

WG22 ANIMATEUR	**COUNTRY**
Dr Jurij Karlovšek (The University of Queensland)	Australia

ITA EXCO - TUTOR	**COUNTRY**
Mr Lars Babendererde (BabEng Group)	Germany

WG22 TASK FORCE	**COUNTRY**
Mr Wolfgang Angerer (Jacobs)	UAE
Dr Vojtech Ernst Gall (Gall Zeidler Consultants)	USA
Dr Jurij Karlovšek (The University of Queensland)	Australia
Mr Hichem Zammit (Bouygues Traveaux Publics)	France

CONTRIBUTORS	**COUNTRY**
Mr Wolfgang Aldrian (MBCC)	Austria
Ms Anne Jacobs (MBCC)	Germany
Dr Jacob Grasmick (Maxwell Systems)	USA
Mr Philipp Dohmen (Amberg)	Switzerland
Mr Michel Rives (Vianova Systems, Building SMART International)	France

External Reviewers who provided ITA review:

ITA REVIEWERS	**COUNTRY**
Mr Heinz Ehrbar (Heinz Ehrbar Partners)	Switzerland
Mr Markus Scheffer (SD Engineering)	Germany
Mr Eric Tournez (Bouygues Travaux Publics)	France

WG22 members and participants who contributed to the review process:

WG 22 REVIEWERS	**COUNTRY**
Mr Gary Furphy (Jacobs)	UAE
Dr Mats Svensson (Tyrens Group)	Sweden
Mr Lorenzo Facibeni (Geodata)	Australia
Mr Daniel Garbutt (Nuclear Decommissioning Authority)	UK
Mr Gert van Aswegen (Department for Infrastructure and Transport)	Australia
Mr Mark Eggleton (New Romans)	Australia
Mr Richard Hardy (Engenium, now Stantec0	Australia
Mr Jure Česnik (Elea iC)	Slovenia
Mr Samo Saje (Elea iC)	Slovenia
Mr Federico Foria (ETS)	Italy

15 >> APPENDIX A – BIM USE CASES

USE CASE	DESCRIPTION	SOURCE
Design variants investigation	Variant investigation based on 3D models of the existing condition including conflict analysis	DAUB
Visualisation (public relations work)	Visualisation of the design including existing buildings and infrastructure	DAUB
Design production environment	Design plans and plans for approval are derived in 2D from the structure model	DAUB
Cost estimation and cost calculation	Model-based and structured quantity determination; Linking of the 3D model with cost data	DAUB
BIM / structural / FE model co-ordination	Co-ordination of domain-specific sub-models by combining models in coordination software for detecting interferences	IFC
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
Health and safety design environment	Consideration of all safety-relevant aspects in the model, especially through the representation of the construction sequence with time; Rule-based checking of escape routes, bottlenecks, closed zones, escape and rescue possibilities; Analyses of working conditions; Consideration of environmentally relevant aspects (closed areas, hazardous substances) in the models (especially in the 4D simulation of the working sequence)	DAUB
Design approval	Approval processes are not currently implemented with models, therefore 2D plans are still necessary … these plans should be linked dynamically with the model	DAUB
Coordination of specialist design work	Assembly of each specialist model to one coordination model; Checking of the specialist models for collisions with other disciplines	DAUB
Progress control of design work	Transparency of design progress in the project or structure; Use in project management to compare with schedule	DAUB
Surveying	To transfer geometrical constraints and input parameters from the 3D models for the structural design of underground structures ... connect existing and preconstruction condition surveys, evolve data through construction / as built etc.	DAUB
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
GIS	Integration of GIS data into the BIM environment to improve design co-ordination and clash analysis	
Change management	Handling of deviations identified in construction progress controls … as well as changes during the design process	DAUB
Geological documentation	Assessment of geotechnical risk along tunnel route	IFC
Spaceproofing	Interface document / agreement between discplines to determine the space requirements for each individual design component - classified as design basis	WG22
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
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
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
Logistics planning	Digital planning and checking of space management, delivery possibilities, supply and disposal etc. with the model; Determination of the effects on logistic capacity of changes to the model; Simulations / variant studies of various logistic solutions incl. representation of the requirements of health and safety and environmental protection as well as time and cost effects	DAUB
Quantity determination	Basis for cost estimation, tendering, billing, logistics, planning as well as during construction for billing and payment purpose	IFC
Compliance management	Automated checking of compliance of the tunnel design with norms and regulations	IFC
Machine guidance & control	Steering a tunnel boring machine through the ground on the basis of the as-designed tunnel axis	IFC
Production of construction drawings	Working drawings, also in 2D, are generated from the structure model	DAUB
Construction progress control	Recording of the actual progress of construction and prompt comparison and adjustment to the intended situation; Digital documentation and stepwise recording or acceptance of construction activity by official inspector or client's construction supervisor	DAUB
As built documentation	Handover of the as-built model, import into Asset management systems	IFC
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
Defects management	Documentation of defects and the corresponding remedial measures in the digital model	DAUB
Structure documentation	Creation of „as built" BIM models; Documentation of the construction process with comprehensive defects management	DAUB
Monitoring	Monitoring of ground deformations during tunnelling	IFC
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
Handover to GIS	Provide the basis for regional / national transportation asset management (network level, programmatic needs analysis)	IFC
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

	STRATEGIC DEFINITION	PREPARATION & BRIEFING	CONCEPTUAL & PRELIMINARY DESIGN	BASELINE REFERENCE DESIGN	DETAILED/ CONTRACTOR DESIGN				CONSTRUCTION	COMMISSIONING & HANDOVER	USE/ OPERATION
					30% Detailed Design	60% Detailed Design	90% Detailed Design	100% Detailed Design			
	✓	✓	✓	✓	✓						
		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		✓	✓	✓	✓	✓	✓	✓	✓		
		✓	✓	✓	✓	✓	✓	✓	✓		
		✓	✓	✓	✓	✓	✓	✓	✓		
		✓	✓	✓	✓	✓	✓	✓	✓		
			✓	✓	✓	✓	✓	✓	✓	✓	✓
			✓	✓	✓	✓	✓	✓	✓		
			✓	✓	✓	✓	✓	✓	✓		
			✓	✓	✓	✓	✓	✓	✓		
			✓	✓	✓	✓	✓	✓	✓	✓	✓
			✓	✓	✓	✓	✓	✓	✓		
			✓	✓	✓	✓	✓	✓	✓		
			✓	✓	✓	✓	✓	✓	✓		
			✓	✓	✓	✓	✓	✓	✓		
				✓	✓						
				✓							
				✓	✓	✓	✓	✓	✓		
					✓	✓	✓	✓	✓		
					✓	✓	✓	✓	✓	✓	✓
					✓	✓	✓	✓	✓		
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									✓	✓	✓
									✓	✓	✓
									✓		
										✓	✓
										✓	✓
											✓

16 >> Appendix B – Level of Definition - Tunnel Model

PAS1192-2-2013 LEVEL OF MODEL DEFINITION	0	1	2	3
	N/A	BRIEF	CONCEPT	DEFINITION
ISO 19650	Strategic planning			
ITA WG22 DEFINITION##	Strategic definition	Preparation & Briefing	Conceptual & Preliminary Design	Baseline reference design
Further Subdivision for the purpose of this document				
				LEVEL OF
OBJECT				
Alignment	NR	NR	✓	✓
Clearance Envelope	NR	NR	NR	NR
Tunnel Intrados	NR	NR	✓	✓
Concrete Outline	NR	NR	NR	X
Annular Grout	NR	NR	NR	NR
Segmentation* **	NR	NR	NR	NR
Boltholes	NR	NR	NR	NR
Grout sockets and plugs	NR	NR	NR	NR
Connectors / Bolts	NR	NR	NR	NR
EPDM gasket	NR	NR	NR	NR
Caulking groove	NR	NR	NR	NR
Gasket groove	NR	NR	NR	NR
Taper	NR	NR	NR	NR
Locating Pins	NR	NR	NR	NR
Alignment Marker	NR	NR	NR	NR
Segment Marking	NR	NR	NR	NR
Packers	NR	NR	NR	NR
Corner and rotational recesses	NR	NR	NR	NR
Additional Accessories	NR	NR	NR	NR
Coating	NR	NR	NR	NR
HDPE Lining	NR	NR	NR	NR
Steel Reinforcement	NR	NR	NR	NR
Fibre Reinforcement	NR	NR	NR	NR
Openings	NR	NR	NR	NR
**Opening Tolerances ** **	NR	NR	NR	NR
AS-BUILT OBJECT				
Lipping	NR	NR	NR	NR
Stepping	NR	NR	NR	NR
Alignment deviations	NR	NR	NR	NR
Ovalisation	NR	NR	NR	NR
Ring Roll	NR	NR	NR	NR
Structural Defects	NR	NR	NR	NR
Non Structural Defects	NR	NR	NR	NR
3D Survey Model	NR	NR	NR	NR

	4				5	6	7
	DESIGN				BUILD & COMMISION	HANDOVER & CLOSEOUT	OPERATION
	Project Delivery						Operation Phase
	Detailed/ Contractor Design				Construction	Commissioning & Handover	Use/Operation
	30% Detailed Design	60% Detailed Design	90% Detailed Design	100% Detailed Design			
	DETAIL						
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	NR	NR	NR	NR	NR	✓	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR*	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	✓	✓	✓	✓	✓	By Asset Owner
	NR	#	#	#	#	#	By Asset Owner
	NR	#	#	#	#	#	By Asset Owner
	NR	✓	✓	✓	✓	✓	By Asset Owner
	NR	✓	✓	✓	✓	✓	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	✓	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	NR	NR	NR	NR	NR	✓	By Asset Owner

16 >> Appendix B – Level of Definition - Tunnel Model

PAS1192-2-2013 LEVEL OF MODEL DEFINITION	0	1	2	3
	N/A	BRIEF	CONCEPT	DEFINITION
ISO 19650	Strategic planning			
ITA WG22 DEFINITION##	Strategic definition	Preparation & Briefing	Conceptual & Preliminary Design	Baseline reference design
Further Subdivision for the purpose of this document				
				LEVEL OF
Ring Model	NR	NR	NR	✓
Basis of Design	NR	NR	NR	✓
Design Report	NR	NR	NR	NR
Geotechnical Report	NR	NR	NR	✓
Durability Report	NR	NR	NR	NR
Coating Specification	NR	NR	NR	NR
Related Specifications	NR	NR	NR	NR
Defect Report	NR	NR	NR	NR
Repair Report	NR	NR	NR	NR
Future Loading	NR	NR	NR	NR
As built Survey	NR	NR	NR	NR
Carbon Coefficient	NR	NR	✓	✓
RING MODEL				
Ring Type	NR	NR	NR	NR
Concrete Grade	NR	NR	NR	NR
Rebar Grade	NR	NR	NR	NR
Fiber Reinforcement Content	NR	NR	NR	NR
Exposure Classification	NR	NR	NR	NR
Fire Rating****	NR	NR	NR	✓
Water Retaining Concrete (Y/N)	NR	NR	NR	NR
Water tightness Critera	NR	NR	NR	✓

Level of Definition - Tunnel Model

Notes:
NR … Not required.
Single pass lining only, for dual pass linings to be developed suitable to solution.
Concrete outline represents permanent lining with engineered thickness.
** to be modelled if a maintainable item.*
*** Tolerances to address unkown segmentation due to ring creep and ring roll.*
Level of Detail can also be understood as Level of Asset Definition.
As built objects are assumed to be represented via tolerances incorporated into the basis for the clearance envelope.
**** Alternatively to models with no segmentation during design, the project can apply the modelling of of the circumferential joing only as an enhanced Level of Detail.*
***** If applicable.*

16 >> Appendix B – Level of Definition - Tunnel Model

4				5	6	7
DESIGN				BUILD & COMMISION	HANDOVER & CLOSEOUT	OPERATION
Project Delivery						Operation Phase
Detailed/ Contractor Design				Construction	Commissioning & Handover	Use/Operation
30% Detailed Design	60% Detailed Design	90% Detailed Design	100% Detailed Design			
INFORMATION						
✓	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
NR	✓	✓	✓	✓	✓	By Asset Owner
NR	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
NR	NR	NR	NR	NR	✓	By Asset Owner
NR	NR	NR	NR	NR	✓	By Asset Owner
NR	✓	✓	✓	✓	✓	By Asset Owner
NR	NR	NR	NR	NR	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
NR	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner
NR	✓	✓	✓	✓	✓	By Asset Owner
✓	✓	✓	✓	✓	✓	By Asset Owner

«The level of information (also called Level of Definition) need of each information deliverable should be determined according to its purpose. This should include the appropriate determination of quality, quantity and granularity of information. This is referred to as its level of information need and this can vary from deliverable to deliverable.
A range of metrics exist to determine levels of information need. For example, two complementary but independent metrics can define the geometrical and alphanumerical content in terms of quality, quantity and granularity. Once these metrics have been defined, they should be used to determine the levels of information need across the whole project or asset. All this should be described clearly within the OIR, PIR, AIR or EIR.
The levels of information need should be determined by the minimum amount of information needed to answer each relevant requirement, including information required by other appointed parties, and no more. Anything beyond this minimum is considered. (Source ISO 19650-1 Chapter 11.2)»

16 >> Appendix B – Level of Definition - Tunnel Model

PAS1192-2-2013 LEVEL OF MODEL DEFINITION	0	1	2	3
	N/A	BRIEF	CONCEPT	DEFINITION
ISO 19650	Strategic planning			
ITA WG22 DEFINITION##	Strategic definition	Preparation & Briefing	Conceptual & Preliminary Design	Baseline reference design
Further Subdivision for the purpose of this document				
				LEVEL OF
OBJECT				
Alignment Set Out Point	NR	NR	NR	NR
Clearance Envelope	NR	NR	NR	NR
Tunnel Intrados	NR	NR	NR	NR
Concrete Outline	NR	NR	NR	NR
Ring Length	NR	NR	NR	NR
Annular Grout	NR	NR	NR	NR
Segmentation	NR	NR	NR	NR
Boltholes	NR	NR	NR	NR
Grout sockets and plugs	NR	NR	NR	NR
Connectors / Bolts	NR	NR	NR	NR
EPDM gasket	NR	NR	NR	NR
Caulking groove	NR	NR	NR	NR
Gasket groove	NR	NR	NR	NR
Taper	NR	NR	NR	NR
Locating Pins	NR	NR	NR	NR
Alignment Marker	NR	NR	NR	NR
Segment Marking	NR	NR	NR	NR
Packers	NR	NR	NR	NR
Corner and rotational recesses	NR	NR	NR	NR
Additional Accessories	NR	NR	NR	NR
Coating	NR	NR	NR	NR
HDPE Lining	NR	NR	NR	NR
Reinforcement cage	NR	NR	NR	NR
				LEVEL OF
Tunnel Model (as cross reference)	NR	NR	NR	X
Concrete Grade / Mix	NR	NR	NR	NR
Rebar Grade	NR	NR	NR	NR
Fibre Reinforcement Content & Type	NR	NR	NR	NR
Water Retaining Concrete (Y/N)	NR	NR	NR	NR
Crack width or equivalent durability criteria	NR	NR	NR	NR
Reinforcement Cover (if applicable)	NR	NR	NR	NR
Accesory data sheets (1)	NR	NR	NR	NR

Level of Definition - Ring Model

Legend: *NR … Not required - '(1) Recommended to embed Pdfs in Ring model - also included in Tunnel Model LOI.*

Notes: *'- Single pass lining only, for dual pass linings to be developed suitable to solution.*
'- Concrete outline represents permanent lining with engineered thickness.
'- Level of Detail can also be understood as Level of Asset Definition.

16 >> Appendix B – Level of Definition - Tunnel Model

	4				5	6	7
	DESIGN				BUILD & COMMISION	HANDOVER & CLOSEOUT	OPERATION
	Project Delivery						Operation Phase
	Detailed/ Contractor Design				Construction	Commissioning & Handover	Use/Operation
	30% Detailed Design	60% Detailed Design	90% Detailed Design	100% Detailed Design			
	DETAIL						
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	NR	NR	NR	NR	NR	NR	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	NR	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	NR	NR	✓	✓	✓	✓	By Asset Owner
	INFORMATION						
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	NR	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	NR	✓	✓	✓	✓	✓	By Asset Owner

The level of information Need (here referred to as Level of Definition) of each information deliverable should be determined according to its purpose. This should include the appropriate determination of quality, quantity and granularity of information. This is referred to as its level of information need and this can vary from deliverable to deliverable.

A range of metrics exist to determine levels of information need. For example, two complementary but independent metrics can define the geometrical and alphanumerical content in terms of quality, quantity and granularity. Once these metrics have been defined, they should be used to determine the levels of information need across the whole project or asset. All this should be described clearly within the Organizational, Project , Asset, or Employer's Information Requirements (OIR, PIR, AIR or EIR respectivley).

The level of information need should be determined by the minimum amount of information needed to answer each relevant requirement, including information required by other appointed parties, and no more. Anything beyond this minimum is not considered. (Source ISO 19650-1 Chapter 11.2)

16 >> Appendix B – Level of Definition - Tunnel Model

PAS1192-2-2013 LEVEL OF MODEL DEFINITION	0	1	2	3
	N/A	BRIEF	CONCEPT	DEFINITION
ISO 19650	Strategic planning			
ITA WG22 DEFINITION##	Strategic definition	Preparation & Briefing	Conceptual & Preliminary Design	Baseline reference design
Further Subdivision for the purpose of this document				
				LEVEL OF
Tunnel alignment and Concrete Outline *	NR	NR	NR	✓
Borehole Logs **	NR	NR	NR	✓
Geological model/sections	NR	NR	NR	NR
Instrumentation and Monitoring	NR	NR	NR	NR

Level of Definition - Geotechnical Model

Legend:
NR … Not required.
** Should not be modified in geological model but included from information contained in tunnel model.*
*** Boreholes will continue to be drilled during the project, and the database/model will expand during later stages.*

	4				5	6	7
	DESIGN				BUILD & COMMISION	HANDOVER & CLOSEOUT	OPERATION
	Project Delivery						Operation Phase
	Detailed/ Contractor Design				Construction	Commissioning & Handover	Use/Operation
	30% Detailed Design	60% Detailed Design	90% Detailed Design	100% Detailed Design			
	DETAIL						
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner
	✓	✓	✓	✓	✓	✓	By Asset Owner

Layout : Shoot The Moon - 04 90 14 48 48 - (1535 - 09/2022)

ITA Secretariat - c/o MIE2 – Chemin de Balexert 9 - CH-1219 Châtelaine (GE) - Switzerland
Tel. : + 41 22 547 74 41 - Email : secretariat@ita-aites.org - Web : www.ita-aites.org