A Case Study of Building Information Modelling (BIM) for Subsurface in Malaysia

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Abstract. Unforeseen ground condition often leads to the occurrence of cost overrun and project delay in Malaysia’s architecture, engineering, and construction (AEC) industries. The implementation of Building Information Modelling (BIM) for subsurface was attempted to reduce uncertainties associated with the underground conditions. A pilot case study was performed to understand the 3D subsurface modelling workflow in BIM environment. A construction site in Ara Damansara, Petaling Jaya, Malaysia was selected for the pilot case study. The site investigation data of the study area were interpreted and input into AutoCAD Civil 3D with geotechnical module to perform the 3D subsurface modelling at various detail levels. The workflow of the modelling process in case study was documented for future references. Through this pilot study, it was found that the adoption of BIM for subsurface modelling could produce soil profiles for different engineering purposes such as visualisation of subsurface conditions during project initiation stage, preliminary conceptual design, and detailed analysis and design of geotechnical structures, particularly foundation. The BIM implementation for geotechnical data improves the management of site investigation data, enhances the visualisation of subsurface profile, and improves the efficiency in communicating the subsurface conditions to all stakeholders in a project team.

1. Introduction

Building Information Modelling (BIM) is the combination of process and software that aids in data management for construction project. The fundamental concept of BIM is the modelling of building in a digital environment before its actual physical construction. The constructed model allows stakeholders to anticipate the potential impacts which are expected to be encountered during construction stage [1]. BIM was defined as a model-based information management system which aids in information coordination and visualisation, project scheduling, cost estimation, facilities management within building life cycle and model analysis for construction project [2]. In 2010, the decision to include BIM in architecture, engineering, and construction (AEC) industries by director of Malaysia’s Public Works Department (PWD) has resulted in the BIM implementation in the construction of National Cancer Institute in Sepang [3]. Along with the development of modelling tools for BIM software, the level of details of the information in the constructed model becomes more complicated and the coverage of information for modelling is widened. In recent years, engineers have started to include geotechnical data in BIM environment. This is due to the unforeseen ground problem which leads to project delay in construction. In Malaysia’s AEC industries, 70% of public
sector construction projects faced project delay [4]. Project delay often leads to the simultaneous occurrence of cost overrun and negative impact on company’s reputation in AEC industries [5].

To understand the benefits of BIM implementation for geotechnical data, a pilot case study for 3D subsurface modelling in BIM environment is performed. The current 3D subsurface modelling techniques in BIM environment are studied to identify suitable software and workflow for pilot case study. The previous examples of BIM implementation for geotechnical data is reviewed to identify its benefits in AEC industry. These information aids in understanding how uncertainties associated with underground condition could be reduced with the BIM implementation for geotechnical data.

1.1. Previous studies of BIM implementation for geotechnical data
The BIM implementation for geotechnical data has been practiced in certain construction projects. In 2016, Bentley software was being applied for BIM-based geotechnical data management in Amur River Bridge project. The project cost of Amur River Bridge project was able to be reduced without affecting the quality of the bridge. The BIM-based geotechnical data management was also applied in China’s Tianjin Architecture Design Institute project, India’s Chennai International Airport expansion project and King Abdullah Finance District (KAFD) project. The implementation of BIM for Tianjin Architecture Design Institute project improves the collaboration between stakeholders and reduces design mistakes with the presence of models. The Chennai International Airport expansion project and KAFD project have problems with soil underneath the building. The implementation of BIM for geotechnical data improves the model coordinate and model analysis process to anticipate the underground soil problems [6].

For construction projects in United Kingdom and Sweden, the BIM implementation for geotechnical data has constructed 3D subsurface model with geotechnical data. In United Kingdom, the 3D subsurface model was created with historical borehole information to decide the numbers and location of additional boreholes for site investigation for Silvertown Tunnel Project [7]. The Hallandsås project [7], Varberg railway tunnel project and Ostlänken’s high speed train railway project in Sweden have allowed stakeholders to identify design mistakes and underground condition with the presence of 3D subsurface models [8].

1.2. Modelling technique
AutoCAD Civil 3D is a BIM-based modelling software which allows the geotechnical data to be visualised in digital environment. The public available software contains extension and tool that aids in data retrieval and 3D subsurface modelling, which are known as HoleBASE SI extension and geotechnical module.

The HoleBASE SI extension allows the AutoCAD Civil 3D to connect with HoleBASE SI digital database for data retrieval. The geotechnical module has a different way to obtain geotechnical data. A local digital database is created in computer by the geotechnical module. The geotechnical data stored in local digital database is either in Association of Geotechnical and GeoEnvironmental Specialists (AGS) format or common-separated values (CSV) format. These formats allow geotechnical module to manage the geotechnical data in BIM environment. Both HoleBASE SI extension and geotechnical module have strata function to create 3D subsurface model in AutoCAD Civil 3D. At most of the time, user might perform 3D editing on the created 3D model with feature lines function to have better view of 3D subsurface model [9].

2. Pilot case study
The selected site for pilot case study is situated at the West part of Ara Damansara, Petaling Jaya, Malaysia (coordinates between 3°6’52.25” N to 3°6’56.88” N and 101°34’2.67” E to 101°34’12.64” E). Figure 1 shows the geological map of peninsular Malaysia [10]. The selected site is within the pink region shown in Figure 1, which is known as PERMIANJURASSIC igneous rocks. Based on the descriptions in Figure 1, the selected site for pilot case study might have granite bedrock with minor granodiorite under the soil layer.
2.1. Data acquisition
The collected information is the final report of the site investigation of the selected site that has been kept by the respective consultant firm. The borehole logs in the appendices of final report are the important information sources for 3D subsurface modelling. The boreholes’ coordinates, reduced level, strata layers and strata thickness are extracted from the available six borehole logs and saved in CSV format. Figure 2 shows the location of the boreholes at the selected site. A total number of six boreholes were drilled and investigated at the site. Figure 3 shows the location of the selected site in Google Map as well as the location of the cross-sections A-A and B-B for visualising their soil profiles. The cross-section A-A passed through boreholes BHA1 and BHA5, while cross-section B-B passed through boreholes BHA2 and BHA6.

2.2. Soil profile
Twelve types of soil are found in the underground of case study site based on the site investigation report. The dominant soil type is sandy silt soil which is mainly distributed at the East part of case study site shown in Figure 3. Based on the layer description of borehole logs for BHA2 and BHA6, granite is found at the end of the boreholes. The appearance of granite is at 27.6 m depth for BHA2 and at 32.5 m depth for BHA6. The presence of granite at the end of boreholes BHA2 and BHA6 indicates that the case study site does within the pink region shown in Figure 1. The water table is higher at Northeast of case study site shown in Figure 3.

2.3. Methodology
In this pilot case study, AutoCAD Civil 3D with geotechnical module was chosen for 3D subsurface modelling. The extracted information from the six borehole logs is saved in “Location Details” and “Field Geological Descriptions” CSV files. “Location Details” file includes Location ID, Location Type, Easting, Northing, Ground Level and Final Depth of boreholes. Location ID is the name of the boreholes, while the Location Type is the method of boring used. Easting and Northing show the coordinates of boreholes based on selected coordinate reference system. The Ground Level represents the reduced level of boreholes, while the Final Depth represents the total strata thickness of the boreholes. The Location ID of the boreholes are BHA1, BHA2, BHA3, BHA4, BHA5 and BHA6.
based on the borehole logs in final report of site investigation. The Location Type of the boreholes is “W” which represents wash boring method. The Easting and Northing of the boreholes are based on the Universal Transverse Mercator (UTM) coordinate system.

The “Field Geological Descriptions” file contains information such as Location ID, Depth Top, Depth Base, Legend Code, Geology Code and Description. The Depth Top shows the value of top layer for each strata layer, while the Depth Base shows the value of bottom layer for each strata layer. The Legend Code is unique number that represents the soil type of strata layer in BIM environment, while Geology Code states the soil type of the strata layer. The Description explains and records simple physical soil properties of the strata layer directly from the borehole logs. The Legend Code in the “Field Geological Descriptions” file follows the legend code that has been set in geotechnical module. The legend code of “901 hard layer”, “902 granite”, “903 water” and “904 soil” are set by using the hatches manager function in geotechnical module.

Four different details models are created based on different data interpretation methods on six borehole logs. The geology code in “Field Geological Descriptions” files is different for each model. For model based on detailed SI data, the geology is directly retrieved from the borehole logs without any editing. The complexity of soil type in borehole reduces for model based on detail generalized data. The geology code of strata layer that has standard penetration test (SPT) value which is higher than 50 is set as hard layer. For SPT value that is less than 50, the geology code of strata layer remains the same and is generalized into largest percentage soil component such as clay, silt, sand, gravel, peat and cobbles. For model based on soil and hard layer, all the strata layers are divided into two groups based on their SPT values. The geology code is hard layer for SPT value which is higher than 50; the geology code is soil for SPT value which is less than 50. For model based on water table, the model only contains two geology codes, the soil and water. The legend code for respective geology code in all the four models is updated and saved in the “Field Geological Descriptions” files.

Both “Location Details” and “Field Geological Descriptions” CSV files are imported into the local digital database created by using geotechnical module. By enabling the boreholes and strata layers in AutoCAD Civil 3D, the 3D subsurface models are shown in the BIM environment. The strata layers are created based on the legend code written in the “Field Geological Descriptions” file. Two alignment lines are created on the 3D subsurface models to present the different views of soil profiles. Figure 3 has shown how the alignment lines are drawn in the model. Figure 4 is the simple flowchart to create 3D subsurface models and 2D soil profiles for different details.

![Figure 4](image-url)

**Figure 4. Simple Flowchart for Creation of 3D Subsurface models and 2D Soil Profiles.**

3. Results
The 3D subsurface models of Ara Damansara were constructed, namely detailed SI data, detailed generalised data, soil and hard layer and water table. These 3D subsurface models are shown in figures 5 to 8. The strata layers in figures were created whenever there were three points of the same soil type available in the boreholes. Some of the strata layers intersected with others, affecting the presentation of the subsurface profile in 3D view. Thus, the visual presentation of the underground soil layer was based on 2D based on the 2D soil profiles, which were extracted from 3D subsurface models, considering the information presentation in 2D profile was neater. Table 1 shows the hatch patterns of the legend codes that are presented in the soil profiles created by sections A-A and B-B. Soil types could be easily distinguished and identified from the overlapped regions in the soil profiles with the presence of the hatch patterns.
Table 1. Hatch patterns of legend codes in Geotechnical Module.

| Hatch Patterns | Legend Code | Geology Code |
|---------------|-------------|--------------|
|               | 301         | SILT         |
|               | 302         | Clayey SILT |
|               | 303         | Sandy SILT  |
|               | 401         | SAND         |
|               | 403         | Silty SAND  |
|               | 503         | Silty GRAVEL|
|               | 901         | Hard layer   |
|               | 903         | Water        |
|               | 904         | Soil         |

3.1 3D Subsurface Model based on Detailed SI Data
Figures 9 and 10 show the different views of soil profiles. The involved legend codes in Figure 9 and Figure 10 are the “302 Clayey SILT”, “303 Sandy SILT”, “403 Silty SAND” and “503 Silty GRAVEL”. Both figures show the soil profile with overlapping regions for four different soil types and three different soil types respectively. The division of the overlapped region for each soil is highly depended on the geotechnical knowledge and experience. The workload for division process increases when the number of different soil types involved in overlapping increases.

3.2 3D Subsurface Model based on Detailed Generalised Data
Figures 11 and 12 present the soil profiles for model based on detail generalised data. The legend code of “301 SILT”, “401 SAND” and “901 Hard layer” are shown in the soil profiles. The presentation of the detailed generalised soil profile is better than detailed SI data soil profile. This is due to the soil generalisation and data interpretation process which reduces the number of soil types in the model.
The number of soil types involved in model based on detailed generalised data is 7. Both soil profiles contain white region in-between the shaded regions of soil. The white region is the unidentified soil types in the model. The soil profiles can be used to determine the location and number of additional boreholes which aids the identification of the unknown soil types in the white region. Eventually, it helps to manage and reduce the uncertainties associated with underground conditions.

3.3. 3D Subsurface Model based on Soil and Hard Layer
Figures 13 and 14 show two different 2D soil profiles for model based on soil and hard layer. The legend code of “901 Hard layer” and “904 Soil” are included in both 2D soil profiles. The soil profiles show the simplified geology of the study site which aids in identifying the location of hard layers, hard layer thickness, location of bedrock and the type of bedrock.

3.4. 3D Subsurface Model based on Water Table
Figures 15 and 16 present the 2D soil profiles views for water table. Both soil profile for water table shows the shaded regions for legend code of “903 Water” and “904 Soil”. The water table soil profiles can be used for analysing and identifying potential ground problems caused by the presence of water.
3.5. Discussion
The soil types found in borehole logs are interpreted to create various detail levels of 3D subsurface models for different engineering applications which is convenience for stakeholders to understand the underground condition. The detailed SI data soil profiles are useful for detailed analysis on physical appearance of underground and visualisation of subsurface conditions during project initiation stage. Besides, the detailed generalised data soil profiles can be applied in site investigation for uncertainties management and be used for detailed analysis and design of geotechnical structures. The soil profiles of model based on soil and hard layer can be used during preliminary conceptual design for foundation. For the overlapping region in the soil profile, the knowledge and experience of geotechnical engineers are critical to analyse the uncertainties of the underground condition. The outcome of analysis will decide the need of additional boreholes and their locations for site investigation. Thus, the BIM implementation for geotechnical data can improve the workflow for site investigation [11] as well as optimise the project resources and cost [12].

The visualisation of 3D subsurface model by referring legend code is found to be better than geology code in AutoCAD Civil 3D. The hatch pattern used by legend code allows easier identification of overlapping region in 2D view, while the colour solid of geology code could not show overlapping region in 2D view at static stage.

4. Conclusion
In this case study, the 3D subsurface modelling workflow for AutoCAD Civil 3D with geotechnical module is found to be easy and convenient. The presence of these models and soil profiles eases the geotechnical data sharing process and improve the efficiency of data management. However, the
challenges associated with the workflow is that the analysis on the produced 3D models is time-consuming. The occurrence of overlapping region in the soil profiles often increase the difficulty of analysis process to identify the possible division of soil types in the region. Furthermore, another challenge associated with the workflow when practicing in Malaysia is the retrieval of borehole logs. Unlike United Kingdom and Sweden, Malaysia does not have any centralized digital database specific for site investigation reports and borehole logs. The historical information of site investigation is difficult to be retrieved. Certain contents of the historical site investigation reports and borehole logs are blur and messy which often causes trouble for data interpretation process. A centralized digital database system should be available for the BIM implementation of geotechnical data to achieve proper data management on site investigation data and borehole logs.

5. References

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