Application Status and Analysis of BIM in Pit Engineering

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Abstract. BIM has developed rapidly in recent years, but there are still problems in the field of pit engineering, such as lack of standards, missing data, and incompatibility of software. The keyword co-occur net and the publication status from CNKI and web of science are overviewed, and the application cases of design, construction and monitoring phases are analysed. Then some typical problems are summarized, such as the difficulty in establishing the interfaces between BIM and FEM software, low utilization in a project and the BIM platform problem. And suggestions for the development in pit engineering are introduced, including formulating standards and codes, developing localization geotechnical BIM software and further research on BIM/FEM integration.

1. Introduction

In recent years, the pit engineering has developed rapidly, and the design and construction level of it in China has been greatly improved, but there is still a problem of high accident rate. As pit engineering is systematic and comprehensive [1], using advanced construction and management techniques to optimize design, improve construction efficiency, reduce construction risks and costs is an important developing direction. Based on the traditional three-dimensional geometric model, BIM builds the information model throughout the full life cycle of a construction project, and supports the exchange, sharing and management of information to realize the Building Lifecycle Management [2], which has been widely used in the field of architectural engineering. Though has been applied in many tunnel projects [3-5], BIM started late in pit engineering, and there are problems such as lack of standards, missing data, and incompatibility of software [6-8].

Pits are temporary structure with small safety storage coefficient and there is no operation or maintenance phase involved, where differ from tunnels. As simply relying on theory and experience can not fully ensure construction safety, monitoring is critical. For the above characteristics of pit engineering, it is especially important to introduce BIM in its design, construction, monitoring and management phases. The work done by all units with BIM is shown in Figure 1. When considering the impact of a pit on its surroundings and the layout of construction site or support structure, the advantages of BIM in visualization and simulation can be given full play to optimize the site layout or enclosure design and inspect collision. Establishing the interface between BIM software and geotechnical FEM software enable rapidly modelling and import data, making it easy to view numerical results. The use of BIM also allows all units to timely grasp the latest and more intuitive...
information in the monitoring phase, not just data, but also images or videos. Safety/risk assessment, quality inspection and progress control can also be carried out with these information and BIM models, which is convenient for constructors to timely discover and respond to quality problems.

Based on the importance and problems in the application of BIM in pit engineering, the literatures related to pit engineering and BIM are summarized, the typical application cases are analysed, the existing problems are summarized and suggestions are given, which can provide reference for future research and development.

2. Literature Review

2.1. Literature sources
This paper takes CNKI as the retrieval source of Chinese literatures and searches for related literatures before 2020 with Chinese keywords such as “pit engineering” and “BIM”, and uses Metrological Visualization Analysis Platform of CNKI to analyse the cases and keywords. Taking the Web of science core library as the retrieval source of English literatures.

Figure 1. The work done by all units in a BIM-based pit.

Figure 2. Publication of papers on BIM and pit engineering in China
2.2. Statistical overview of BIM in pit engineering

The CNKI’s index analysis of publications, citations and references of literatures related to BIM and pit engineering are shown in Figure 2. It shows that the relative literatures did not appear until 2012 and their references can be traced back to 1998, indicating that the applications of BIM in pit engineering started late. Since 2015, the number of relative literatures increased dramatically and reached a record high in 2018. At the same time, the number of citations to them has increased rapidly. This shows that although relative research and applications started late, more and more of them focus on the topics with the rapid development. However, pertinent English papers are relatively few in number recently [9-12] and a lack of review papers in English. Therefore, go further study on the field of BIM in pit engineering, combine new techniques to solve or improve the existing problems, and realize high-quality, high-level and high international impact applications, is an important goal of the development of China in this field.

The keywords co-occur net is shown in Figure 3. It indicates that “deep pit” is the most relevant keyword with “BIM”, which is considered that most of the current research and applications are concentrated on high difficult deep pits. Deep pits attach great importance to the monitoring, so BIM-based monitoring is very consistent with the characteristics and development direction. The keyword co-occur net also shows that the research pays more attention to construction phase including simulation and management. There are few relatively research on design phase, however its development needs to combine with the superiority of BIM. Therefore, it is necessary to strengthen the applied research of BIM in the full-phase of pit engineering.

3. Applications of BIM in excavation engineering

3.1. Application cases

According to the results of literature analysis, the typical application cases of BIM in each phases of projects in recent years are listed, and the features, results and problems of each are summarized, and the results are shown in the table 1.
3.2. Applied analysis

Table 1 indicates that the most BIM-based projects focus on construction phase, this is because majority of deep and large pits that face the problems of complex surroundings, shortage of land and complicated technology are located in cities. Therefore, BIM is suitable for site layout optimization.
and complex technical clarification. And due to the importance of deep pit monitoring, researches on safety/risk assessment, automatic monitoring and visual early warning have become the focus in recent years in order to give full play to the characteristics of BIM visualization and integration. In addition, BIM-based advanced technologies such as UAV and 3D laser scanning have also been applied in progress control and quality inspection in some projects. Similar to general buildings and tunnels, BIM is mainly used for three-dimensional modelling, drawing output, collision inspection and engineering quantity statistics in design phase.

There are two current obstacles to the promotion and application of BIM in pit engineering, namely technical obstacles and poor awareness. Technically, the BIM models lack stratum data, construction data, and monitoring data. Structural models are only considered in traditional BIM models and strata models that is essential for underground engineering such as pits are ignored. The pattern of enclosure, construction methods and process have a great impact on the safety, cost and construction period of projects, thus it is hard to ensure safety by BIM models with no construction data or monitoring data. The reason for the lack is the obstacles to the information exchange and sharing between different software. Different units use different types of software to accomplish the task. The units include investigation units, design units, construction units and supervising units, and the corresponding responsible information are investigation data, design parameters and data for mechanical analysis, construction data and monitoring data. At this stage, it is a challenging thing to integrate these into one BIM model. Poor awareness means that BIM has not been widely accepted in this field. BIM has been applied just in some highly difficult or representative pits and many of them even not in forward design, and the modelling work is based on CAD drawings, which betrays BIM's original idea.

4. Problems and suggestions for BIM in pit engineering

Combined with literatures, analysis of typical cases, the problems and suggestions are summarized as follows.

4.1. Problems

Lack of standards and codes. Existing IFC standards and the researches based on IFC standards are mostly focused on architectural engineering, while few focuses on underground engineering [22], and even fewer focus on extending IFC entities of enclosure structure of pits [23]. In addition, China's BIM standards or codes in this field have not been involved yet.

Incompatibility of BIM software and platform. Most BIM platforms are based on Revit, an American software. Its Chinese version still has differences and defects in localized samples, national and local codes and common family. Moreover, its models are more applicable for general buildings, but for underground engineering such as pits lack stratum data. The difficulty now is to simulate excavation directly on the stratum model. In terms of monitoring and risk assessment, there are problems such as disunified platform, low visualization level and only colour expression of early warning result [24].

Low level of BIM/FEM integration. BIM models have realized the model transformation interface on some structural analysis software. However, for accurate analysis on some complex structure of deep and large pits, they still need to be rebuilt by commercial FEM software. Thus, the numerical results can only be viewed in those software and cannot be associated with BIM models, resulting in the difficulties of data management and low integration.

In addition, BIM technology has been applied in the design, construction and monitoring of deep and large pits, but not throughout the whole life cycle. And BIM models are even built according to CAD drawings, which makes it difficult to give full play to the advantages of BIM.

4.2. Suggestions

The standards, codes of BIM for pit engineering should be established and expanded. The foundation of realizing collaborative work with BIM is the unified data standards. Therefore, information expression and modelling methods related to pit engineering in IFC should be further expanded to facilitate modelling in BIM software. At the same time, China should improve the data fusion standard of BIM software as soon as possible, so that BIM can be widely applied in this field.
By integrating stratum model and structural model in one BIM software and directly simulating excavation process in the stratum model, model transformation process between different software will be saved and various errors will be avoided. Therefore, integrating these models in BIM is worth studying and developing. While the monitoring technology and safety/risk assessment based on BIM should continue to develop to improve the visualization effect of graded warning and deformation of enclosure structure.

Integrating the whole process data in BIM can realize the closed-loop delivery and unit integration, also improve work efficiency and project benefit, as shown in Figure 4. Therefore, it is necessary to carry out the study on dynamic association and seamless integration of pits between BIM model and whole process data, so as to realize continuous optimization of the construction scheme.

![Diagram](image)

Figure 4. The work done by all parties in a BIM-based excavation project.

Automatic integration capabilities of BIM software and FEM software should be promoted in order to get calculation and analysis data quickly; take the basic BIM model as a information carrier and manage the data of investigation, construction, monitoring and analysis by integrated BIM/FEM platform will effectively guarantee the quality, safety, economy and other indicators of complex pit construction and then realize the optimal benefits.

BIM brings a new development mode called IPD (Integrated Product Development) for the construction industry and breaks the tradition in the meantime. It lays emphasis on information synchronization and the benefits of multi-party cooperation and is according more with the characteristics of BIM [25]. Therefore, it is also necessary to strengthen the BIM awareness of the design units, construction units, monitoring units and owners, then promote the applications in pit engineering during the design, construction, monitoring and delivery phases.

5. Concluding remarks

This paper aimed to summarize and analyse the research and applications of BIM in pit engineering. The publications of relative literatures and keywords co-occur net are introduced, and the recent typical applications in design, construction and monitoring phases are analysed. Base on the literature review and cases analysis, the problems such as lack of standards and codes, low level of BIM/FEM integration, incompatibility of BIM software and platform problems. Correspondingly, suggestions are given for improving the standards, promoting the establishment of localization geotechnical BIM software for China and BIM/FEM integration platform.

As mentioned above, to combine the characteristics of pit engineering with the advantages of BIM will bring good news to the design, construction and monitoring phase. The rise of underground engineering has led to the development of BIM in this field in recent years, which also brings great challenges. Therefore, the application trend of BIM in pit engineering should be followed to make itself go towards digitization and informatization.

6. References

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