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A Brief Discussion on Sustainable Application Strategies of BIM Technology in Underground Space Development

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Abstract: With the acceleration of urbanization, the development of underground space has become an important way to alleviate the shortage of urban land and improve the comprehensive carrying capacity of the city. However, the development of underground space faces many challenges, such as technical difficulty, high cost and environmental impact. With its innovative application in engineering design, construction and management, building information modeling (BIM) technology provides a new solution for the efficient, safe and environmentally friendly development of underground space. The purpose of this study is to explore the application strategy of BIM technology in the development of underground space, and to analyze how it can promote the sustainability of underground space development.Firstly , this paper analyzes the current situation, challenges and the importance of sustainability of underground space development through literature review, and summarizes the development and application of BIM technology. Then, the principle and function of BIM technology are studied, and its application potential and strategy in the development of underground space are discussed. Through case analysis, the application of BIM technology in different stages of planning and design, construction management and operation and maintenance management is discussed in depth, and the application strategy and evaluation framework to promote the sustainability of underground space development are put forward. Finally, the , which provides a scientific basis for the decision-making of underground space development, and puts forward a series of practical suggestions for the application of BIM technology in underground space development. Despite the limitations of the study, such as the limited number of cases and the lack of discussion on the deep application of BIM technology, this study provides a new perspective and method for the sustainability of underground space development, which has important theoretical and practical significance for urban planners and engineering circles.

Keywords: Underground Space Development; Building Information Modeling (BIM); Sustainability; Application Policy; Assessment Framework

1 Introduction

1.1 Research background and significance

With the continuous acceleration of global urbanization, the expansion and optimization of urban space has become an important issue in urban planning and development. As an important part of urban space, the rational development and utilization of underground space is of great significance to alleviating the shortage of urban land and improving the comprehensive carrying capacity of cities. However, the development of underground space faces multiple challenges such as high technical difficulty, high investment cost and complex environmental impact. In this context, how to achieve efficient, safe and environmentally friendly development of underground space has become an urgent problem for urban planners and engineers.

As an innovative information technology, BIM (Building Information Modeling) technology provides a new solution for engineering design, construction and management by creating and managing digital models throughout the project life cycle. The application of BIM technology can not only improve the accuracy and efficiency of engineering design, but also achieve optimal resource allocation and effective risk control during the construction and operation and maintenance stages . Therefore, the application of BIM technology to underground space development is of great value in promoting underground space development in a more efficient, safer and more environmentally friendly direction.

1.2 Research objectives, methods, and technical routes

This study embarks on an in-depth exploration of the strategic application of Building Information Modeling (BIM) technology in the development of underground spaces, with a keen focus on enhancing sustainability. The research aims to dissect the current scenario and challenges faced in underground space development, highlighting the crucial role of sustainability. It delves into understanding the fundamental principles and functionalities of BIM technology, assessing its potential to revolutionize the planning, design, construction management, and maintenance of underground spaces. Through a blend of literature review, case analysis, and field research, the study systematically investigates BIM technology's application strategies and its capacity to foster economic, environmental, and social benefits in underground development.

Key objectives include the analysis of BIM technology's impact on the sustainability of underground spaces, proposing a framework for sustainability assessment, and formulating a comprehensive application strategy based on BIM technology. Central questions revolve around identifying the primary technical and managerial hurdles, determining how BIM technology can address these challenges, and evaluating the effectiveness of BIM technology across different stages of underground space development.

The technical route of the study encompasses a thorough literature review to grasp the importance of sustainability and the current status of BIM technology. It then progresses to explore BIM's application potential and strategies in underground space development, selecting representative cases for in-depth analysis of BIM technology's role in planning, design, construction management, and operational maintenance. The culmination of this research is the proposal of an application strategy and evaluation framework for BIM technology, aimed at enhancing the sustainability of underground space development, with its feasibility and effectiveness verified through field research.

2 Literature review

2.1 Current status and challenges of underground space development

With the rapid development of urbanization, it has become a trend for urban space to extend underground. The development and utilization of underground space can effectively alleviate the problem of urban land shortage and improve the efficiency of urban space utilization. However, the development of underground space faces challenges such as high technical difficulty, high cost and many risks. For example, the construction difficulty of underground projects is higher than that of ground projects, and it is necessary to consider many factors such as geological conditions, groundwater and construction safety. In addition, the development of underground space may also have an impact on the surrounding environment, such as ground subsidence and changes in groundwater levels, which need to be fully considered during the development process.

2.2 Development and application of BIM technology

As an emerging information technology, BIM technology has been widely used in the construction industry. By creating and managing three-dimensional digital models of projects, BIM technology realizes information integration and management throughout the project life cycle. The application of BIM technology can improve the accuracy and efficiency of engineering design, optimize the construction process, reduce costs, and improve engineering quality. In the development of underground space, BIM technology can be used in geological analysis, construction simulation, structural design, resource management and other aspects, providing strong support for the planning, design, construction and operation and maintenance of underground projects.

2.3 The importance of sustainability in underground space development

Sustainability is an important principle of current urban development, and underground space development also needs to follow the principle of sustainable development. The sustainability of underground space development involves three aspects: economy, environment and society. Economic sustainability requires that underground space development should have a reasonable return on investment and economic benefits; environmental sustainability requires that the impact on the natural environment should be minimized during the development process to protect the ecosystem; social sustainability requires that underground space development should meet social needs, improve the quality of life of residents, and promote social harmony. To achieve the sustainability of underground space development, it is necessary to comprehensively consider various aspects such as planning, design, construction, operation and maintenance, and adopt effective technical and management measures.

2.4 Relationship between BIM technology and underground space sustainability

There is a close relationship between BIM technology and the sustainability of underground space development. The application of BIM technology helps to improve the economy, environmental friendliness and social benefits of underground space development, thereby promoting its sustainability. For example, BIM technology can be used in the planning and design of underground space, and through precise geological analysis and structural design, it can optimize the spatial layout and improve the efficiency of space utilization; in the construction stage, BIM technology can be used for construction simulation and resource management, reduce material waste and reduce construction costs; in the operation and maintenance stage, BIM technology can be used for facility management, energy management and safety management, improve operation and maintenance efficiency and reduce operating costs. In addition, BIM technology can also be integrated with other technologies such as GIS and IoT to realize the intelligent management of underground space and further enhance its sustainability.

2.5 Research gaps and contributions of this study

Although existing studies have shown the potential of BIM technology in underground space development, there are relatively few studies on the specific strategies and methods of BIM technology to promote the sustainable development of underground space. In addition, the particularity of underground space development also makes the application of BIM technology face some new challenges and problems. Therefore, this study will fill this research gap, through in-depth analysis of the application of BIM technology in underground space development, explore its specific strategies and methods to promote sustainable development, and provide theoretical guidance and practical reference for underground space development.

3 BIM technology principles and its application in underground space development

3.1 Core Principles of BIM Technology

BIM (Building Information Modeling) technology is a digital-based building design, construction and management method. Its core principle is to create a shared knowledge resource containing all the physical and functional information of the project to support decision-making throughout the project life cycle. BIM is not a single model or technology, but an integrated system involving multiple disciplines, processes and tools. The BIM model contains the building's geometric information, physical properties, performance data and operation and maintenance information, and realizes the integration of multi-dimensional data through parametric modeling.

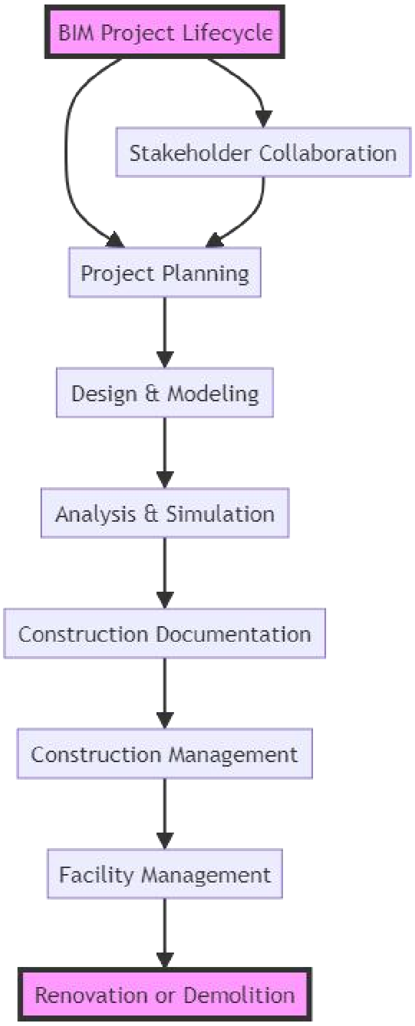

Figure 1

3.2 Application of BIM in underground space planning and design

In the planning and design stage of underground space, the application of BIM technology can significantly improve the accuracy and efficiency of design. Designers use BIM software to perform three-dimensional modeling of underground space, which can intuitively display the relationship between underground structure and surrounding environment, and optimize spatial layout and structural design. BIM model can simulate the lighting, ventilation, flow of people and other conditions of underground space, helping designers to evaluate the rationality of design solutions. In addition, BIM technology can also perform conflict detection to avoid conflicts between structure and equipment in design, and reduce design changes and rework.

Take the underground space planning and design phase of the Luotian Reservoir-Tiegang Reservoir water diversion tunnel project as an example. Through the 3D modeling function of BIM software, designers were able to create accurate underground tunnel models that not only show the structural details of the tunnel, but also reflect the complex relationship with the surrounding terrain and underground facilities. This 3D visualization enables the project team to have a deeper understanding of the layout of the underground space and optimize the tunnel path and structural design accordingly to adapt to geological conditions and environmental requirements.

BIM technology further played a key role in simulating key environmental conditions of underground space. Designers used BIM models to simulate conditions such as lighting, ventilation, and human flow, and evaluated the impact of different design options on the environmental quality of underground space. For example, by analyzing the ventilation effect inside the tunnel, the ventilation system design was optimized to ensure good air quality during construction and operation, and to evaluate the evacuation efficiency in emergency situations.

BIM technology's ability to detect conflicts has greatly improved the efficiency of the design phase. By integrating all relevant professional information in the model, designers can discover and resolve potential structural and equipment conflicts in the early stages of design, reducing later design changes and rework during construction, saving time and costs, while also improving the safety and reliability of the project.

The application of BIM technology also promotes collaboration among multidisciplinary teams. In the Luotian Reservoir-Tiegang Reservoir water diversion tunnel project, the BIM model serves as a shared platform, enabling engineers and designers from different fields to work together and exchange design ideas and feedback in real time. This cross-disciplinary collaboration not only speeds up the design process, but also improves the quality of design decisions, ensuring that the final design plan can comprehensively consider multiple needs and restrictions.

In this case, BIM technology provides accurate geographic information support for engineering design by integrating geographic information system (GIS) data. This includes the collection of geographic information data such as surface, landforms, facilities and equipment. These data are collected by drones in the core area of the city and generate high-precision real-life three-dimensional GIS models, laying the foundation for the accurate planning and design of underground tunnels. Through the integrated application of BIM and GIS, the project team can effectively identify and analyze the risks of underground tunnel construction, reduce construction risks, and ensure the smooth excavation of shield tunneling. The application of BIM technology also promotes collaborative work among project teams, simplifies the data processing process, and improves the scientific nature of decision-making and the efficiency of construction management. In the preparation stage of operation and maintenance management , BIM technology provides data support for project operation and maintenance by adding completion information, laying the foundation for the establishment of a smart platform and the smooth implementation of operation and maintenance management .

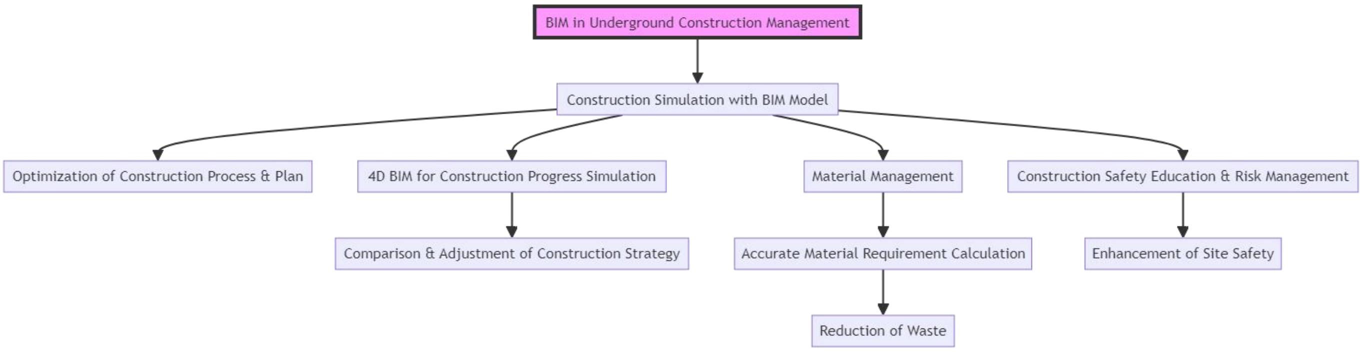

Figure 2

3.3 Application of BIM in underground construction management

During the underground space construction phase, the application of BIM technology helps to improve the efficiency and safety of construction management. The construction team can use the BIM model to simulate the construction and optimize the construction process and construction plan. Through four-dimensional (4D) BIM technology, the construction progress can be simulated, the construction plan and the actual progress can be compared and analyzed, and the construction strategy can be adjusted in time. The information in the BIM model can also be used for material management, accurately calculating material requirements and reducing waste. In addition, BIM technology can also assist in construction safety education and risk management, and improve the safety management level of the construction site.

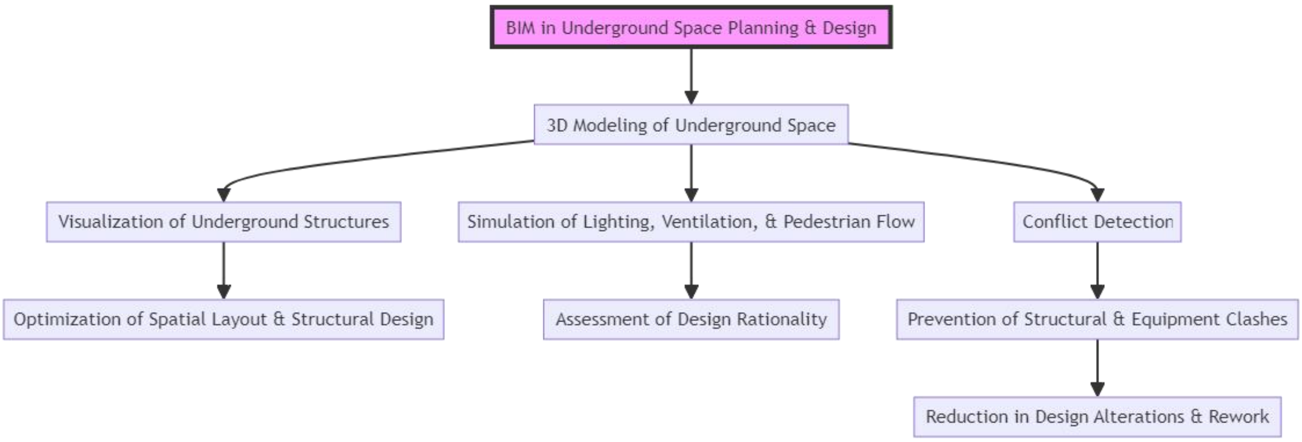

Figure 3

Taking the underground comprehensive pipeline corridor project in Xiongan New Area as an example, the application of BIM technology has become a key factor in improving construction efficiency and quality. From the planning and design stage, BIM technology has assisted the team in scientific survey and design through the establishment of three-dimensional models, ensuring the rationality and foresight of the pipeline corridor design. At this stage, the use of BIM models not only predicted and resolved spatial conflicts, but also provided effective solutions to problems such as pipeline layout.

When entering the construction drawing review stage, BIM technology plays the role of a communication medium, enabling all construction parties to communicate intuitively and efficiently based on the three-dimensional model, significantly improving the efficiency of discovering and solving drawing problems. In addition, the combination of BIM and GIS technology plays an important role in construction simulation , especially in safe construction simulation, which improves the intuitiveness and understanding of safety briefings for on-site implementation personnel through three-dimensional animation simulation.

In the construction management stage, the application of BIM technology has been further deepened, especially in the aspects of collision verification and reserved opening verification. BIM technology integrates all design drawings into one model through model construction, intuitively discovers and coordinates design problems, and effectively avoids the increase of time cost in the construction process. At the same time, BIM technology also helps to establish a refined reinforcement model, improving the accuracy and efficiency of construction.

In order to enhance construction efficiency and guarantee quality, the integration of BIM and GIS technologies has been employed to simulate and visually present on-site construction plans. This innovative method of technical disclosure merges various elements such as drawings, construction processes, and standard atlases, markedly enhancing the effectiveness of technical communication. Furthermore, BIM technology is utilized to create construction process simulation videos, ensuring the optimal construction process plan is achieved through extensive discussions with construction units. This approach has established a robust digital foundation for subsequent operation and maintenance management, paving the way for intelligent and information-based management practices. In the context of the Xiongan New Area underground comprehensive pipeline corridor project, the application of BIM technology has not only heightened design precision and construction efficiency but also elevated safety management standards while providing substantial data support for future operation and maintenance.

3.4 Application of BIM in underground space operation and maintenance management

In the realm of underground space operation and maintenance management stage of underground space, the application of BIM technology can improve the efficiency of operation and maintenance and the performance of facilities. The operation and maintenance team can use BIM models to maintain and manage facilities, quickly locate the location of facilities through the information in the model, and obtain the maintenance history and performance data of facilities. BIM technology can also assist energy management by analyzing the energy usage of buildings and formulating energy-saving measures. In addition, BIM models can also be used for the formulation and drills of emergency plans to improve the ability of underground spaces to respond to emergencies.

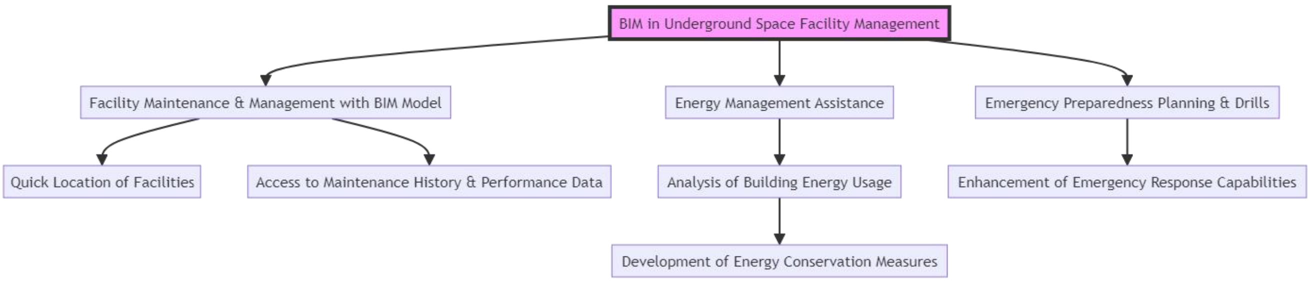

Figure 4

Taking the maintenance phase of the Beijing Urban Sub-Center Underground City Complex Project as an example, BIM technology has played a vital role, especially in realizing the digital delivery and intelligent management of building information. The project team provided detailed data support for operation and maintenance management by adding detailed completion information to BIM model components, including spatial information such as building information, area information, floor information, and room information, as well as eight major types of equipment information including power, lighting, intelligence, network, monitoring, measurement, switch, and storage . The integration and coding of this information, through close communication with the property company, compiled a detailed digital coding system to ensure the efficiency and accuracy of operation and maintenance work .

The combination of BIM technology and smart platforms enables real-time monitoring and control of buildings during the project operation and maintenance phase . Through the smart platform, managers can obtain key information such as "overall building situation", "equipment operation status", "machine room equipment supervision" and "fire alarm" in a timely manner, and push information to on-site personnel through a real-time response mechanism to ensure that problems can be quickly resolved. This intelligent operation and maintenance management model not only improves the monitoring capabilities of buildings, but also greatly improves the response speed and processing efficiency of emergencies.

BIM technology in the operation and maintenance stage is also reflected in the continuous optimization of the project's full life cycle management. Through continuous technology upgrades and functional expansion, the BIM model has become a bridge connecting design, construction and operation and maintenance, providing a reliable data foundation for the long-term operation and maintenance of the project. This not only improves the level of intelligence in operation and maintenance management , but also provides practical cases and experience for the digital transformation and high-quality development of the construction industry.

3.5 Challenges and Solutions of BIM Technology

Although BIM technology has great application potential in underground space development, it also faces some challenges in practical application. For example, the operational complexity of BIM software requires users to have high technical capabilities; the creation and maintenance of BIM models requires a lot of time and resources ; data compatibility issues between different BIM software, etc. In order to overcome these challenges, it is necessary to strengthen BIM technology education and training, improve the BIM application capabilities of practitioners; develop more efficient and automated BIM modeling tools to reduce the workload of model creation and maintenance; promote the unification of data standards and formats between BIM software, and realize seamless data exchange and integration.

3.6 Conclusion

This chapter introduces in detail the principles of BIM technology and its application in underground space development. BIM technology provides strong support for the planning, design, construction and operation and maintenance management of underground space through the creation and application of digital models . The application of BIM technology not only improves the efficiency and quality of underground space development, but also helps to achieve the sustainability of underground space development. However, the application of BIM technology also faces some challenges that need to be overcome through education, technological innovation and standardization.

4 Sustainability assessment of underground space development

In this chapter, we will explore the sustainability assessment of underground space development, which involves an in-depth analysis of the three dimensions of environment, economy and society. The assessment framework will be established based on the principle of sustainability to ensure that the development of underground space meets the needs of the present while not compromising the interests of future generations.

4.1 Environmental Impact Assessment

Environmental impact assessment is an important part of sustainability assessment. The impact of underground space development on the ecosystem needs to be considered from multiple perspectives . For example, underground construction may change the path of groundwater flow and affect the growth conditions of surface vegetation.

In terms of environmental impact assessment, a case worth noting is the Nanning Underground Integrated Pipeline Project. During the construction process, the project paid special attention to the protection of groundwater resources and adopted a series of advanced geological exploration technologies and construction methods to reduce the impact on the environment.

Before planning and construction of the Nanning Underground Integrated Pipeline Project, detailed geological surveys were first conducted, using 3D geological modeling technology to accurately analyze the underground soil, rock, and groundwater distribution. With this data, the project team was able to identify the main flow paths of groundwater and avoid these sensitive areas when designing the pipeline corridor, thereby reducing the interference of construction with groundwater flow.

In terms of construction methods, the project uses non-excavation technologies such as pipe jacking and shield methods, which can complete the construction of underground pipe corridors without destroying surface vegetation and soil structure. In addition, advanced stratum reinforcement technology is also used during the construction process to ensure the stability of the surrounding soil layer and avoid groundwater loss or pollution caused by construction.

In order to further reduce the impact on groundwater resources, the project has also implemented strict water resource management measures. This includes collecting and treating wastewater generated during construction to ensure that the water meets environmental standards before being re-injected into the groundwater system. At the same time, the project has also established a groundwater monitoring system to monitor the groundwater level and water quality in the construction area in real time to ensure that construction activities will not have a long-term negative impact on groundwater resources.

Through these comprehensive environmental impact assessments and management measures, the Nanning Underground Pipeline Project successfully minimized the impact on groundwater resources, demonstrating the possibility of achieving environmental protection and sustainable development in urban underground space development. This case provides valuable experience and reference for the construction of subway systems in other cities, and emphasizes the importance of conducting environmental impact assessments during underground space development.

Through case analysis, we can see that in the construction of Nanning's urban subway system, the negative impact on groundwater resources was successfully reduced by adopting advanced geological exploration technology and construction methods.

Resource consumption and energy efficiency are another key point in the assessment. Underground space development usually requires a lot of building materials and energy. By adopting BIM technology, the use of resources can be optimized in the design stage and energy efficiency can be improved during the construction process. Data shows that projects using BIM technology can reduce energy consumption and material waste by about 10% on average.

Pollution emissions and waste management are also aspects that cannot be ignored in environmental assessment. Noise, dust and construction waste generated during construction need to be properly handled. An effective waste management strategy can not only reduce environmental pollution, but also bring economic benefits to the project through waste recycling and reuse.

4.2 Economic feasibility analysis

Economic feasibility is the decisive factor in whether a project can proceed smoothly. Cost-benefit analysis is an important tool for evaluating economic feasibility. By comparing the costs and expected benefits of different underground space development plans, the most cost -effective plan can be determined. In addition, return on investment and risk assessment are also indispensable. Policy support and market factors will also affect the economic feasibility of underground space development.

4.3 Social Impact Assessment

Social impact assessment focuses on the impact of underground space development on residents' quality of life and social structure. Underground space development may bring positive impacts such as easing traffic congestion and increasing public space, but it may also cause problems such as resident relocation and changes in community structure. Social participation and public satisfaction are important indicators for measuring social impact. Through questionnaires, public hearings and other methods, we can collect public opinions and suggestions on underground space development projects, thereby optimizing project design and improving social acceptance.

4.4 Comprehensive evaluation method

In order to comprehensively evaluate the sustainability of underground space development, a comprehensive evaluation method is needed. Multi-criteria decision analysis (MCDA) is an effective tool that can help decision makers weigh multiple evaluation criteria. By constructing a comprehensive evaluation model, different development options can be comprehensively compared, so that the most sustainable option can be selected.

Based on the above assessment, we can draw conclusions about the sustainability of underground space development. The results of the environmental, economic and social assessments will guide us to make specific recommendations and improvement measures. These recommendations will help improve the sustainability of underground space development and ensure that the project can meet current needs while leaving room for future development.

5 Application strategies of BIM technology to promote sustainable development of underground space

This chapter will explore how to use Building Information Modeling (BIM) technology to promote the sustainability of underground space development. As an integrated digital tool, BIM technology can play a key role in various stages of underground space development, including planning and design, construction management, and operation and maintenance management .

5.1 BIM application strategy in the planning and design stage

In the planning and design stage, the application of BIM technology can significantly improve the design quality, optimize the spatial layout, and reduce resource waste. Through 3D modeling, designers can identify potential design conflicts and structural problems at an early stage, thus avoiding later modifications and rework. In addition, BIM technology can also be used to simulate the natural lighting, ventilation, and flow distribution of underground spaces to achieve more efficient energy utilization and a more comfortable spatial environment.

5.2 BIM application strategy in the construction phase

The construction phase is one of the phases with the greatest resource consumption and environmental impact in underground space development. The application of BIM technology in this phase can improve construction efficiency, reduce material waste, and ensure construction safety. Through the BIM model, the construction team can make accurate material budgets and construction plans to achieve the optimal allocation of resources. At the same time, BIM technology can also be used for real-time monitoring and quality control of the construction process to ensure that the construction process meets design requirements and safety standards.

5.3 BIM application strategy in the operation and maintenance management stage

During the operation and maintenance phase of underground space development, leveraging Building Information Modeling (BIM) technology significantly boosts operational efficiency, extend the life of facilities, and reduce maintenance costs. BIM models can integrate facility operational data, such as energy consumption, equipment status, and maintenance records, to provide comprehensive operational information for facility managers. In addition, BIM technology can also be used for predictive maintenance and fault diagnosis. By analyzing operational data, potential problems can be discovered in advance and preventive measures can be taken.

5.4 Application of BIM Technology in Life Cycle Management

BIM technology plays an important role in the full life cycle management of underground space development. By combining BIM models with technologies such as geographic information systems (GIS), the Internet of Things (IoT) and virtual reality (VR), digital and intelligent management of underground space development can be achieved. This integrated management method can not only improve the development efficiency of underground space, but also provide support for the sustainable operation of underground space.

Through the above analysis, we can see the potential of BIM technology in promoting the sustainability of underground space development. The application of BIM technology can not only improve the quality of design and construction, but also optimize operational efficiency and reduce environmental impact. Therefore, it is recommended to widely apply BIM technology in underground space development projects and combine it with other advanced technologies to achieve a more efficient, environmentally friendly and sustainable development model.

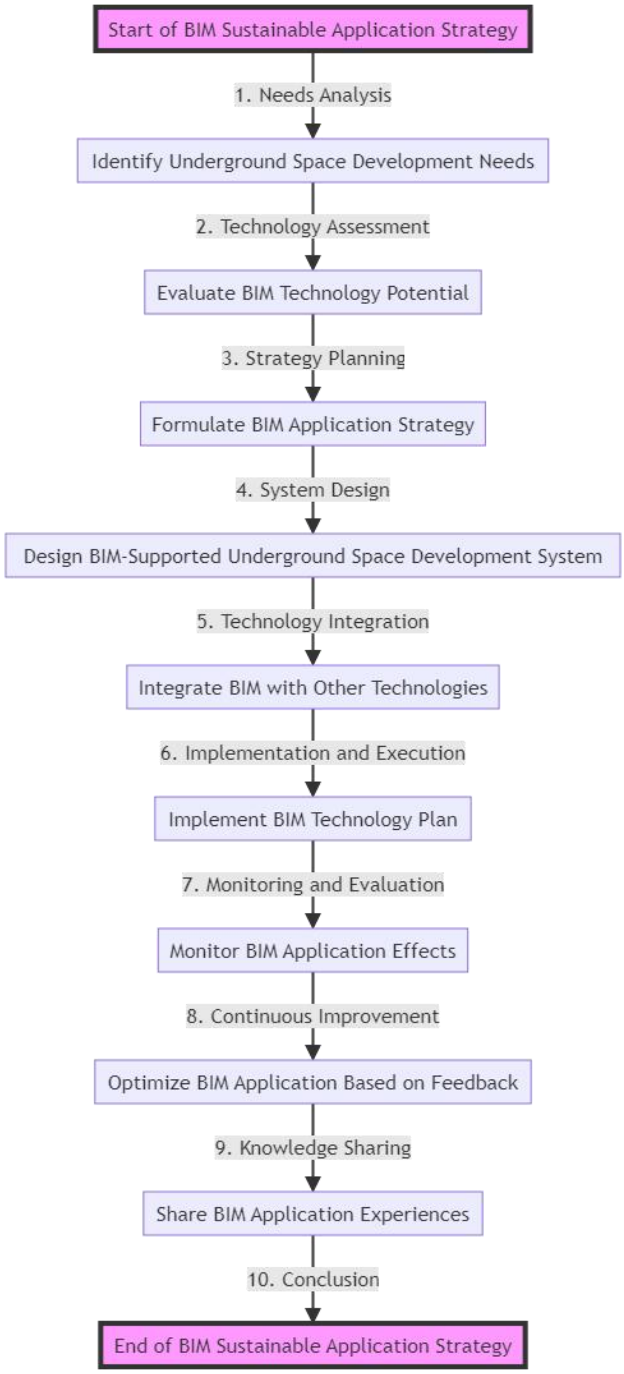

Figure 5

6 Conclusions and Recommendations

6.1 Research Conclusions

This study explored the application of BIM technology in underground space development and its impact on promoting sustainable development through comprehensive theoretical analysis. The study found that BIM technology can significantly improve the efficiency and quality of planning, design, construction, and operation and maintenance management of underground space development projects. By using BIM technology, efficient use of underground space can be achieved, resource consumption can be reduced, environmental pollution can be reduced, economic benefits can be improved, and social benefits can be enhanced, thereby promoting the development of underground space in a sustainable direction.

6.2 Research Contributions and Innovations

The main contributions and innovations of this study include:

The application framework of BIM technology in underground space development is proposed, and the specific application strategies of BIM technology in different development stages are clarified. Combined with the principle of sustainability, a sustainable evaluation system for underground space development is constructed, which provides methods and tools for evaluating and improving the sustainability of underground space development. A sustainable evaluation framework for underground space development based on BIM technology is proposed, which provides a scientific basis for decision-making on underground space development.

6.3 Research limitations and future research directions

Although this study has achieved certain results in the application of BIM technology and the sustainability assessment of underground space development, there are still some limitations:

The limited number of research cases may affect the generalizability and applicability of the conclusions. The in-depth application of BIM technology in underground space development, such as the integrated application with GIS, IoT and other technologies, has not been explored in depth. The research on the technical and management problems that may be encountered in the application of BIM technology and the corresponding solution strategies is not comprehensive enough.

Future research directions may include:

Expand the scope of case studies and improve the universality of research conclusions. Conduct in-depth research on the integrated application of BIM technology and other technologies to explore more efficient underground space development models. Conduct a more comprehensive study of technical and management issues in the application of BIM technology and propose more specific solutions.

6.4 Suggestions for underground space development practices

Based on the conclusions and findings of this study, the following suggestions are put forward for underground space development practice:

Actively adopt BIM technology in underground space development projects to improve the efficiency and quality of project planning, design, construction, and operation and maintenance management . In combination with the characteristics of underground space development, formulate and implement strategies and standards for the application of BIM technology to ensure the effective application of BIM technology. Establish a sustainability assessment system for underground space development, regularly evaluate the sustainability performance of projects, and adjust development strategies in a timely manner. Strengthen education and training on BIM technology, improve the BIM application capabilities of practitioners, and provide talent support for the application of BIM technology. Promote the integrated application of BIM technology with other technologies, such as GIS, IoT, etc., to realize the digital and intelligent management of underground space development. Through these measures, the sustainability of underground space development can be promoted, the efficient use of underground space resources can be achieved, and contributions can be made to the sustainable development of cities.

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