

# The use of BIM technology in geotechnical engineering

## L'utilisation de la technologie BIM en ingénierie géotechnique

J. Gondar

*JETSj, Geotecnia Lda, Lisbon, Portugal*

A. Pinto, C. Fartaria

*JETSj, Geotecnia Lda, Lisbon, Portugal*

**ABSTRACT:** The degree of uncertainty making part of the geotechnical engineering, associated with the need for constant collaboration from the project to the construction site stages, makes the Building Information Modeling (BIM) a methodology to explore in all the construction sector, including the geotechnical engineering field. In this paper, the case study of the BIM technology applied to an underground parking lot project in Lisbon center, Portugal, will be shown with the purpose to demonstrate the advantages of using the BIM methodology. The paper will point out the BIM use for a geotechnical project, ranging from the design to the pre-execution. With this purpose, a 3D BIM model was created along with the topography and geotechnical / geological layers and then, exploring several tasks, ranging from the structural design to the construction site scheduling, quantities and cost measurement activities, generating the 4D and 5D models. Several software tools were used, testing the interoperability among different platforms.

**RÉSUMÉ:** Le degré d'incertitude inhérent à l'ingénierie géotechnique, associé à la nécessité d'une collaboration constante du projet aux étapes du chantier, fait de la *Building Information Modeling* (BIM) une méthodologie à explorer dans tout le secteur de la construction, y compris le génie géotechnique. Dans cet article, l'étude de cas de la technologie BIM appliquée à un projet de parking souterrain dans le centre de Lisbonne, au Portugal, sera présentée dans le but de démontrer les avantages de la méthodologie BIM. Le papier mettra en évidence l'utilisation BIM pour un projet géotechnique, de la conception à la pré-exécution. À cette fin, un modèle 3D BIM a été créé avec les couches topographiques et géotechniques / géologiques, puis en explorant plusieurs tâches, allant de la conception structurelle à la planification des chantiers, des quantités et des activités de mesure générant les modèles 4D et 5D. Plusieurs outils logiciels ont été utilisés pour tester l'interopérabilité entre différentes plates-formes.

**Keywords:** BIM; Geotechnical Engineering.

## 1 INTRODUCTION

Performance issues in construction has been discussed throughout the 20<sup>th</sup> century and they are still real nowadays. In 1983, a study was done to find out the reason behind the lack of productivity of the construction sector. It referred that more than the half of the time wasted in construction activities was due to the lack of effective management practices and that it was needed “*a more timely and accurate control over*

*design, planning and scheduling, budgeting, procurement, material logistics, and quality assurance*”

In the design process, the broadly used CAD 2D systems are error-prone, sometimes due to the difficulty in visualizing 3D elements and detecting clashes (Eastman *et al.*, 1974). The reliance on 2D models creates the need for at least two drawings of the same piece of the element to represent and interpret it in a tridimensional way.

In the case of geotechnical engineering, according to the National Economic Development Office (UK), 37% of the schedule overruns had ground problems as a major cause. This kind of projects are based on data obtained by geotechnical investigation and the degree of uncertainty is high. Another characteristic of this sector is the risk associated for both the construction staff and for the structural integrity in case of failure or collapse of this kind of geotechnical structures. This makes the underground construction both a physical and a financial risk (Sterling, 2017). The geotechnical projects need an early constant coordination with the structure and architecture disciplines. This process of interdisciplinary collaboration must be fluent to increase the project's delivery time.

### 1.1 BIM concept

Building Information Modeling (BIM) concept appeared around 1974. Eastman identified some of the weaknesses of the architectural drawings at the time. He considered them to have “many inherent weaknesses” and to be “highly redundant”. He envisioned what he called at the time a “Building Description System” (BDS), with representation based on objects containing information (Eastman *et al.*, 1974). The BIM concept is a methodology and a framework that is based on the use of parametric elements that include, not only a tri-dimensional geometry but also other useful information for the whole building's lifecycle, from the design to the exploitation, and its deconstruction. This methodology promotes an early stage design team-up with an improved collaboration among the different project's stakeholders. The collaboration is guaranteed by a high degree of interoperability – the capacity of seamlessly exchange information between different platforms.

In a first stage of the project, a tri-dimensional parametric model is created. This model is a visual representation of the project, very close to the real one yet to be built. It characterizes spatial

relationships, geometry, and geographic information. A BIM based software is used to make the integration among disciplines of the project and to navigate inside the model. This stage is designated by 3D/BIM. Adding the time variable to the 3D objects generates the 4D/BIM model. This time information makes possible the visualization of the construction processes through the project schedule, allowing a simulation of the project and a better control of allocated resources and the necessities at different stages of the execution. With the cost information a 5D/BIM model is obtained and it is possible to simulate and compare different constructive solutions or materials and to have a tighter control over the budget along the execution plan. The dimension 6D/BIM concerns the energetic and sustainability performance and the 7D/BIM is usually related to facilities management capability.

## 2 3D/BIM MODEL

### 2.1 Case study

The research is based on a public underground parking lot project in Lisbon that includes the excavation and construction of four underground floors and the corresponding exit ramp. Figure 1 shows the project's deployment area and some of the main construction restraints that include the surrounding streets and infrastructures, especially the future Learning Center of Lisbon University and the Lisbon's Metro line.

The geological and geotechnical conditions were assessed by four Standard Penetration Tests (SPT) and a piezometer, to determine the groundwater level position. After the SPT test were completed, the site ground area was divided into four geotechnical zones (table 1) that were also used to create the surface representation in the 3D model.

*Table 1. Geotechnical zones and parameters*

Geotechnical Zone	ZG3	ZG2A	ZG2B	ZG2
	Fills	Miocene		
Unit weight $\gamma$ (kN/m <sup>3</sup> )	18	19	20	20
Internal friction angle $\phi'$ (°)	24	32	34	36
Cohesion (kPa)	-	5	10	20
Young modulus (MPa)	3	10	20	50
N <sub>spt</sub>	0-7	6-26	30-45	60

were placed with an average spacing of 3.60m at all floor levels to ensure the suitable drainage conditions.

The BP were braced by two levels of temporary ground anchors and steel props, at the corners. At each level, the bored piles were braced by distribution beams and, at the top, by a capping beam.

Regarding the general execution process, a survey to neighboring infrastructures and preparation of the site was done with diversion of the traffic and services affected and the instrumentation plan is set up. The peripheral BP

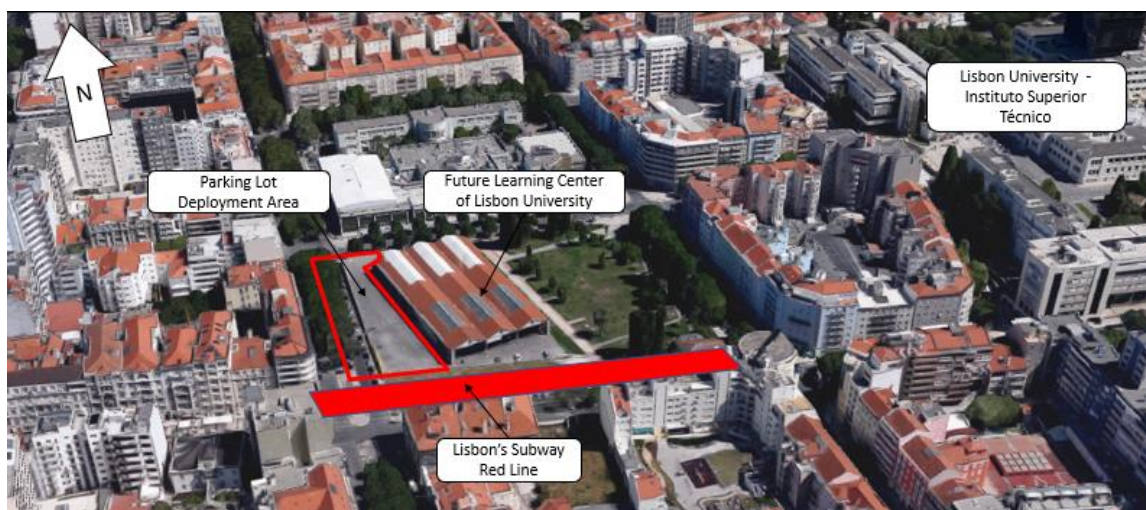


Figure 1. Excavation site and surroundings. Source: adapted from Google Maps

The increase in displacements from the excavation works must be controlled and monitored throughout the execution stage by the application of an instrumentation plan.

The designed solutions for the retaining structure were a peripheral retaining structure, with the execution of bored piles (BP) and by the execution of king-post walls in the alignment adjoined to the future Learning Center. The BP system adopted included piles with 600mm diameter with 1.20m spacing. These piles have a length of approximately 16.0m to cover the depth of the excavation and an embedment length of 4.0m. The soil between the piles was lined after the excavation by a 4+4cm layer of shotcrete for confinement and protection of this soil. Geodrains

piles and underpinning of the “Gare do Arco do Cego” columns were executed followed by the cleaning of the piles top and execution of the capping beam. The temporary ground anchors and the corner props were installed after the concrete hardening and the excavation till the level of the first distribution beam can be performed. Geodrains were installed along with two layers of shotcrete (4+4cm) and the distribution beam is executed with the next level of ground anchors. This process was repeated until the bottom of the excavation is reached and the internal structure could be built, from the base to the top, deactivating the anchors and props.

## 2.2 Parametric modeling

The software used to produce the 3D model was the Autodesk Revit 2018 that guarantees IFC interoperability with other applications. It comes with a library of parametric elements and allows the modeling of new ones.

The preparation of the model is important and can avoid time losses and increase the modeling efficiency in the long-run (Thakur and Rao, 2014). For this project, the units, project phases, and survey points were early defined. The definition of phases gives the model a time variable for the project. Having this information associated with the parametric elements will allow a quantity take-off associated with each phase and ease the graphic representation of the model for each defined construction stage. In this case it was used for the measure of quantities for the earth works.

### 2.2.1 Retaining structure

The model for the retaining structure was created based on the project documentation available in 2D CAD drawing files and the descriptive memory. The modeling started by importing CAD drawing to the modeling pane.

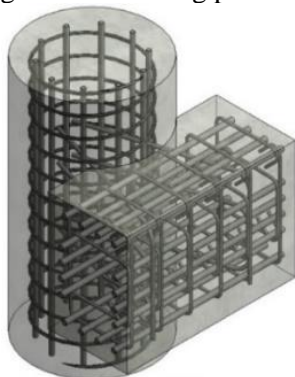


Figure 2. Rebar intersection representation

Then, the bored piles were modeled, following the distribution and capping beams along with the slabs and the reinforcement details.

The objects automatically adjust their length according to the defined constraint's position and their geometry adapts according to it. These

changes are spreaded across all views and representations of the project.

Some objects were not available in Revit library and had to be created. This happened with the ground anchor object and some annotations to represent the instrumentation devices.

The ground anchors are an important element to represent. Its geographic position should be accurate and the characteristics clear for the contractor to execute. To create the ground anchor, an object was found in an online BIM library although with some characteristics missing such as the anchor bulb – an important feature to represent. This element was thus edited, creating the required parameters and geometry associated with its material information. The parameters created were the bulb length, the bulb diameter, as well as the total anchor length, defined by the free length plus the bulb length. It was also required to define the material of the grout bulb created.

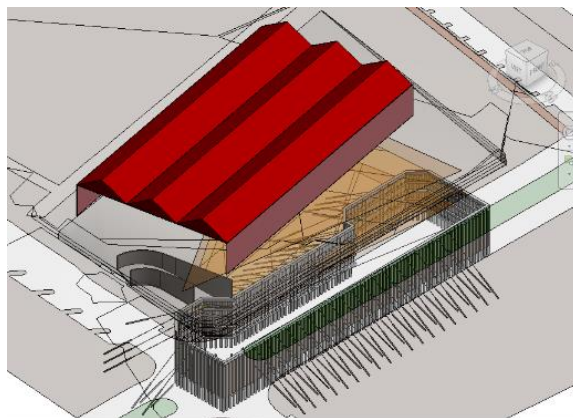


Figure 3. Complete model of the retaining structure

With a BIM approach, any kind of geometric element can be defined and associated with parameter values to meet the user's requirements. These parameters can then be used for quantities take-off, construction planning or facilities management. This flexibility allows several kinds of project stakeholders to take part in BIM methodology and be a support for the study of design changes, as well as for the decision-making process.

### 2.2.2 Topography surface

In geotechnical projects, the topography and subsurface are especially important to support the design solutions and estimate earthwork quantities. The surface was modeled using Revit tools by importing a 2D CAD file with elevation points. The subsurface and the geotechnical zones were defined using the *Autodesk AutoCAD Civil 3D*, that has a module specific for the purpose.

With the surfaces added to the model, it was possible to confirm that the length and the vertical angles of the anchors are compatible with the soil characteristics, and some optimizations were possible.

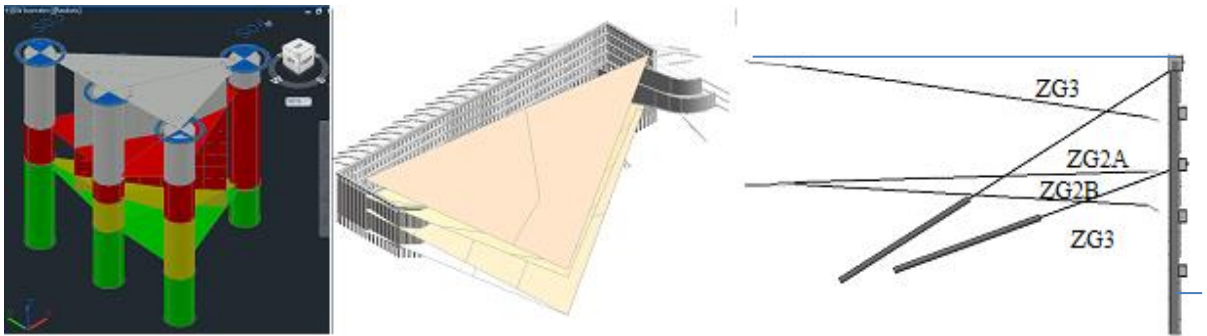


Figure 4. Geological zones in Civil 3D (left), in Revit (middle), and compatibility analysis (right)

### 2.2.3 Connection with a structural design software

Since the modeling in BIM is done using parameters that represent geometry and material properties attributed to elements, this information can be used to support the structural design. It avoids the reduplication of work when modeling the structure in the respective analysis software. Revit creates an analytical model along with the geometric one, which should be prepared to be sent to the structural analysis software. It is important to ensure that the elements are properly linked and that there are no unconnected nodes. The used software was the Robot Structural Analysis, from the same software provider of Revit.

The interoperability is improved if the analytical model is prepared beforehand, what

can be time consuming. It is although an advantage to have the information regarding the sections, the grids and the materials of the elements automatically ready after the export. Defining the names of the materials in Revit according to the ones used in the Eurocodes, provided by Robot software, will save time adjusting the section properties in this software. After optimizing the solution in Robot, the changes in the sections are assumed by Revit, as the models are linked. So, when the cross-section of an element is changed due to optimizations or to ensure design code's requirements, the changes are reflected in the 3D model and in all created views and sheets.

## 3 CONSTRUCTION MANAGEMENT BASED ON BIM

The software used to create the 4D and 5D models was the *STR Vision CPM* from *TeamSystem*. It does guarantee interoperability with several programs used by AEC sector including IFC and scheduling files types. This software allows the budget management of several projects simultaneously with several tools to support construction managers' activities.

### 3.1 Construction planning based on a 4D/BIM model

The process of planning a construction project is a complex task that includes several interrelated variables, sometimes difficult to predict. The site construction manager usually receives data from the different disciplines (geotechnical, structure, architecture, mechanical, electrical and plumbing, etc.) and must combine those avoiding clashes and by promoting health, safety, and quality of the finished works. Traditionally, the site planning process is done based on two-dimensional drawings, what makes it a difficult task. The schedule needs to be interpreted by the construction managers sometimes just based on abstraction.

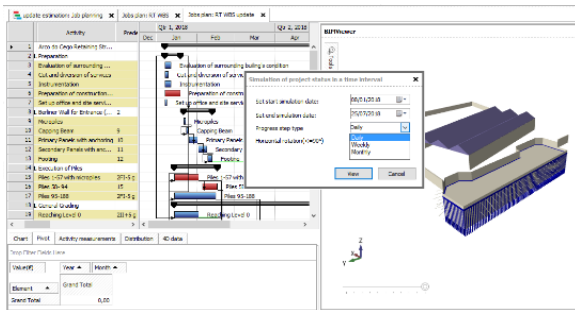


Figure 5. 4D model

Some of the advantages of the 4D-ready process are an improved team collaboration, improved control of logistics, acknowledge of the manpower allocation, sequencing of operations and facilitated re-scheduling, what reflects in an increased value of the proposals. It is also useful for other stakeholders in the project, for example, to show the project owner different options in the construction processes that can be adjusted according to eventual set-backs found during the construction, usual to happen in geotechnical works.

To create the 4D/BIM model, the construction plan was done based on the project documents available and using reference values for the activities' production. The Critical Path Method (CPM) was used and the main activities were

then assigned to the estimated production rates and the respective duration was determined. The critical path determined was composed by the execution of the piles, followed by the excavation and the execution of the capping beam and the distribution beams with the anchors at the different levels. The excavation must be coordinated with the execution of the piles, beams and corresponding anchors to avoid an excessive reduction of the soil's passive impulse and the risk of collapse of the retaining structure. The excavation should then be made just until the bottom level of the last beam executed. The excavation activity was broken-down in levels from 0 to -4. It was considered that the excavation could be done in a sloped shape in the direction of the center of the exasite. The first level of excavation and the execution of piles' activity had an end-to-end relationship. This means that, for the excavation to be done till the level -1, was necessary the execution of piles to be also completed. Besides, a lag was added to some activities to guarantee, for example, the hardening of the piles' concrete.

The standard IFC file of the 3D model was used by exporting it in Revit. The IFC file type recognized correctly the parameters attributed to the objects. After uploading the 3D/BIM model to the software, the scheduled activities were connected to the objects. To do this, the planning created in MS Project was also imported to by the STR Vision CPM software. When this step was completed, it was possible to generate a simulated animation of the construction process (figure 5).

### 3.2 Budget management based on a 5D/BIM model

With BIM technology, the information regarding the cost and suppliers can be linked to the 3D objects. The budget management and the cost evaluation are useful tools for contractors and designers. The quantities take-off capabilities can help avoiding mistakes, common in the traditional CAD 2D approach.

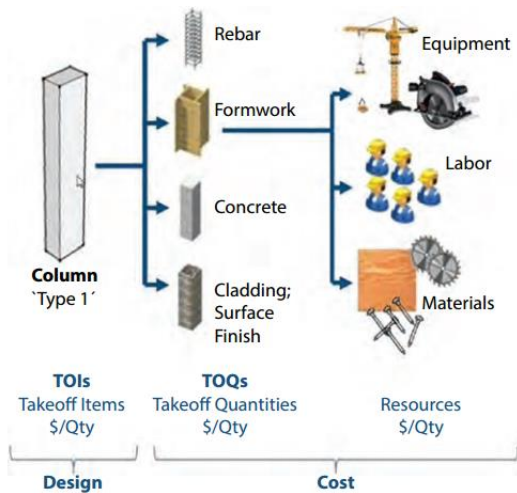


Figure 6. 5D/BIM data flow. Source: Vicosoft

### 3.2.1 Quantities measurement based on BIM

To create the 5D/BIM model, the resources that each parametric element needs to be executed should be first specified. Then, when this element is measured, all the materials, labor, equipment, time, and other relevant cost variables will be associated with it.

To make the quantity take-off, the procedure was the following: definition of different price categories; creation or import of the WBS; creation or import the items price lists; items analysis in terms of resources needed; measurement of quantities and creation of measuring rules.

When these steps are completed the measurements are done by selecting the 3D objects in the software visualizer and creating measurement rules that are saved for a future use. This can be particularly useful for an almost automatic quantities take-off. Also, if design changes happen – what is usually probable – the saved rules can be useful for a fast evaluation of the design changes impact in the global cost. The cost can be analyzed in customizable dashboards, for example, to relate the cost of each WBS. With the increase in the schedule detailing, the cost information will also be more accurate. To increase the detailing, it is necessary to reduce the length of the timeframe considered and associate the

parametric objects executed in this amount of time.

### 3.2.2 Procurement based on BIM

One available tool helps to facilitate the procurement and the evaluation of the supplier bids. By using the measurements done, a spreadsheet file can be exported with the prices for the supplier or the subcontractors to fill. After the file is filled in, it can be imported and associated to specific price categories for analysis of the best proposals. The price estimation can then be updated with the chosen proposal.

### 3.2.3 Cost analysis with design changes

Another useful tool is the capability to evaluate design changes in the 3D model and perform a budget comparison. This is done by using the previously set measuring rules. The two models are then displayed, showing the measurement differences between them. Then, a dashboard can be created to analyze impact of the changes in the budget (figure 7). This analysis can be performed by selecting different parameters to be the target of analysis such as the budget difference by WBS, by floor level, or by item.

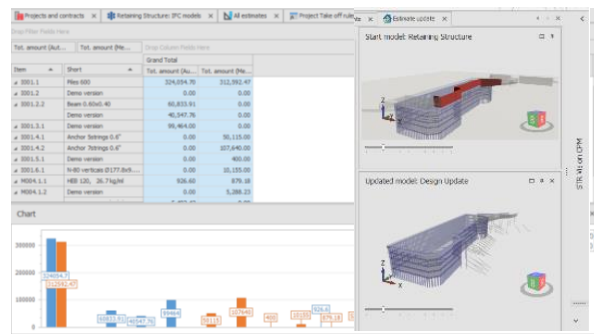


Figure 7. Design change cost analysis.

## 4 MAIN CONCLUSIONS

The purpose of this paper was to demonstrate how BIM methodology could be applied to a geotechnical project. To do so, a tri-dimensional model of a retaining wall structure was created

and then, it was used to explore the scheduling and construction management tools (Figure 8).



Figure 8. View of the final excavation works.

The interoperability was tested with interactions between different software platforms. Not always the interaction between different software was done smoothly. The exchange between Autodesk Revit model to the STR Vision CPM was done using the standard IFC file format. Some versions of IFC file type were not fully compatible, neither was found information regarding this topic from the software makers. Also, the connection between Revit and Robot needed some extra modeling time spend to adjust the analytical connections between objects. The creation of the analytical model by Revit seems to have a margin for improvement. Modeling needs some training experience to improve the models' quality and reduce the time required to complete the project's documentation. The drawings production through BIM had benefits when design changes were needed. Because the information is centralized, the changes in the 3D model are transmitted across the different drawings pieces. This advantage has a positive implication in the optimization of the engineering solutions, especially when project's delivery deadlines are short. The quantities take-off through BIM helped to verify and improve measurements done in the traditional way. The centralized

information gives a global overview for construction managers, that will reflect in a faster and more accurate decision-making.

Upstream changes in the project's design or downstream changes coming from product price changes could be quickly evaluated. With the data centralized in the BIM parametric elements, the information could be switched and updated, giving the project's manager an increased operational control. This allowed a consistent support for decision-making when analyzing multiple construction processes, design options or when evaluating the impact of price material changes.

The AEC industry can find in BIM, a route for its so needed increases in productivity because it is able to promote a leaner construction process, by reducing the reduplication of work and some traditional error-prone activities. By encouraging an early stage design collaboration, avoiding risks and increasing operational control over the whole project's lifecycle.

## 5 ACKNOWLEDGEMENTS

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