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The role of BIM in geotechnical engineering with application to deep excavations in urban areas

Le rôle du BIM dans l'ingénierie géotechnique et son application aux excavations profondes en milieu urbain

H. Popa
Technical University of Civil Engineering Bucharest, Geotechnical and Foundation Department, Romania

L. Batali, M. Berdigylyjow
Technical University of Civil Engineering Bucharest, Geotechnical and Foundation Department, Romania

ABSTRACT: Building Information Modelling (BIM) is becoming an increasingly important tool in civil engineering, both for design and construction process. If the use of BIM in superstructure projects is currently well implemented, for the infrastructure projects it remains fairy uncommon. However, infrastructure works are often involving the highest risks and also significant costs. Works such as deep excavations in urban areas are known from this point of view and their treatment in all phases (geotechnical study, design, field tests, execution and service) is a special one in order to reduce the associated risks of neighbouring buildings. All this lead to high costs which, in order to be reduced and to reach an optimal project, require a permanent and real-time evaluation of the behaviour of the construction in relation to those envisaged in the design. The need to know all the details of the project during the design, execution and behaviour in service by all involved stakeholders is obvious. The volume of data to be analysed and correlated is often very high and their treatment in short and due time very difficult. BIM offers the best opportunity to do so. The paper presents the role of BIM in geotechnical engineering projects with application to deep excavations in urban areas. Are presented some succesful case studies showing how BIM can be implemented in geotechnical design and monitoring and also a case study for emphasizing the need of a BIM-based approach for assessing and managing the risks of deep excavations on neighboring structures.

RÉSUMÉ: La modélisation des informations du bâtiment (BIM) devient un outil de plus en plus important en génie civil, tant pour les processus de conception, que pour celui de construction. Si l'utilisation du BIM dans les projets de superstructure est actuellement bien mise en œuvre, elle reste assez rare pour les projets d'infrastructure. Cependant, les travaux d'infrastructure sont souvent ceux qui impliquent les risques les plus élevés et des coûts importants. Les travaux tels que les fouilles profondes en zone urbaine sont connus de ce point de vue et leur traitement à toutes les phases (étude géotechnique, conception, tests sur le terrain, exécution et service) est un moyen particulier de réduire les risques associés aux bâtiments voisins. Tout cela entraîne des coûts élevés qui, pour être réduits et pour atteindre un projet optimal, nécessitent une évaluation permanente et en temps réel du comportement de la construction par rapport à ceux envisagés dans la conception. La nécessité de connaître tous les détails du projet lors de la conception, de l'exécution et du comportement en service de toutes les parties prenantes impliquées est évidente. Le volume de données à analyser et à corréler est souvent très important et leur traitement rapide et difficile à réaliser. BIM offre la meilleure opportunité de le faire. L'article présente le rôle du BIM dans les projets d'ingénierie géotechnique avec une application aux excavations profondes en zone urbaine. Sont présentées quelques études de cas de succès montrant comment BIM peut être implémentée dans la conception et le suivi géotechnique et aussi une étude de cas pour mettre en évidence la nécessité d'une approche basée sur BIM pour l'évaluation et la gestion des risques des fouilles profondes sur les constructions voisines.

Keywords: building information modelling; geotechnical engineering; deep excavations

1 INTRODUCTION

Retaining structures to support deep excavations are engineering works that are specific to urban constructions. They are also part of any urban infrastructure renewal program, useful for restoring urban networks and communication routes, building underground car parks and underpasses, deep basements etc.

Urban construction involves a number of features, such as:

- the proximity of existing buildings, in most cases old, vulnerable buildings, sometimes part of national patrimony;
- intensive use of space;
- difficult access and restricted workspace;
- the existence in the ground of the various utilities (gas pipelines, electricity and telephone networks, sewage etc.);
- the sensitivity of land and buildings to ground disturbance by excavation and lowering groundwater level;
- the effect of underground constructions on groundwater (Dimache et al., 2015).

With the economic development and urbanization, excavations go more and more deeply in the ground, often in difficult terrains. These conditions require advanced analyse methods, respectively, complex calculation models of the retaining structures, taking into account all the conditions of the site: the characteristics of the soil, the geometry of the retainig structure, the materials involved, the existence of neighboring constructions etc.

But, in order to be able to make the right decision regarding the optimal solution it is necessary that all this information be available in a format accessible quickly by all the stakeholders involved: client, designer, entrepreneur etc. This possibility is provided by the BIM – Building Information Modelling. At present, more and more engineering companies use it for large-scale projects. This allows to reduce the duplication of work and of the complexity of interface integration. Although, at present, BIM is particularly common to superstructures, it becomes more and more useful for the underground works as retaining structures for deep excavations in urban areas.

2 RISKS ASSOCIATED WITH DEEP EXCAVATIONS

The risk-generating factors associated with deep excavations in urban areas can be grouped as follows (Popa, 2009; NP 120-2014):

- *Site-related factors*. Construction sites may be located in built-up areas or in free construction areas. The sites located in built areas are distinguished by at least one of the following features: the presence of buildings and / or monuments nearby; the existence on site or in the immediate vicinity of underground networks (water, sewer, gas, district heating, electricity etc.); the proximity of urban roads; the presence of overloads in the neighborhood.
- *Geometric features of the deep excavation.* An irregular contour and large scale dimensions

of the excavation increase the complexity of the support system. As the depth of the excavation increases, not only the difficulties of carrying out the work, but also the risks for the work itself or for the neighboring constructions, increase.

- *Ground-related factors*. It is possible to distinguish in this case sources of risk generated by some geotechnical or hydrogeological particularities of the site, such as the presence of a heterogeneous stratification, with soil layers having unfavorable mechanical properties, the presence of a groundwater above the final excavation level, the presence of a confined aquifer below the final excavation level etc. Another group of sources of risk generated by the ground is related to a limited number of investigation points and a relatively small number of samples tested in laboratory.
- *Design of the deep excavation*. Even when site conditions are well known and designer is an experienced one, using accepted methods in current design practice, it must be recognized that the precision of geotechnical calculations is limited. It is therefore necessary to apply a design strategy that eliminates this risk source by adopting appropriate safety coefficients.
- *Execution of the deep excavation*. Irrespective of the adopted solution, deep excavations are special works. Each of the components of such a work brings, through the used technology and materials, its own sources of risk. To these are added those brought by antrepreneurs lacking of similar experience in similar field conditions, or without a suitable equipment for the requirements of the work etc.
- *Earthquake action*. In the event of an earthquake during the existence of the deep excavation, both the retaining structure and the constructions or installations in its area of influence will be affected.
- *Time of excavation exposure over the design one*. A deep excavation in urban area is designed for a limited lifetime, having a temporary character. If the exposure duration exceeds the provisions of the project, measures shall be taken to monitor and secure it.

In general, the protection of neighboring buildings from the risks of deep excavations can be divided into three stages (Chang, 2006):

- pre-excavation analysis;
- monitoring and prevention during excavation;
- compensation after damages.

In order to mitigate all these risks associated with deep excavations it is necessary to know and continuously monitor the project in all phases: geotechnical study, design, execution and service. Also, the final work will become a neighborhood for other future works, thus influencing them. For all this information to be united and available in a unitary way, a complex digital instrument is needed and this is provided by BIM.

3 BIM CONCEPT

Builing Information Modelling (BIM) is a technology, rather than a specific program, that offers an integrated platform to improve design, increase delivery speed for design and construction and ensure the flow of information without interruption.

Although the roots of BIM can be find back to the parametric modelling research in 1980s, the Architecture – Engineering - Construction (AEC) industry practically started to implement it in projects from the mid 2000s (Azhar et al., 2012).

The National Building Information Modelling Standards (NBIMS) committee of USA defines BIM as follows: “BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" (NBIMS, 2010).

In Europe, EUBIM TaskGroup defines BIM as follows: "BIM is digitalization for the construction sector. From a public stakeholder perspective, BIM can provide significat efficiency benefits to public works, to public value for money and be a driver for growth and competitiveness" (EUBIM TaskGroup, 2017).

From a technical point of view, BIM is a 3D modelling of a project with links to all information related to its components. The major difference from the traditional method is that the latter describes the construction through independent plans. Changing one of the plans requires checking and modifying other related plans, which can lead to errors and management difficulties. In BIM all objects are defined in terms of building elements and systems with all information related, including the physical or functional characteristics (Azhar et al., 2012).

BIM represents a virtual model, allowing all team members (owners, architects, engineers, contractors, suppliers) to colaborate accurately and efficiently. Table 1 provides the BIM applications for stakeholders (Azhar et al., 2012).

Table 1. BIM Applications (Azhar et al., 2012)

BIM application	Owners	Designers	Constructors	Facility managers
Visualization	x	x	x	x
Options analysis	x	x	x	
Sustainability analyses	x	x		
Quantitiey Survey		x	x	
Cost Estimation	x	x	x	
Site Logistics	x		x	
Phasing snd 4D scheduling		x	x	
Constructability analysis		x	x	
Building performance analysis	x	x	x	x
Building management	x			x

The benefits for the owners can be summarised as follows: early design assesement to verify the requirements, possibility to evaluate building performance and maintainability, low financial risk because of reliable cost estimates, better marketing of the project due to the 3D visualisations, complete information in a single file. The benefits for the project designers, constructors and facility managers can be also easily identified from Table 1.

4 BIM APPLICATION AT DEEP EXCAVATIONS – CASE STUDIES

Although BIM is currently more and more widespread in the design and execution of complex structures, this is relatively uncommon for geotechnical structures such as deep excavations. However, as seen in chapter 2 of the paper, the risks associated with these works are important and their management is essential. Thus, the use of BIM for these types of works is becoming more and more common due to the benefits of mitigation and controlling the risks involved. In the recent literature there are already some reported case studies, some being briefly described here after.

4.1 Case study 1

A BIM-based monitoring system can be used for a rapid interpretation of data in order to take decisions, to plan interventions etc.

The efficiency of such system was proved for the excavation of the O6 Station for the Kaoshiung metro, Taiwan, (Wu et al., 2015). The excavation was constructed by cut-and-cover method, in a crowded urban area, the maximum excavation depth being of 19.6 m. The pit was retained by a 1 m thick and 36 m deep diaphragm wall. In such a complex environment, a construction project team must pay greater attention to the environmental impacts during a deep excavation project. Individual analysis of monitoring results is difficult and inefficient. Therefore, all monitoring data was collected and stored into a database and visualised based on BIM system. In the system were implemented functions of risk assessment to automatically facilitate reading and discriminating, resulting in time and errors reduction in the risk assessment process. Another benefit is the speed of communication between the teams of engineers involved in the construction. An overview of the 3D model is shown Figure 1.

The system was implemented based on commercial hardware and software comprising the Bentley AECOsim Building Designer, which supports visualization of a 3D model with some capabilities for 3D object manipulation and information query with Application Programming Interfaces (API) for functionality extensions.

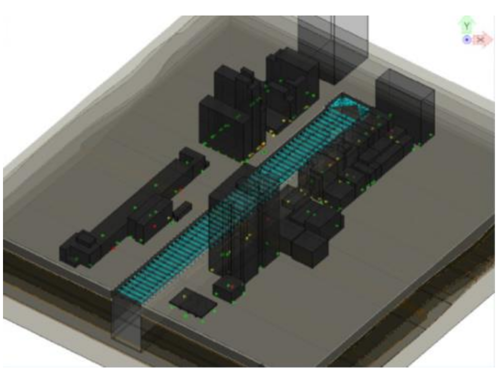

Figure 1. 3D model (Wu et al., 2015)

4.2 Case study 2

Tanaka et al. (2017) illustrated how BIM can be used to aid geotechnical engineers to plan and design for temporary works like a deep excavation in urban area.

The construction was approximately 125 m by 50 m wide and 19 m deep and consists of 61-storey tower with 15-storey podium and 4-storey car park basement. The focus was on the deep excavation design at the podium area where there were two complex sets of ramps. A BIM – Revit model was built to understand the complex geometry of the permanent structure before designing the scheme of temporary lateral support system. Finally an irregular strutting arrangement was proposed which had benefit of an independent relationship between the strutting removal stages and casting of the permanent lateral supports scheme as shown in Figure 2.

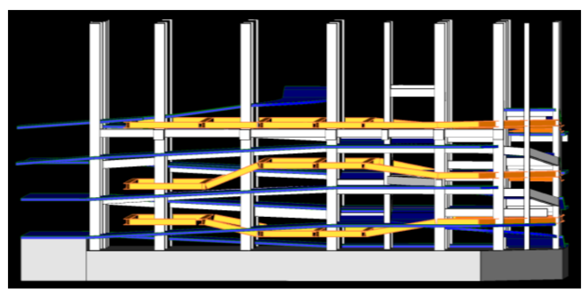

Figure 2. BIM model of strutting arrangement (Tanaka et al., 2017)

4.3 Case study 3

Gondar et al. (2018) presented the BIM implementation for a deep excavation for the Infinity Tower in Lisbon. The excavation depth in this case varied from 17.60 m to 6.25 m.

The conceived solution was a Bored Piled Wall (BPW) with 600 mm diameter piles spaced from 0.80 m and 1.20 m. The piles length range from 21.60 m to 10.30 m,. The BPW was braced, at each floor level, by reinforced concrete slab bands and temporary ground anchors.

The architecture project geometry was performed in a 3D BIM model. The existing topography was designed in the BIM software, and the architectural model was linked to the file and the geographic position of the surface was coordinated with the architecture model and the existing lot boundary. The solution was then tested using a numerical analysis software. The geometry from the BIM model and the loads from the numerical modelling were then exported to a structural analysis software. The retaining solution was then adjusted according to the results obtained (Figure 3).

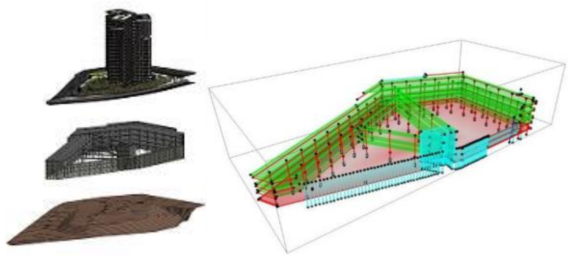

Figure 3. 3D Architecture and the retaining BIM model (Gondar et al., 2018)

5 BIM IN ROMANIA

In Romania large infrastructure works are required for transportation (highways, bridges, tunnels), as well as works in urban areas implying large-sized underground works (parkings, deep basements, metro tunnels etc.). The necessity of implementing a BIM strategy is obvious, but there is no national program for this goal, therefore use of BIM is still rare. Only some large design companies are implementing BIM in structural design, but there is no application yet in geotechnical engineering.

Even if the preoccupations related to the influence of underground works on neighboring buildings led to a full monitoring of deep excavations in all phases, this is done in a classical manner, with separate documents, the designer being required to correlate them all (Ene et al, 2015).

However, recent works proved once more the utility of a BIM-type approach, as for example the following case study.

At present a building with 4-storey basement and 11 above ground storeys is in construction in Bucharest. The area in which the building is to be built is in development and around are several other buildings, also, in construction, generally with 2 – storey basement (figure 4). Building 1 has a 2-storey basement + groundfloor + (5 – 9) above-ground storeys and it is located at 24 m away from the new excavation. Buildings 2 and 3 have 2-storey basement + groundfloor + (8-12) above-ground storeys and are located at 6.85 – 23 m from the new excavation.

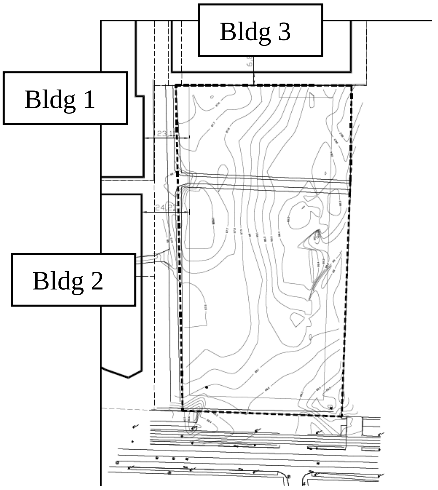

Figure 4. Neighboring buildings

The lithology of the site is characterised by an alternance of coehesive and granular layers, the granular ones being also aquifers. The 4-storey basement requires a deep excavation of approx. 16 m depth, the excavation level being at the upper level of the second aquifer, which is a confined one. The retaining solution was a diaphragm wall of 18 – 28 m deep. As a consequence, dewatering works are required for a complete dewatering of the first aquifer and a draw-down of the second, confined, aquifer.

The first aquifer could be completely closed by the diaphragm walls, but not the second one, which leads to an influence of the dewatering works outside of the excavation. The owners of the neighboring buildings have, thus, asked for a study showing the influence of the dewatering on their properties. This was an relatively difficult task as lacking of a 3D image containg both the geotechnical data and the neighboring structures with their basement and corresponding embedded walls.

Calculations have been performed in two stages:

- *Stage 1*: determining the groundwater depression curves by 3D modelling using USGS MODFLOW. The hydrogeological model is extended over a 7 km^2 surface (Figure 5). The hydro-dynamic spectrum showing the influence of the dewatering works is presented Figure 6.
- *Stage 2*: Finite Element modelling (Plaxis) of the influence of dewatering on the neighoring buildings. Figure 7 is showing the induced settlements in one of the sections.

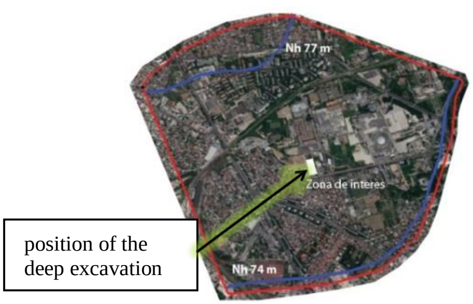

Figure 5. Hydrogeological model and boundary conditions

This study has been difficult and time consuming as each involved designer had to built its own model and there was no common virtual model. A BIM-based design could have facilitate this process and all stakeholders would have had access to all data allowing to assess the risk for the neighboring buildings. Such situations are more and more encountered in large urban areas and BIM is the only solution at present to manage all the interactions that can appear in the underground.

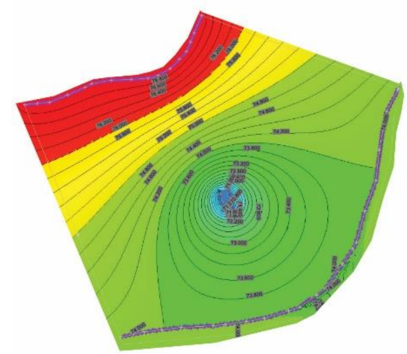

Figure 6. Hydro-dynamic spectrum with the influence of dewatering

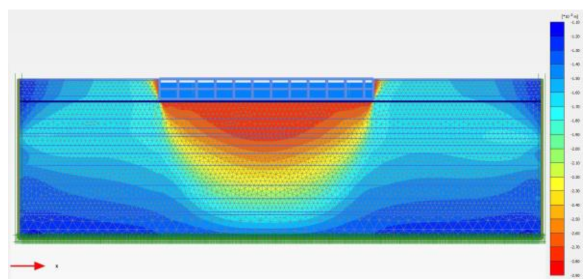

Figure 7. Settlements due to dewatering

6 CONCLUSIONS

BIM represents at present a solution to manage large construction projects which is more and more used. Using BIM leads to ease and rapidity in exchanging information between the stakeholders, leding finally to important cost savings. However, although the urban infrastructure projects requiring deep excavations are implying in most of the cases associated risks on the vicinities, this is especially the type of projects where BIM is not currently used.

Paper presents the risks associated with deep excavations and the possibilities that BIM offers for mitigate them. Are illustrated some cases of succesful applications of BIM and also is dscribed the actual stage of BIM implementation in Romania. A case study from Romania is presented, showing that in absence of a BIM-based approach the detailed analysis of the interaction between new and old structures or between the underground structures and the groundwater is difficult and time consuming. Also the risks are higher in this case as the various stakeholders cannot have access to all data and therefore, the analysis is sometimes not accurate.

7 ACKNOWLEDGEMENTS

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