Practical Experience and Findings relating to the Preparation of a BIM Model for the Subsoil Foundations of a Tunnel Construction Project

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The paper describes the practical experience and findings acquired during the preparation of a BIM model for the foundations of a tunnel construction project.

Tunnelling • Geotechnics • BIM • Modelling • Foundation subsoil

1 Introduction

Building Information Modelling (BIM) is a model-based process aimed at optimising the planning and execution of a building project and its various operations. This is achieved using a digital whole model in which various sub-models and subject models are integratively processed with the aid of special BIM software solutions. While BIM technology has already become well-established in the field of structural engineering or building construction there are still a number of challenges to be faced before the BIM method can be fully applied in the civil engineering and underground construction sector.

This paper will seek to show to what extent it is possible, on the basis of the current technology and software development status, to deal with the subsoil modelling process and manage the interfaces between the static-constructional constraints of the tunnel structure and the geotechnical and structural engineering parameters and attributes. Particular attention is paid here to the data exchange formats, as these play a key role in maintaining the transparency and consistency of the digital data during the BIM process.

With reference to a tunnel survey project based on conventional planning methods and its derived geotechnical assessment a study was also carried out with a view to using the software solutions currently available to produce a subsoil model with all the necessary geotechnical and tunnel-engineering parameters and attributes.

2 Multidimensional Planning of 2D to xD

The BIM method introduces new planning dimensions to the already standard 2D and 3D planning techniques. The 3D model of a building, of the kind that is currently the norm today, can be extended by factors such as 'build time' and 'construction costs' (Fig. 1). Introducing the build time into an existing 3D model means designating the latter as a 4D model. Factoring-in the build time and the construction costs then generates a 5D model.

However a BIM model is created not merely by extending its dimensions. In fact there is a much more important step involved when building the 3D model itself. The aim here is to develop an overall model (OM)

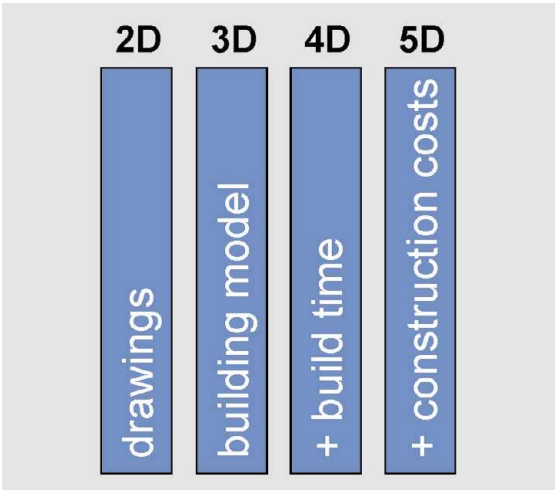


Fig. 1: Dimensions in the BIM

based on different subject models (SMs) that in turn are composed of various component models (CMs). The overall model then contains all the relevant factual data, comprising parameters, attributes and relationships. The parameters primarily feature the geometric properties of each individual physical object (PO). The attributes describe all the characteristics of a physical object. These can for example comprise material properties (concrete quality, exposure class, steel grade etc.), soil properties, manufacturer specifications, installation instructions, etc. The relations describe the relational connection between the individual physical objects (POs) as well as the connections between the individual subject models (SMs), which can be mutually interdependent. The relations between the SMs are only represented in the overall model (OM).

3 Model Structure

In order to execute a tunnel construction project using the BIM method it is first vital to obtain the funda-

mentals by digitally processing the data that have been gathered during the exploration and survey phase. The challenge here is to develop a model structure for the foundation subsoil and to establish this in normative terms and in open and neutral data exchange formats. This is essential if the digital data is to be made compatible for use in a BIM model, in this case for tunnel construction work.

For a BIM geotechnics model it is therefore expedient according to [1] to divide the 'foundation subsoil' subject model up into the following component models:

- Digital terrain model (DTM)
- Soil layer model/homogeneous area model/drilling profile
- Groundwater level models
- Unexploded ordnance survey model (and separate subject model if necessary)
- Model showing areas suspected of contamination
- Model showing structural elements present in the subsoil/identified obstacles

4 Model Granularity

Model granularity [2] describes the maturity level of the planning and/or development stage in various developmental stages for geometric and semantic data in the BIM model. The internationally accepted terms Level of Geometry (LoG), Level of Information (LoI), Level of Detail (LoD) and Level of Development (LOD) have been established for this purpose. In the structural engineering industry LOD is applied with five stages ranging from 100 to 500.

4.1 Model Granularity LoX Foundation Subsoil

As far as the foundation subsoil is concerned there are currently no recommendations for determining the completion status with the granularities LoG, LoI, LoD and LOD, as is shown in section 4.2 for tunnel construction under [2].

Furthermore, the established model granularities from the structural engineering field cannot be directly adapted for the BIM subsoil model. According to [3] geotechnics involves a 'relatively high degree of uncertainty' and taking the LOD definition in structural engineering as an example it is apparent that this is very much based on the planning phases. Such a definition cannot be directly applied in the case of the BIM subsoil model.

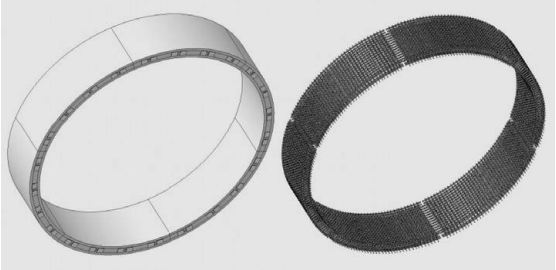


Fig. 2: Example of tubbing support/reinforcement in LoG 400 [5]

In [3] a LODgeo is presented that makes a statement about the level of detail of the BIM subsoil model using existing prospection data and archived drill logs in a certain grid pattern. However it remains questionable whether and how the model granularities that are familiar to the structural engineering industry can be applied for a BIM subsoil model and whether it is possible in simplified terms to start on one level from a LOD 100 for a BIM subsoil model or even a 'stock model'.

4.2 Model Granularity LoX Tunnel Construction

The DAUB working group [2, 4] has submitted recommendations for subsurface construction that seek to define the completion status with the granularities LoG, LoI, LoD and LOD.

The level of detail in the parametrisation, i. e. the depth of geometric information on the components of a BIM model, is designated as the Level of Geometry (LoG) according to the recommendations of the DAUB working group.

For subsurface construction work the DAUB recommendation specifies LoGs for 'conventional excavation and support methods' and for 'tunnels with full-face extraction and tubbing supports'. The level of detail is subdivided into four main stages of 100 to 400. These relate to the relevant methods used in subsurface construction, such as extraction, roof support (outer shell and other support measures), sealing, inner shell and internal support system.

The project concept design must specify in the client information requirements (EIR) and BIM execution plan (BEP) exactly which applications correspond to which LoG in certain phases of the project.

In its annex 1 'Proposal for using a Level of Geometry (LoG) in conventional tunnelling' and annex 2 'Proposal for using a Level of Geometry (LoG) in mechanised tunnelling' the DAUB working group provides help and advice on determining the level of detail in the individual LoG stages. The DAUB working group points out that these should be seen as a recommendation and not as a rule. **Fig. 2** presents an example of a LoG 400 in the form of a tubbing support system with its associated reinforcement.

The Level of Information (LoI) describes the level of detail of the attribution of a component in the BIM model. As well as providing semantic information on the component in question it is essential to retain a unique ID of the specialist object in the form of a GUID (Globally Unique Identifier) or a simulation code that is generated uniquely for every object in the BIM model.

The Level of Detail (LoD) describes the amalgamation of the LoG and LoI according to [2]. By contrast with the structural engineering sector this does not

generate a new definition as the original use of the LoG from structural engineering can be transferred to the subsurface construction field. In the LoD stage, according to [2], the allocation of the attributes (LoI) and geometric detail level (LoG) is documented with reference to the respective application for each component in the modelling guidelines. Unlike the structural engineering sector, however, there is here no need to use an LoD 500 (as built), as the maturity level can be described in the Level of Development (LOD).

The Level of Development (LOD) describes the maturity level of a BIM model. The LODs are recorded and fixed in the EIR and in the BEP. A life-cycle assessment for the structure is carried out early in the project design stage and from this it is possible to define the requirements of the individual project phases. In the Level of Development it is possible, among other things, to create views of choice of routing, the removal of excavated material and collisions with existing structures.

In [2] the DAUB working group proposes the following models for an advanced planning status:

- Concept model (overviews prior to execution)
- Execution model (maturity level for 2D plan derivation)
- Production model (incorporation of actual performances, e. g. geology and tunnel drivage classes)
- 'As-built' model (model for handover to the operators as the basis for a stock model or operator model)

5 State of the Art and Data Exchange Formats

Certain tools, in the form of software solutions, have to be developed and applied for the practical execution of the BIM method. High-grade, user-friendly software solutions already exist for the structural engineering industry that enable integrative working in the BIM environment. As well as the existing range of software it is the software-spanning data exchange that is of particular importance for practical work. However, consistent standards are still needed in order to exchange interdisciplinary and software-spanning data between the different technical planners. According to the BIM guidelines for Germany [6] the Open BIM Standard should eventually be established with the introduction of the BIM method for the planning and building of structures. In the field of structural engineering the Industry Foundation Classes (IFC) Format is increasingly becoming mainstream. The buildingSMART forum supports open interfaces for the BIM method and makes great efforts to find and establish standards and solutions for technical tasks.

5.1 Open BIM Standard

The Open BIM standard describes open and neutral interfaces for an effective and transparent exchange of data between all parties involved a project planned using the BIM method. In Germany efforts are under way to ensure that the data exchange formats will not be exploited as a means for gaining monopoly status by a software manufacturer. There are already a number of proprietary data exchange formats that have their merits for certain specialist applications [7].

For public sector infrastructure projects the phased plan that was put forward by the Federal Ministry of Transport and Digital Infrastructure (BMVI) [8] in 2020 calls for the use of the Open BIM Standard for projects being planned with the BIM method. As several proprietary data exchange formats have already established themselves, as mentioned above, further data packages besides the data in the Open BIM Standard can be supplied to the client as add-on applications in the form of proprietary exchange formats. The provision of the digital data must however be based on the Open BIM Standard and be fully in keeping with the phased plan of the BMVI as the use of proprietary data exchange formats can lead to overly close ties to certain software manufacturers, which can result in a lock-in effect [7]. This system then prevents public-sector clients having to prescribe the use of certain software products, possibly even in the EIR. Such a stipulation would affect the general trading and competition conditions and would force public-sector clients into being excessively tied to the most internationally active software manufacturers [6].

Another benefit of the Open BIM method is that major infrastructure projects often take decades to plan and execute and may then have an operating lifetime of as much as 100 years. In situations requiring the long-term storage of digital data as submitted by the contractor it is not possible to guarantee that a proprietary data exchange format will continue to be developed and maintained over the years. The use of the Open BIM Standard prevents any loss of digital data as the open data exchange formats can continue to be developed independently of the software manufacturers.

One of the greatest challenges for the implementation of the Open BIM Standard is the programming of error-free interfaces, which have to be tested at an early stage and must output to the export data in such a way that the import side can reload them along with all the export data. In order to be able to export and import the complex digital BIM data error-free the user also has to manually configure the export and import process [6].

5.2 Industry Foundation Classes – IFC

The IFC specification is an open, standardised data exchange format in which a BIM model with all its physical objects and their factual data (parameters, attributes and relationships) can be interchanged across different software systems in a specified data schema. This has now been updated in other versions since the IFC4 standard was published in 2013 [6].

buildingSMART International, which in Germany trades under the name buildingSMART e. V., continues to develop its IFC exchange formats [9] and is working to establish an open and neutral IFC data exchange format for other specialist fields too. This includes the IFC Bridge, IFC Road, IFC Rail and IFC Tunnel standards that are currently being developed for the infrastructure sector.

The IFC structures are being updated for the aforementioned data exchange formats on the basis of the requirements laid down for the individual specialist areas, an operation that is being carried out in association with various countries, universities and companies that are involved in the development of the BIM method.

The data exchange format IFC Tunnel, for example, has for some time been the focus of two research projects being carried out at German universities. These are primarily concerned with definitions for the tunnel construction operation and the tunnelling machines and with the level of detail for BIM tunnel models [10].

5.3 Additional Data Exchange Formats

Other proprietary and open data exchange formats have already established themselves alongside the IFC model:

- CityGML (City Geographic Markup Language)
- gbXML (Green Building Extensible Markup Language)
- COBie (Construction Operations Building information exchange)
- XML (Extensible Markup Language)
- OKSTRA (Object catalogue for road and transport)

5.4 Common Data Environment – CDE

The Common Data Environment (CDE) is a cloud-based data environment that can be accessed by all participants working within a project being planned using the BIM method. All project information is filed and centrally administered within this data environment using the SSOT (single source of truth) concept. In order to have as neutral and as open an access as possible to the digital data for the BIM project the CDE is often provided with the option of web-based access to the project data. This at least allows the project participants to view the relevant data independently of the software in use [11].

The CDE operates on the SSOT principle, which means that all project members always have access to current project data and therefore can also work with these updated digital data. However, in the majority of cases a distinction is made between a CDE for all project participants and one that is intended for the specialist planners themselves. This is because not every planning and processing status is immediately shared with all the project members. The data are only obligatorily released centrally to everyone involved when a specified maturity level has been reached and a quality assurance procedure completed [11].

6 Modelling the Foundation Subsoil

The subsoil modelling work carried out for the project study used Hole-Base SI standard software from Bentley (formerly Keynetix) for creating the drilling database and Autodesk Civil 3D software from Autodesk for generating the subsoil model. A future paper will examine the practical experience acquired with other types of software (e. g. Leapfrog Works) for the foundations modelling work.

6.1 HoleBase SI Drilling Database

A large portion of the data only existed on paper or in PDF format. The bore logs were also available in proprietary bop format, which is the data format of the iDat WinBohr program. The next step was to select and compile specific prospection data on tunnel construction. This selection was summarised in an Excel file and provided with the following parameters, which would subsequently be stored in HoleBase SI:

- **Location ID** – definitive borehole name
- **Location type**
- **Easting** [m] according to Gauss-Krüger Zone 3
- **Northing** [m] according to Gauss-Krüger Zone 3
- **Ground level** [m] – height above mean sea-level
- **Final depth** [m] – metres drilled per entry point
- **Routing distance** [km]

As well as the parameters, which were essentially the descriptive geometrical data, various attributes were also saved in HoleBase SI. Here it has to be noted that the attributes are in some instances dependent on parameters, especially when building geological objects in the BIM project. Attributes are directly related to parameters in the BIM object 'drilling profile'. This fact relates in particular to the lithologies and soil properties, which are related to the parameter 'metres drilled'.

The drilling profile attributes from the existing bore logs in PDF format were taken over and manually transferred into HoleBase SI. This particularly included the downhole information and its long-text description.

HoleBase SI operates with a linked SQL database. As no CDE existed in this particular case the data from the drilling database were stored in a local SQL environment. HoleBase SI was developed specifically for the UK market and already contains adaptations for other areas, especially the American one. For this reason a number of presets are still required before the program can be employed in the German market.

As it is also possible in HoleBase SI to store the results of laboratory tests the contact data of those labs that the engineering team worked with during the course of the project can also be lodged here. This

means that the laboratory results can be allocated to the particular lab that did the work.

The Borehole Log profile was used to input the borehole data. This allows the following data to be stored in eight steps:

1 **Locations**
2 **Drilling details**
3/4 **Wells and water strikes**
5 **Samples**
6 **Results - in situ**
7 **Results - environmental**
8 **Geology**

In the first step (**locations**) the parameters are defined for each borehole. This mainly includes the location ID, the location type, the final depth [m], the ground level [m], the northing [m] and the easting [m]. It is also possible to store a date for the beginning and end of the drilling work. This allows each hole to be clearly identified in the BIM process.

In the second step (**drilling details**) information can be entered on the drilling process and on the spatial position of the hole. This is of an advantage for boreholes that cannot be drilled down vertically due, for example, to geological reasons such as faults or the spatial location of the joint structure. Moreover, corrections for boreholes that were originally planned as vertical can in theory be carried out in respect of deviations from the nominal position of the hole.

In the third step (**wells and water strikes**) information can be supplied on the optional development of the groundwater monitoring station. This includes, for example, data such as the diameter of the standpipe, the date of the development and the filling of the cavity between the standpipe and the hole.

In step four, also **wells and water strikes**, information can be provided on the groundwater that has been encountered.

In step five (**samples**) information is stored on the collected samples. This provides an opportunity to allocate each sample a clear ID and to define the sampling method. Data can also be stored on the depth positions (depth top [m] and depth base [m]) and on the number of blows.

In step six (**results - in situ**) the results of any in situ tests carried out are updated.

In step seven (**results - environmental**) environmental burden values, such as the results from the FID (flame ionisation detector) and PID (photo ionisation detector) tests, can be entered with the current presettings. Here it would also be appropriate to check whether geo-environmental lab results, such as LAGA categorisations, could be inserted instead.

Step number eight (**geology**) is very important for the subsequent preparation of a BIM subsoil model. This is where the geological data from the drill core survey can be stored with the help of stratigraphic boundaries and lithology. The 'legend code' makes it possible to display the characters for the different soil types in accordance with DIN EN ISO 14688-1 or DIN 4023 and DIN 21920.

These saved legend codes later make it possible to use automatically created bore logs in HoleBase SI. In addition, when the drilling profiles are subsequently being compiled in a BIM-capable CAD program, such as AutoDesk Civil 3D, it is possible choose between two different displays, i. e. legend codes or geology codes.

Geology codes play a key role during the subsequent modelling of the foundation subsoil. Like legend codes they can be individually created and edited in HoleBase SI. It is absolutely essential that the geology codes are laid down by an experienced geologist or geotechnical engineer who can professionally collate the downhole information in idealised soil layers.

As well as enabling the manual input of data HoleBase SI can also import prospection data. The following data formats can be imported using HoleBase SI:

- AGS files
- Key Logbook
- gINT
- pLog Tablet
- Geodasy
- CSV (comma-separated values).

The import that most closely matches the Open BIM Standard is that which is based on CSV files.

The datasets entered in HoleBase SI or imported using CSV files can also be exported. Alternatively it is possible to export AGS formats in the file versions 3.1, 4 and 4 NZ. Data exported in this way can be used for subsequent processing with the BIM method. HoleBase CONNECT Civil 3D Extension is a special tool available from HoleBase SI that is able to integrate HoleBase SI in AutoDesk Civil 3D. It is therefore appropriate to develop the subsoil model with this program as it enables a loss-free transfer of data.

As well as outputting drilling data as CSV files HoleBase SI is also able to produce DIN-compliant protocols under the mantle of a preset document template. The data stored in HoleBase SI can therefore be output very quickly and easily as bore logs, for example, which will be compatible with the preset document templates and so meet UK standards. Updating the document templates for the European rulebook and the various national annexes would be both useful and desirable.

6.2 Subsoil Model AutoDesk Civil 3D

The subsoil model was constructed using the BIM-capable CAD program Civil 3D. This is especially suitable for linear construction projects and contains many useful tools for the rail and road construction sector along with functions for the integration of all kinds of geodetic information. The HoleBase CONNECT Civil 3D tool was used to transfer the information stored in the drilling database to the CAD software. This involved

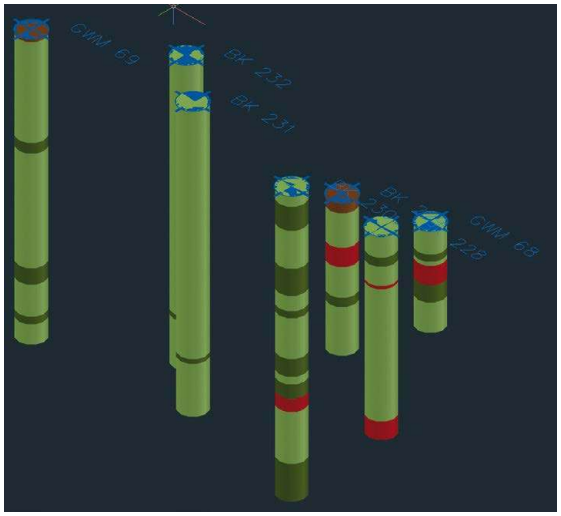


Fig. 3: Civil 3D – extract of 3D view of imported drilling profiles

using the tool to establish a direct link to the SQL database, from which it was then possible to read out digital data in the drilling database.

When establishing this connection and taking over the digital data from the SQL database the main focus is on the parameters with all their embedded geometric properties and the attribute information on the lithological and petrographic characteristics. The moment the link to the SQL database is made the desired project is selected (this having already been created in HoleBase SI Standard) and the digital data from the drilling database are automatically inserted in the CAD drawing.

The exploration results and the soil layers stored in HoleBase SI can be viewed in 3D (**Fig. 3**). The standard setting provides for the soil series to be represented using the geology codes that were previously defined in HoleBase SI. By selecting the setting 'locations' there is also the option of switching the display to Legend Codes, BGS Lexicon, Boundary or Geology Code 2. Using Geology Code 2 is especially beneficial when a second interpretation is required. This means that HoleBase SI can be used to specify other geology codes and the compilation of similar soil layers can be interpreted in different ways and multiple times.

The drilling profiles are automatically inserted as blocks. The drilling points in the 3D CAD space are determined by the coordinate parameters defined in HoleBase SI (easting, northing) and by the ground level. The correct colour representation for the geology codes has to be preset via the layers in Civil 3D. HoleBase SI automatically generates layers for each soil bed and other shapes and drawing elements. The layers established by HoleBase SI are identified by the abbreviation KNX, which is displayed before each layer name.

When it comes to further processing in particular it is important to remember that the drilling profiles are automatically represented with a five-fold height exaggeration. This factor is of special relevance if additional elements that have not been generated by HoleBase SI, such as a digital terrain model, are to be loaded into the 3D drawing.

The displayed drilling profiles of relevance can be selected in Civil 3D via the HoleBase SI Location Manager. By this means it is possible, for example, to create sub-subject models for a planning segment or to exclude inconclusive or archived boreholes from the modelling exercise.

In conformity with the geology codes laid down in HoleBase SI it is possible initially to generate the stratigraphic boundaries automatically using the HoleBase CONNECT Civil 3D tool (**Fig. 4**). As can be seen in **Fig. 4** the HoleBase CONNECT Civil 3D tool generates stratigraphic boundaries between the existing drilling profiles using linear interpolation in 3D space. These boundaries and any lenses present have to be reprocessed and professionally interpreted.

The digital terrain model (DTM) is inserted into the model as an additional stratigraphic boundary in the upper soil layer. The automatically created upper boundary does not correspond to the actual ground surface. This plays an important role for subsequent direct volume calculations from the 3D model, as this allows the accuracy of the calculations to be increased. The automatically generated stratigraphic model, with the DTM as the uppermost stratigraphic boundary, can be seen in **Fig. 5**. The digital terrain model and the drilling points are represented with a five-fold height exaggeration. This greatly facilitates the visual understanding of

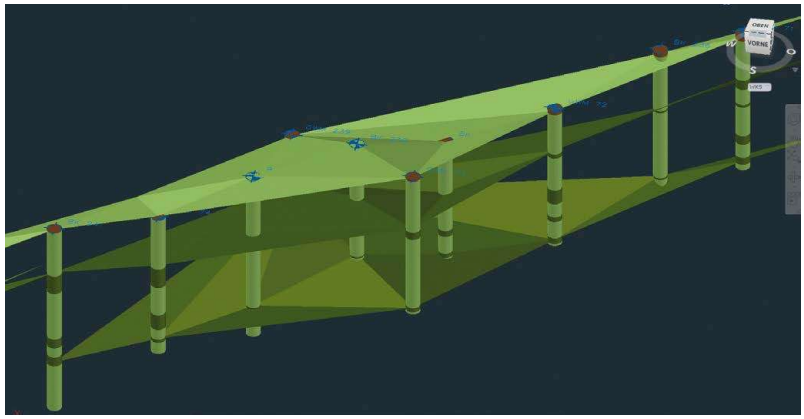


Fig. 4: Civil 3D – extract from automatically generated strata boundaries

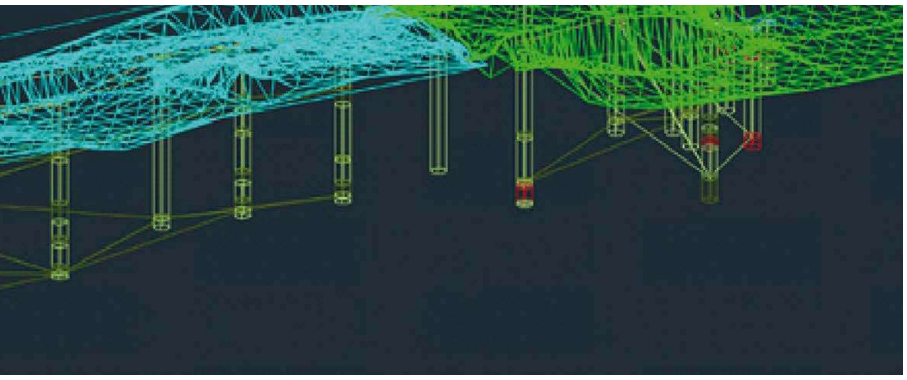


Fig. 5: Civil 3D – extract of 3D view of imported drilling profiles

the subsoil situation and allows a precise interpretation to be made.

The adjustment and interpretation of the 3D subsoil model is achieved by way of cross sections in the interpretation and profile tools. This allows sections to be placed anywhere in the 3D space and created as a 2D section along with the actual 3D model (**Fig. 6**). The cross sections are in relation to the 3D model and any change in this model has a direct effect on the 2D section and vice versa. After the stratigraphic boundaries have been adapted in Civil 3D the result is an approximative 3D model of the foundation subsoil (**Fig. 7**).

However, with the improved representation of the 3D strata model one also arrives at the limits of what is technically possible with the programs in use. It is apparent that the stratigraphic boundaries cannot all be fully recognised and processed using the HoleBase CONNECT Civil 3D tool. Freehand editing of the boundaries is only possible to a limited extent. This is in part due to the fact that the prospection data for the underlying project were not planned for a BIM project. The body of data is therefore insufficient to create a meaningful 3D subsoil model, as is evident in **Fig. 8**.

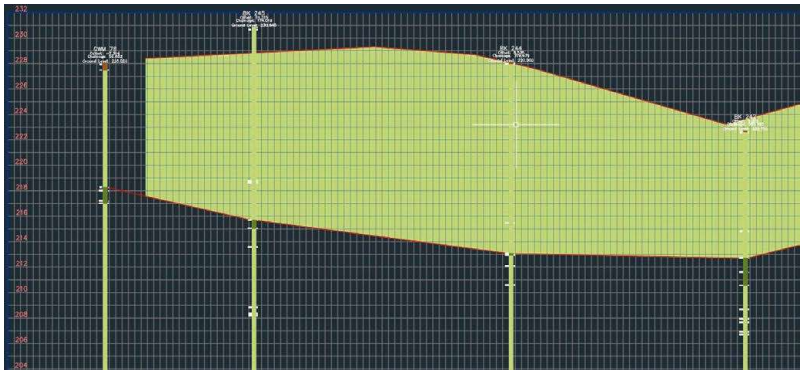


Fig. 6: Civil 3D – 2D section with HoleBase CONNECT Civil 3D Tool

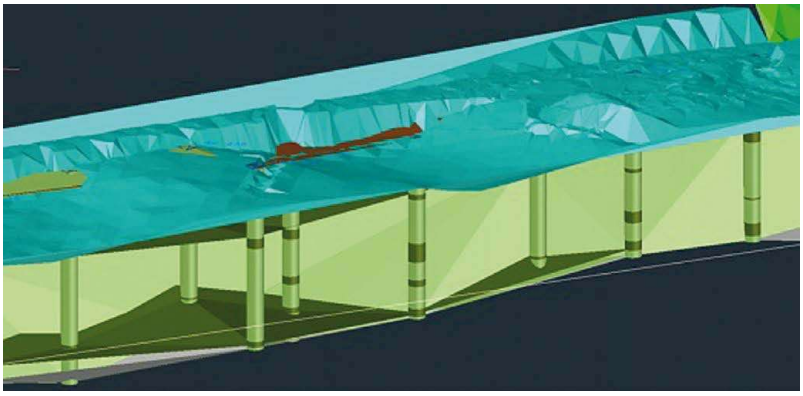


Fig. 7: Civil 3D – 3D model with partly adjusted strata boundaries

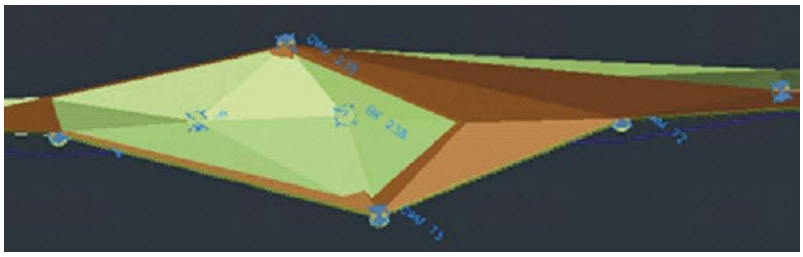


Fig. 8: Civil 3D – plan view of 3D subsoil model

7 Conclusions

As outlined above, HoleBase SI Standard software can be used to store and manage the results of a drilling campaign in a centralised database. The idea behind the program consistently follows the BIM method and allows digital data to be imported and exported, even using Open BIM. The open data exchange interface is restricted here to the CSV format (CSV = comma-separated values). The advantage of this is that the data can be opened and edited software independently, though it does have the disadvantage that they can only be read in and out in a format prescribed by the program.

Another point of discussion concerns the control of the input data. Bore logs are recorded in situ or at the drill core storage facility and are compiled manually. This does not entail mechanically generated digital data, such as that provided by survey instruments for example, that can be input directly by the computer. There is a certain error susceptibility attached to this as the datasets for each prospection have to be digitised again manually after each drill core recovery. If this is not done immediately in a BIM-capable drilling database, such as HoleBase SI, but in a standard bore log program of the kind commonly used in the industry, such as iDat WinBohr or WinSchi, the data will have to be transferred again manually into the BIM-compatible drilling database. This increases error susceptibility and in fact runs counter to the BIM principle. On the other hand, when reconditioning the data from the subsoil exploration stage it is customary that the geotechnical information from the drill returns has to be re-assessed on site on the basis of further direct (laboratory and field tests) and indirect (e. g. geophysical findings) results when the geotechnical/tunnel engineering report is being prepared. It is at this point at the very latest that the BIM-compliant data preparation work can begin.

When creating a drilling database that is fully in keeping with the BIM concept the aim must be to store and manage the data in as interface-neutral a way as possible. Here the aforementioned experience has shown that error susceptibility can be reduced when the amount of manual data processing required is kept to a minimum.

In order to be able to maintain centralised drilling databases in accordance with the BIM method it is also important that the tunnel construction parameters established by the geologists and geotechnical engineers can be directly stored in the drilling database. These parameters must also be definable as attributes in relation to the idealised soil layers and/or homogeneous areas. As regards the further course of the project in the BIM process the geotechnical and tunnel engineering attributes that are related to the lithology and stratigraphic

boundary parameters can be used as a calculation basis for the constructional/static BIM tunnel model when the BIM subsoil model is being generated and put to use. However this is not technically possible at the moment. The relevant tunnel construction attributes have to be entered manually in the BIM subsoil model or must be taken from the subsoil report and transferred manually to the structural calculation program by the support design engineers.

The options provided for interpreting the natural ground layers in the HoleBase CONNECT Civil 3D tool are basically well thought-out, though they do limit the user somewhat, even when there is a relatively small exposure density and fairly minimal ground complexity, as in this particular case. It remains to be established whether the concept being proposed at [3] represents a method by which the arrangement of the proposed drilling points can result in a meaningful BIM subsoil model.

Of course the ability to create lines, surfaces and solid bodies with the Civil 3D standard tools is still there. It would therefore also be possible to extrapolate a BIM subsoil model from linearly arranged prospection data. However this would not be in keeping with the BIM concept of open and neutral data continuity, as the drawing elements produced in this way would no longer have a direct link to the digital data stored in the drilling database. An alternative option would be to go back to the drilling archives, which can be integrated into the BIM process provided the database is well maintained. The data from the drilling archives can be digitised in the drilling database and linked to the BIM subsoil model using the HoleBase Civil 3D tool. However as the drilling archives are not always readily available or are some distance away this is not really a reliable way to go about developing the model boundaries of a BIM subsoil model. Moreover, it would be beneficial for future operations if the drilling archives were to be available from the regional authorities in open and neutral data exchange formats so that these could be used for further projects of this type.

It can therefore be concluded that, subject to the aforementioned restrictions, a BIM subsoil model is now realisable using the HoleBase SI, Civil 3D and HoleBase CONNECT Civil 3D Tool programs. It should be noted, however, that introducing the BIM method into company operations means a huge outlay in terms of time and cost for staff training and learning sessions and for the acquisition of the programs themselves. Even configuring HoleBase SI, involving as it will all manner of adaptation and customising to meet the needs of the company concerned and to comply with German norms and standards, requires a period of familiarisation that should not be underestimated. This is the point where the benefit-cost ratio has to be properly looked at. Similarly, extensive knowledge and experience in dealing with the CAD-BIM software AutoDesk Civil 3D will also be required. The BIM method will however prevail in the end, as is being stipulated for German transport infrastructure projects by the phased plan being proposed by the BMVI (Federal Ministry for Transport and Digital Infrastructure). While a lot of spadework still has to be done in this area, this will all pay off in the long run and will deliver improvements in the quality, openness and transparency required for the planning, execution and operation of infrastructure works.

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