# Problems of using BIM in Variant Design of Reconstruction Processes in Underground Parts of Buildings and Structures Using Universal Machines

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***Abstract:*** Building information modeling (BIM) is quickly transforming the construction sector, with significant improvements in project results. In recent years, as the construction industry has shifted from new building construction to building maintenance and usage, the need for BIM has increased. The life cycle of a building can be divided into several periods, the largest of which are the stages of design, construction, operation, and demolition of the building. The process of building information modeling mainly affects the building design and construction stages, minimally affecting the stages of operation and demolition. This is influenced by a number of factors, such as the low level of development of regulatory literature, or the lack of a modern technical base for the implementation of measures for the operation of the building using information models. As the development and use of BIM in new construction projects becomes more common, the construction industry begins to worry about and discuss the implementation of digital and intelligent management by creating As-is BIM for existing buildings and using BIM in the operation, maintenance, and building renovation or demolition phases. Processes of reconstructing underground parts of buildings and structures cause special challenges. This article summarizes the existing practices and concerns in this field, outlining vectors for further research and efforts.

Keywords: BIM, underground construction, restructuring, repair, operation, project integration, prefabricated construction

## 1. Introduction

Building Information Model (BIM) technology has already seen widespread usage in the realm of architecture, although it is rarely applied in subterranean construction. Meanwhile, the design, construction, and operation of underground structures is a complex task for all participants in the life cycle of the facility. Such projects involve a huge number of issues related to both planning, coordinating the project with the existing infrastructure, and solving local technical problems.

At the same time, the current construction conditions in large cities are such that the most intensive construction work is carried out in the central part of populated areas. A distinctive feature of modern urban construction is the desire to develop underground space. In recent years, most large cities in the world have seen an increased interest in the widespread use of underground space. This is due to increased urbanization, the rapid development of ground transport, a shortage of urban space, and a number of other reasons. A new direction has emerged in urban planning - underground urbanism (Ovenden, 2020). Underground space is also attractive for shopping and entertainment complexes. The largest of these facilities is located in Toronto (Canada). Underground streets under the business part of Toronto connect 27 km of shopping alleys, five subway stations, parking lots, department stores, hotels, and a railway terminal. The total development area is about 370 thousand m$^2$ (Reynolds, 2019). World experience shows that for comfortable living in a metropolis, it is necessary to develop not only the appearance of the city. The volume of underground space input should account for 20–25% of the total construction (Shirowzhan & Zhang, 2020).

Meanwhile, the main problems of developing the underground space of cities, first of all, include the following (Shirowzhan & Zhang, 2020; Pankratova et al., 2024):

– The need to ensure the preservation of existing buildings (in other words, the geotechnician must assess its additional deformations, which is problematic to solve within the framework of strict engineering methods);

– The need to preserve existing ecological systems;

– The condition of minimal intervention in the geoecological environment.

Technical problems of constructing underground structures are mainly due to the need to create and subsequently operate the internal space. The presence of such internal voids causes the effect of one-sided horizontal soil pressure, which requires sufficient strength of the walls of underground structures. Due to the high groundwater level and the possibility of its change, the geotechnician must ensure both the watertightness of enclosing structures and bottom, and the stability of the structure from floating up (after all, the bottom is subject to hydrostatic pressure of water). When constructing underground structures in open deep (usually at a depth of more than 4-5 m) pits, it is necessary, on the one hand, to ensure the stability of their walls, and on the other hand, uneven loosening of the soil of the pit bottom is possible due to its greater rise in the central part. This phenomenon accordingly causes large settlements of the foundation base in the middle part of the structure (Khoo & Ooi, 2023). One of the most difficult problems is namely the reconstruction and repair of the underground parts of such structures.

Deficiencies in the subsurface components of buildings and structures might be caused by poor design or construction, or by unanticipated or changing geologic conditions in the earth underneath the structure. Another major cause for repairs is that many structures have outlived their planned life expectancy, and hence the construction components are decaying (Yin et al., 2020). Because the reasons of deterioration vary, the technique of restoration may differ from instance to case. The severity of the degradation and the structural significance of the defect are two factors that influence the repair approach. The cause of the flaw should be identified before any repair work is performed; otherwise, the same problem may occur again.

Specific obstacles develop in the procedures of reconstruction of underground portions of buildings and structures, particularly when employing universal machines (typically, these machines include piercing tools, vibratory plows, underground utility vehicles, tunneling equipment, load and haul equipment, dewatering systems and shotcrete solutions and others). In comparison to above-ground knowledge, the information accessible on this habitat is limited. This study suggests BIM for subsurface applications as a solution to this information gap.

A key issue is that the information accessible about this environment is somewhat limited in comparison to above-ground information. BIM for subsurface applications is increasingly seen as a solution to this information gap. The production and ongoing update of BIM for a manufactured object guarantees that structural data is available and used throughout its lifetime. A BIM for subterranean applications combines data about surface structures, such as buildings, and subsurface infrastructures, such as pipelines, with information on the surrounding ground, soil and rock qualities, and groundwater regime into a unified framework.

## 2. Method

In the process of the research, methods of system analysis and content analysis were applied. Based on the preliminary selection of sources using keyword search, based on the tools of grounded theory, a sample of sources was formed for inclusion in the study. The main provisions of the theory of CAD construction, the theory of building information modeling (BIM), provisions of methods of integrating software products and information systems, specifics of theories and methodologies of project management were used for the study.

## 3. Results and Discussion

As previously said, BIM methodology has recently transformed the architectural, engineering, and construction professions (Akintola et al, 2020). BIM is a collaborative working process for developing and managing construction projects, with the primary goal of centralizing all important project information in a digital information model developed by all stakeholders.

There is little question that BIM is gradually revolutionizing construction and civil engineering projects above ground, while its present applications are mostly for visualizing projects in 3D and identifying collisions between disciplines (Liz et al., 2018). However, its use in underground construction projects is still limited (Li et al., 2021; Geng & Vojtasik, 2018), and it is precisely in these types of projects with high investment, technical complexity, and a high cost in the event of an error that this collaborative work methodology can be most effectively applied.

In recent years, the literature has included references to conceptual frameworks based on the BIM approach for improving the administration of subterranean projects utilizing the drill-and-blast method (Sharafat et al., 2021). In the execution of the Arnotegi tunnel, documented in the study of Baraibar et al. (2022), it was possible to contribute to this leap in the integration of the BIM approach, where it was able to exhibit its full potential, both as an instrument and as a process. The site of the construction is in the municipality of Bilbao, Spain. The Arnotegi tunnel is a two-lane tunnel, with one tube for each direction of traffic. The tunnel in the mine corresponding to the roadway in the Cantabria direction (Axis 1) is 1727 m long, whilst the tunnel in the mine dug for the carriageway in the Donostia direction (Axis 2) is 1722 m. From a geological standpoint, the Arnotegi tunnel passes through Cretaceous stony terrain composed of siltstone with sandstone floors and no substantial water inflow. The tunnel was dug using drill-and-blast methods, with the exception of gallery junctions, which were excavated mechanically. Five forms of support were constructed based on the geotechnical properties of the excavated materials, with varying proportions of bolts, shotcrete, and iron trusses. Appendix 9 of the contract's specific technical specifications listed the implementation of the BIM methodology as a contractual service, which is defined as the preparation and development of coordinated and collaborative databases and information models with the goal of improving information integration and coherence throughout the asset's lifecycle. In order to facilitate coordination with subsequent contracts and subsequent infrastructure operation and maintenance tasks, the primary contractual requirement was to deliver a BIM model of the Arnotegi tunnel at the end of the infrastructure works. This model had to include all pertinent tunnel construction elements, including both graphic and non-graphic information (Figure 1).

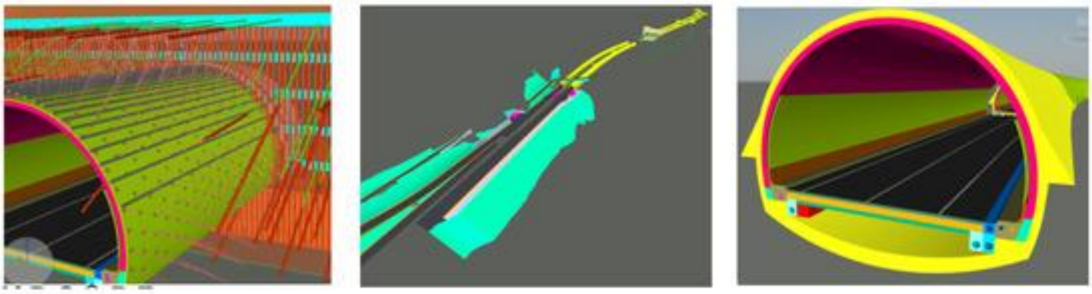

Fig. 1. BIM methodology focused on the complete life cycle of the infrastructure: model view with geotechnical information (left); general model view (canter); model view for checking interference in facilities (right) (Baraibar et al., 2022)

The planned BIM applications for the Arnotegi tunnel project's development and the operating phase that follows are listed in Table 1 in order of priority.

Table 1. Intended BIM uses in the Arnotegi Tunnel (Baraibar et al., 2022)

| No. | Priority | Description of the Objective-BIM Value Added | Expected BIM Use |
|---|---|---|---|
| 1 | High | Modeling of the present ground surface and the facilities placed in the target area | 3D Modelling Basis |
| 2 | High | Having an early digital model of the expected work serves as help for initial decision-making and as a reference for work control and monitoring | 3D model for comparison |
| 3 | High | Design and integration of models with other disciplines, contracts, and 3D coordination | Visualization, 3D coordination, integrating disciplines, and review |
| 4 | High | Obtaining and properly managing documents such as drawings, views, and three-dimensional photographs, renderings, tables, films, and so on. | Obtaining and managing documents |

| | | | |
|---|---|---|---|
| 5 | High | Coordination and communication among the agents involved ensures that the model housed in the CDE (common data environment) is continually updated through consecutive graphic adjustments and documentation contributions | Integrated collaborative management |
| 6 | High | Creating an integrated "as-built" model based on excavation phases that includes the tunnel’s actual shape and all of its components, enabling for data collecting. All paperwork created throughout the design and construction phases must be included. This model must include integrated graphical and non-graphical information on the completed works created during the project phases. | Integrated document management and work monitoring |
| 7 | Medium | General oversight of the entire strategy | 4D planning |
| 8 | Medium | The information required to provide traceability of the bill of quantities breakdown must be included in the objects in the models | A bill of quantities |
| 9 | Medium | Creating a digital reality model with huge kinematic capture | Future integration in operator manager |

To achieve the purposes outlined in the table above, three primary BIM models were created: an initial model, an updated model, and a follow-up model that was updated on a regular basis during the project. The first model, which was based on the promoter’s two-dimensional project, was primarily used for a 3D design, interference identification (Figure 2), and collaborative study of potential solutions to these interferences during model-based meetings.

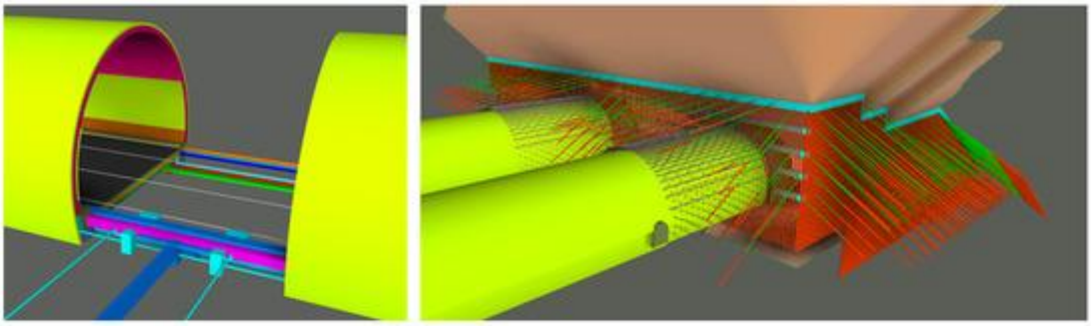

Fig. 2 - Critical areas in the initial model for interference detection (Baraibar et al., 2022)

The second phase saw the development of an updated BIM model (Figure 3), which was primarily used for 4D planning, coordinating the 3D design with the remaining project lots and across disciplines, and serving as a reference base for the construction process by incorporating the resolution of all the discrepancies found in the original model.

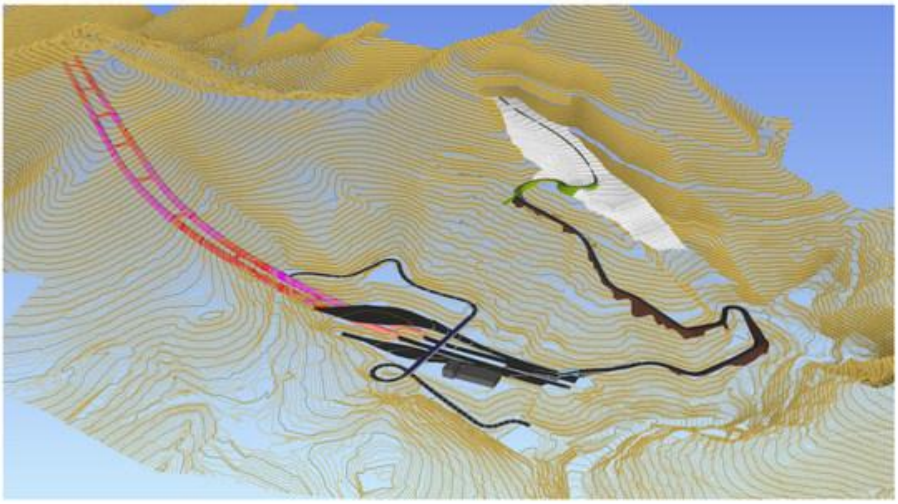

Fig. 3. Updated model of the Arnotegi tunnel and landfill site (Baraibar et al., 2022)

Lastly, incremental as-built modeling was done in accordance with the actual progress while the job was being done. Its geometric control (tolerances in each tunnel advance step and section entry), integration of new control geometries (sensors and other auscultation devices), and even assistance in the analysis of alternatives to special treatment solutions for the tunnel were the primary uses of this follow-up model. Over the course of the project, the follow-up model was updated 126 times per week. Furthermore, an intelligible visualization of the condition of the revegetation in each location has been made possible by the thorough monitoring of the sowings and the landfill site’s development.

As correctly noted by Chapman et al. (2019), there is a wealth of data and information about above-ground structures and infrastructures. For instance, to keep an eye on such buildings and environmental conditions, wireless sensors can be attached and visual inspections can be performed. However, there is a dearth of data and knowledge on subterranean environments, such as geology, ground water, and existing buried infrastructure, such as pipelines (kind, location, and condition). Future planning inside urban subterranean area as well as building efforts to maintain, repair, upgrade, and install new buried infrastructure may be significantly impacted by this lack of knowledge. Furthermore, the subterranean environment is frequently chaotic in character. Additionally, underground infrastructure's routes and state are typically invisible. The historical absence of planning and regulation of the use of subterranean space is the cause of these findings (Hou et al., 2016).

Compared to conventional open cut (or trenched) excavations, trenchless techniques like pipe jacking, microtunnelling, and horizontal directional drilling (HDD) have several benefits. Reduced traffic jams, less of an effect on the neighborhood, and less harm to the nearby infrastructure are among the benefits. However, the absence of trustworthy knowledge on subterranean features, including the location of buried services or ground conditions, might raise hazards (Dong et al., 2015). To reduce these hazards, it would be beneficial to have access to 3D models that include data from the ground and its contents. Providakis and associates (2019). In this regard, the quality of the data and the way it may be used and presented are important features of these models.

Research indicates that combining above-ground data with information on subterranean infrastructure and ground conditions yields a valuable tool (Jaw, 2014). Projects involving trenchless construction or maintenance can benefit from this technology. Additionally, it can increase the sustainability and durability of both surface and subsurface transportation systems while lowering risks—possibly to less than those associated with open cut operations. Scholars have suggested BIM for subsurface applications in order to accomplish these objectives (Leite, 2019; Khandelwal et al., 2025).

These days, a lot of new construction has an as-built model that includes all of the structural and construction details. Unfortunately, the majority of BIMs do not include any details on the underground infrastructure or subsurface ground conditions around the building. Thus, improved planning and engineering risk evaluations would be possible with a BIM for subterranean applications (referred to in the literature as “BIM for the Underground” (Smith, 2023), that includes data on both above- and below-ground infrastructure.

A 3D picture of all surface and subsurface physical infrastructure may be produced by incorporating the buried infrastructure data from mapping surveys into the building models. However, geological and underlying conditions must also be included in the model in order to provide a more comprehensive BIM that incorporates information from below ground. Ground studies of the location and its surroundings can yield this geological data. A 3D geological model may be created using borehole data. The final model, however, is frequently created by seasoned geologists and geotechnical engineers (i.e., their experience, opinion, and judgment are inherently embedded to the information) because 3D geological models are an interpretation of the discrete location information (Wang & Xiong, 2021). Therefore, it's critical to comprehend this aspect of the model and avoid taking it at face value.

Once the information has been included into the BIM for the Underground system, the data may be used more dynamically, i.e. exported to other packages or custom software (such as SketchUp software) for specialized analysis. The augmented data (or interpreted information) is then sent to the BIM environment (using SketchUp software) for viewing and future usage (Providakis et al., 2019). Figure 4 depicts the export and import of information using the SketchUp program. The information that would be stored in the BIM framework is also shown, including surface structures, subsurface geology, and buried infrastructure.

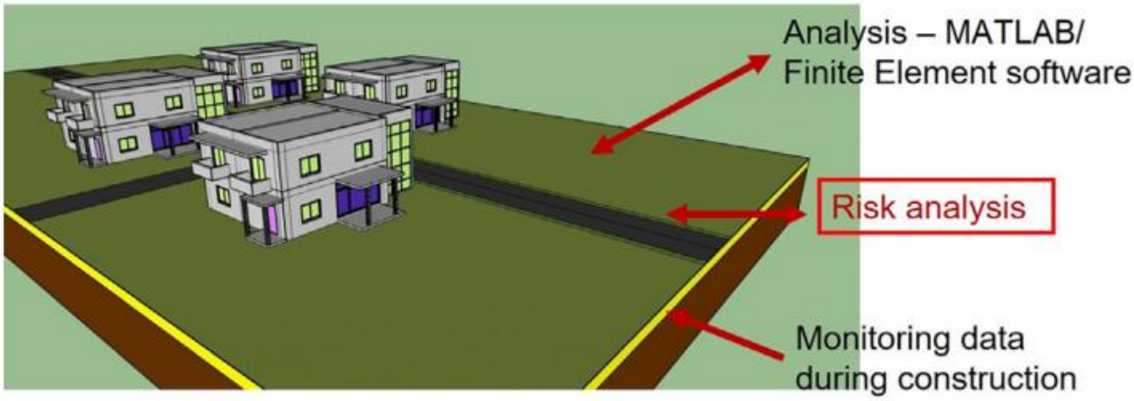

Fig. 4- The BIM for Underground concept, containing surface building, subsurface geological, and buried infrastructure information, that can be interacted with dynamically (Bartels et al., 2020)

Such technique introduces a novel way to data storage and presentation of geotechnical characteristics and other information utilizing BIM. The generated model can be supplemented with additional information, such as a settlement risk assessment. As a result, the user now gets a complete and useful tool for conducting early evaluations and making decisions.

There are potential possibilities for managing subsurface applications using BIM, such as combining multi-source geotechnical data with construction data within BIM (Zhang et al. 2018). Meschke (2018) investigated similar geotechnical data storage and modelling applications. However, as an alternate option, there is a methodology that uses a complete visualization tool (SketchUp) to serve as an interface between the BIM database and analytical tools. Providakis et al. (2019) introduced the use of 3D solid objects or pieces to store underground information (for example, geological layers or pipelines). Any topological or qualitative characteristics of these 3D subterranean components may be given and modified as element properties, in the traditional finite element method. They may then be translated using proprietary code in MATLAB and SketchUp to tabulate the information in a BIM-compatible way.

Uncertainty is commonly connected with subterranean situations. For example, there is uncertainty in geological interpretation and parameters, location and positional coordinates, and the physical characteristics of underground facilities. All of these can be represented in the proposed technique as extra characteristics connected with a specific BIM element or as a new layer inside the BIM model. A length of subterranean pipe may have a positional uncertainty of ±50 mm horizontally and ±100 mm vertically. This data may then be used as needed in further MATLAB investigations or as a parametric input for a finite element study. Geological components in BIM might also have uncertainty linked with parameters by providing it as an extra property. If there are several geological interpretations of borehole data, these alternative geological models can be incorporated as separate layers to BIM. As a consequence, engineering decisions are easier to make when this information is needed for future projects or modifications to a current project.

Figures 5a and 5b demonstrate how the idea of dynamic BIM for the Underground may be applied to a new 1.0-m diameter sewer built utilizing microtunnelling (pipe jacking) techniques. Figure 5(a) depicts the planned location, whereas Figure 5(b) depicts the existing subsurface infrastructure from BIM in 3D. The model includes all nearby buildings' BIMs as well as subsurface geological information. The 3D subsurface information in the model includes normal superficial (soil and artificial ground) and bedrock layers. The BIM-building data were stored alongside the subsurface pipe information. The combined model in Fig. 5 provides a thorough example of common feature shapes for an urban utility network. This model was created in the SketchUp visualization environment using BIM data.

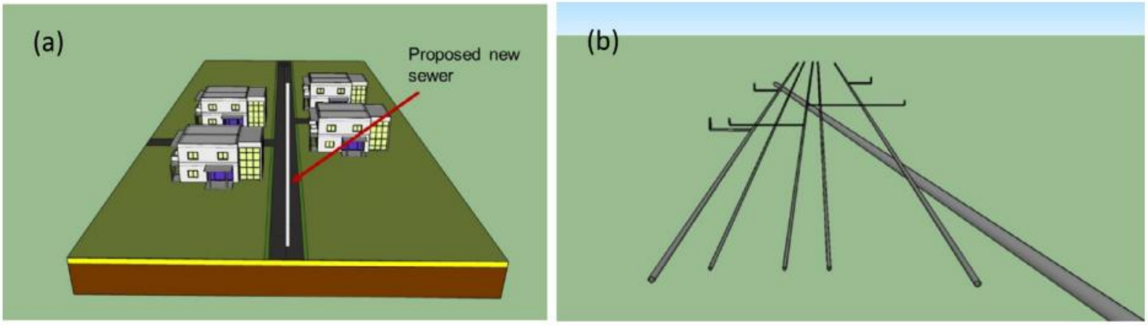

Fig. 5. (a) Site for the proposed sewer, including buildings and geological information from the BIM file, and (b) existing buried infrastructure contained within BIM (Bartels et al., 2020)

Tunnel construction and maintenance is a major area of BIM use. Tunnel building and restructuring is a complicated project that needs thorough planning and execution. This is where Building Information Modeling (BIM) shines as a game changer. The primary benefits of utilizing BIM for tunnels are outlined as follows (Huymajer et al., 2024):

1. Visualizing the Impossible: BIM generates a digital counterpart of the tunnel, allowing teams to see the project from all angles before breaking ground. This helps to spot possible issues early on, saving time and money.
2. Coordinating Complexities: With so many players engaged in tunnel building, coordination is critical. BIM serves as a central hub, ensuring that everyone has access to the most up-to-date information while reducing disputes.
3. Risk Mitigation: By simulating several scenarios inside the BIM model, possible hazards may be detected and handled ahead of time, improving project safety and lowering unexpected costs.
4. Resource Optimization: BIM provides data-driven decision-making by offering insights into material utilization, equipment needs, and labor allocation, resulting in more efficient resource management.
5. Integration with Smart Technologies: BIM may work with other smart technologies, such as Geographic Information Systems (GIS) and Internet of Things (IoT) devices, to provide real-time data and improve decision-making.
6. Environmental effect Reduction: By optimizing designs and avoiding needless excavation, BIM helps to reduce the environmental effect of construction projects.

The development of information modeling technologies in the world is mainly associated with the increasing importance of information technologies and large-scale practical use of three-dimensional models in software packages, the emergence of new standards for the implementation of projects in the presentation with mutual linkage of the graphical and computational parts of the project, as well as with additional information obtained during the production of work and during the operation of the constructed building. At the same time, these data, which are of interest to a geotechnical engineer, in most cases, are either not included at all or are included in a minimal volume. An attempt to solve the problem and implement digital technologies in geotechnics was made by Bentley Systems, a company specializing in the creation of information products, which in 2018 acquired PLAXIS company (a FE program for geotechnical calculations), gINT (a program for processing the results of field explorations) and SoilVision (positioning itself as a global database of soil characteristics and a program for processing laboratory tests). However, as experts from Bentley Systems themselves say, the integration of information technologies into geotechnical construction is still far away (Khandelwal et al., 2025).

The peculiarity of the BIM technology approach is that the construction object is designed as a single whole and a change in any parameter entails an automatic change in the other parameters and objects associated with it, including drawings, visualizations, specifications, and a calendar schedule. BIM approaches allow all changes and additions to be promptly reflected in the created building structure, providing architects, designers, and utility specialists with complete information. At the same time, information related to the geotechnical problems of the object does not fit so well into the specified schemes. Information on the geological structure and, as a rule, on the communications adjacent to the building cannot be complete, but consists of a set of discrete data. Information on communications at the site of excavation of shafts in the presence of new workings can be significantly modified during the exploration and during the work. Information on the geological structure, on the one hand, is clarified after each of the drilled wells in the building spot, and on the other hand, it is also associated with explorations outside the building spot. At the same time, there are no documents regulating how to build a three-dimensional geological model between engineering-geological wells. It is a well-known fact that when conducting explorations by various survey organizations, significant differences are observed not only in the main indicators of the physical and mechanical properties of soils, but even in the set of EGE (García & Jessurun, 2020). In addition, even industry leaders in terms of processing the results of field engineering-geological explorations still build engineering-geological sections in a semi-automatic mode, with manual assignment of layers.

From the point of view of geotechnicians, there is no consensus on what information on the physical and mechanical properties of soils should be included in the BIM model for possible use in calculations. There are a large number of calculation approaches. Previously used solutions of the elasticity theory do not meet modern requirements. They are being replaced by numerous nonlinear models of mechanical behavior of soil - Cam Clay, MC, HS, HSS, etc. Often, these models are not documented, their parameters are determined without involving the regulatory framework. The number of soil testing methods is extensive, while the results of these tests yield different values of the desired parameters. In practice, to obtain adequate calculation results, in most cases, expert assessments of the obtained test results are necessary. A very big question is how to include and structure all this information within the BIM model.

It should be noted that in geotechnical practice it is often impossible to structure and reduce all information to a uniform form. The results of geotechnical monitoring or exploration of existing buildings often do not fit into predetermined schemes. It is necessary to store a large amount of diverse information, the structure of which is not known in advance. Thoughts about the need to introduce non-standardized information into the model arise not only among geotechnicians, but also among specialists involved in the construction of BIM models of existing buildings based on the results of explorations and measurements.

## 4. Conclusion

To summarize, the BIM data standard system for underground engineering primarily provides standards for the standardization and consistency of data throughout its entire lifecycle, facilitating the exchange and storage of BIM data, and achieving data sharing and reuse of BIM data based on different participants, work stages, and application platforms. Furthermore, it may be used to direct and standardize professional software development. The BIM data standard system for subsurface engineering is structured into four categories: data description standards, categorization and coding standards, storage standards, and exchange standards (Yang et al., 2023). This system covers the organizational methods, process control, and information management of the entire process of implementing a BIM project in underground engineering, including management process, implementation promotion, policy guarantee, responsibility division, project information management regulations, and data security management requirements. It primarily consists of underground engineering information model project management standards and standards of data management.

The process of creating and enhancing standards, however, takes time. The standard system must be optimized, revised, and supplemented later on by merging experience summaries of engineering projects with practical application, all while maintaining the system's scientific and practical essence. In order to accomplish a positive cycle, it is also required to stay up to date, integrate more new disciplines and technologies into the standard system framework, improve the BIM standard system framework for subterranean engineering, and eventually create an integrated system.

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