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Article

Conflict of rights in high-rise underground space development: Comprehensive analysis of legal regulation and biomechanical impact

Qiaohong Pan[1,*], Shuaiqi Song[2]

[1] Law school, Henan University of Urban Construction, Pingdingshan 467036, China
[2] School of Civil and Transportation Engineering, Henan University of Urban Construction, Pingdingshan 467036, China
*** Corresponding author:** Qiaohong Pan, 30100202@huuc.edu.cn

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Abstract: Aiming at the conflict of rights in the development of underground space of high-rise buildings, this paper puts forward a comprehensive analysis framework combining the influence of legal norms and biomechanics. Starting from biomechanics, this paper specifically discusses the rights disputes in three aspects of underground space land transfer fee, the ownership of underground civil air defense project and the ownership of community underground garage, and introduces a biomechanical evaluation model supported by GIS platform to ensure the safety and stability of the project. When considering the underground space land transfer fee, the stability and load-bearing capacity of the soil, which can be analyzed through biomechanical principles, directly affect the feasibility and cost of construction. Just as the skeletal structure of an organism provides the foundation for its movement and survival, the underground geological structure dictates the safety and economic viability of building projects. In the discussion of the ownership of underground civil air defense projects, biomechanical models can be employed to evaluate the potential impact of disasters. By simulating how the structure withstands external forces like earthquakes or explosions, similar to how a creature's body adapts to survive in harsh environments, we can better determine the responsibilities and rights of different parties. Regarding the community underground garage, the layout and design need to conform to human biomechanics. Adequate space for vehicle entry, exit, and pedestrian movement, considering factors such as comfortable walking angles and clear sightlines, ensures convenience and safety, much like how organisms' habitats are optimized for their daily activities. The study found that the municipal government has issued policies to clarify the specific content and scope of underground space use rights, established a unified approval process to strengthen supervision, and promoted the application of biomechanical evaluation models, thereby improving project quality and reducing potential risks. The experimental results show that this comprehensive management strategy effectively alleviates the conflict of rights, promotes the smooth progress of the project, and provides institutional guarantee and technical support for the sustainable development of the city. This paper not only solves the current right conflict problem, but also provides valuable experience for the rational use of urban underground space resources and the maximization of social benefits in the future.

Keywords: high-rise building; underground space development; law regulation; biomechanics

1. Introduction

The development of underground space in high-rise buildings is a complex, multidisciplinary issue not fully addressed in current literature [1,2]. This study bridges this gap by integrating legal regulation with biomechanical considerations to offer a novel approach to resolving rights conflicts during underground space development. By merging these two aspects, the research contributes both theoretically and practically, guiding policy-making and urban planning.

Urban vertical expansion highlights the need for frameworks addressing both surface and subsurface property rights. The originality of this work lies in its interdisciplinary approach, linking legal studies and engineering sciences to provide comprehensive solutions for underground space challenges [3,4]. With rapid urbanization and scarce land resources, expanding building space upwards and downwards has become common, leading to numerous high-rise buildings and supporting underground projects. Underground spaces serve various functions—such as parking, commercial facilities, civil air defense—and are integral to urban operations [5,6].

However, this also introduces complex rights conflicts requiring multi-perspective analysis and resolution [7]. At the legal level, underground development challenges traditional real right systems, affecting land ownership, use rights, and adjacent rights. Different stakeholders often have conflicting views on key issues like ownership definition, development scope, and construction permits [8]. For example, unclear boundaries in old urban areas can lead to safety concerns and rights infringement, resulting in prolonged litigation. Commercial developments may expose legal regulations' inability to keep pace with innovative practices, necessitating clear rule frameworks.

Biomechanical factors, often overlooked but crucial for development effectiveness and sustainability, pose significant risks. Deep excavation can alter soil stress distribution and groundwater flow, threatening existing building foundations [9,10]. Soil bearing capacity changes nonlinearly with depth and excavation method, risking foundation settlement and wall cracking, which can endanger structural stability and users' rights. Ecologically, underground development can disrupt microenvironments, interfere with microbial communities, and weaken urban ecological resilience, contradicting green development goals [11,12].

The interaction between legal regulation and biomechanics is essential for shaping sustainable underground development. Legal frameworks define property rights and boundaries, while biomechanical assessments ensure structural and environmental integrity. Combining these dimensions mitigates risks and promotes sustainable development [13]. Clear legal definitions prevent disputes, and biomechanical evaluations identify threats to stability and ecology. Integrating biomechanical principles into legal frameworks allows for informed decision-making, reducing damage to adjacent structures and preventing environmental degradation.

Previous research often treats legal and biomechanical aspects separately, focusing either on rule logic or engineering parameters without interdisciplinary integration. Consequently, development processes face rights disputes or ignore ecological mechanics, burying safety and ecological risks. This study focuses on the intersection of law and biomechanics, using legal standards and empirical simulations to clarify rights conflict logic and provide strategies for legislative optimization and project implementation improvement, advancing three-dimensional urban development on a solid legal and ecological foundation.

2. Correlational research

With the acceleration of urbanization, underground space development has become an important way to improve urban land use efficiency and expand urban development space. Domestic and foreign scholars have gradually deepened the research in this field and obtained some important results.

Under different academic perspectives, the concept of underground space has different interpretations. For example, in the framework of law, Yan [14] emphasized in his master's study that underground space is defined as an area that can be controlled and utilized by human beings to meet various interest needs, which covers ecology and environment. Moreover, this space is subject to laws and regulations and becomes the object of transaction or management between legal subjects. However, Yuan et al. [15] and other scholars put more emphasis on the perspective of sociology. They believe that urban underground space is a product of social development, specifically referring to a series of places for people to use below the surface of the city, which not only supports People's Daily life, but also participates in a wider range of social service functions. In addition, there are many studies on the risk assessment and technology application of underground space. In their study in 2015, Nezarat et al. [16] sorted and graded the geological risks in underground engineering by combining the experience of geological experts and multi-criteria decision-making technology. Hyun et al. [17] also discussed the problems that may be encountered during tunnel construction in the same year, and used Fault Tree Analysis (FTA) and Analytic Hierarchy Process (AHP) to evaluate the probability of risk occurrence and its influence, so as to systematically evaluate the overall risk level.

For the suitability evaluation of urban underground space development, Lu et al. [18] proposed a multi-layer framework aimed at quantitatively assessing the geological engineering conditions of urban underground space development, and applied it to a specific railway station area. Peng and Peng [19] put forward the evaluation method of urban underground space resources based on Geographic Information System (GIS), which can comprehensively consider a variety of factors, such as geological conditions and environmental impacts, and make a more comprehensive assessment. Jiang et al. [20] proposed a new method for dividing underground space, that is, using the unit volume of Grid + Voxel for three-dimensional division, which is more effective than the traditional two-dimensional division. Ye et al. [21] further deepened this idea by using variable fuzzy set theory to carry out three-dimensional quality evaluation, which provided a new way for the evaluation of urban underground space resources. Durmisevic and Sariyildiz [22] focused on the data processing of underground stations, and adopted the neural network method to integrate multiple influencing factors and form a comprehensive evaluation system. Youssef et al. [23] combined GIS technology, remote sensing technology and analytic hierarchy process to evaluate the suitability of engineering geological conditions and identify potential geological disasters that may affect construction projects.

3. Method

In order to comprehensively explore the rights conflicts in the development of underground space in high-rise buildings, and make a comprehensive analysis combined with legal regulations and biomechanical effects, this paper adopts a multidisciplinary research method.

3.1. Conflict of rights in high-rise underground space development and its governance strategy

In high-rise building underground space development, rights conflicts primarily emerge in three areas: disputes over underground space land transfer fees, ownership of underground civil air defense projects, and ownership of residential community underground garages.

Firstly, the core issue in land transfer fee disputes is whether the government can re-transfer underground space usage rights after surface land rights have been transferred, and if additional fees should be collected. Local governments aim to boost fiscal revenue by establishing multi-level construction land use rights, while developers and the public question the fairness of repeated charges, fearing increased costs that could be passed on to consumers. Such disputes can harm investment climates, market vitality, and government credibility. Clarifying the scope of underground space use rights is urgent to prevent double transfers or excessive fees.

Secondly, ownership disputes of underground civil air defense projects stem from unclear divisions of ownership, use, and profit rights. The principle "who invests, who uses, and who benefits" lacks specific standards for different scenarios. Historical issues and policy changes add regional variability, complicating tenure definitions. Unclear ownership can dampen investor enthusiasm and hinder management and maintenance, potentially impacting public safety. Establishing a unified approval process for civil air defense projects ensures they meet national security standards and protects all parties' interests.

Lastly, disputes over residential community underground garages pit developers against owners regarding the original ownership and fair allocation of these spaces. According to Article 275 of the Civil Code, agreements on parking space ownership should be made through sale, donation, or rental. However, many projects lack clear agreements, leading to difficulties in resolving later disputes. These conflicts directly impact residents' quality of life and community harmony. Improving laws and regulations to guide fair processing methods is essential for fostering a better living environment.

3.2. Biomechanical evaluation model construction

Considering the complex geological conditions and technical requirements involved in underground space development, it is crucial to ensure the safety and stability of the project. Therefore, this paper introduces a biomechanical evaluation model based on GIS (geographic Information System) platform, aiming to provide scientific basis and technical support for the development of high-rise building underground space from the perspective of the suitability evaluation of engineering geological conditions.

3.2.1. Common factor evaluation model

The suitability evaluation of engineering geological conditions for the development of urban underground space, after the weight is finalized, the comprehensive evaluation method must be selected according to the characteristics of the index system. Such as addition synthesis, multiplication synthesis, substitution method, etc., are common methods of comprehensive evaluation. Aiming at the evaluation of common factors, this paper uses multi-objective linear weighted sum function to construct the mathematical model of suitability evaluation, and the formula is as follows:

$$V=\sum_{j=1}^{m}\left(W_j\cdot X_j\right)=\sum_{j=1}^{m}\left[\frac{W^0\cdot S_j(X)}{\sum_{j=1}^{m}\left(W_j^0\cdot S_j(X)\right)}\cdot X_j\right] \tag{1}$$

In this equation, V represents the total score of all common factors, W^0 is the initial weight, $S_j(X)$ is the piecewise weight adjustment function of the index state, X_j is the adjustment weight, X_j is the standardized value of the index. In the evaluation of common factors, once the index value changes, the piecewise weight adjustment function $S_j(X)$ of the index state will change, and then the key model parameters such as index weight will also change, and finally the evaluation results will be different. This coincides with the characteristics of urban engineering geology affected by the internal differences of evaluation indexes.

3.2.2. Sensitivity factor evaluation model

Generally speaking, sensitive engineering geological conditions, such as collapse, earthquake and active fault, will limit the development of underground space. When carrying out underground space development projects, it is necessary to actively avoid the areas with such sensitive engineering geological conditions and the surrounding areas affected by them. During the suitability evaluation of engineering geological conditions, any area affected by sensitive engineering geological conditions should be directly delimited as a prohibited development zone. In view of this, this paper evaluates the sensitive engineering geological conditions and ordinary engineering geological conditions separately, and analyzes the buffer zone of sensitive engineering geological conditions with the help of GIS technology, so as to clarify its influence scope. The area within the buffer zone is regarded as the restricted development zone, and such restricted development areas should be excluded subsequently.

Based on the above analysis, we may wish to use the product exclusion method to build a mathematical model of sensitive factor evaluation, that is, the result of GIS buffer analysis is implemented binarization assignment operation. If an evaluation unit is in a restricted development area, it is assigned a value of 0. If the evaluation unit is outside the restricted development zone, it will be assigned a value of 1. The formula is as follows:

$$I=\prod_{i=1}^{n}R_i \tag{2}$$

where, I is the total score of the sensitive factor (I=0or1), R_i (I = 1,2, ..., n) is the score of the ith sensitive factor.

3.2.3. Comprehensive evaluation model

After determining the evaluation model of common factors and sensitive factors, it is necessary to use GIS to implement multiplication and superposition operation, so as to achieve the comprehensive evaluation of the suitability of urban underground space development engineering geological conditions. Combined with Equations (1) and (2), the comprehensive evaluation model is deduced as follows.

$$M = V \cdot I = \sum_{j=1}^{m} \left(W_j \cdot X_j\right) \cdot \prod_{i=1}^{n} R_i = \sum_{j=1}^{m} \left[\frac{W^0 \cdot S_j(X)}{\sum_{j=1}^{m}\left(W_j^0 \cdot S_j(X)\right)} \cdot X_j\right] \cdot \prod_{i=1}^{n} R_i \quad (3)$$

3.2.4. Evaluation method

1) Grid cell method

The raster cell method involves dividing a study area into uniform grid cells for spatial analysis. Conceptually, it transforms geographic space into a grid of equidistant, equal-sized cells, akin to overlaying a map with uniform squares. Each cell stores attribute information for its location, such as soil bearing capacity or groundwater depth in engineering geology.

During the evaluation process, extensive data on landforms, geological structures, and geotechnical properties are gathered from field surveys, geological maps, and engineering reports. These data are then allocated to each grid cell according to established rules. An evaluation index system is constructed based on specific objectives, like assessing suitability for underground space development. Factors such as geological stability and rock/soil strength are considered, and attribute values for each cell are calculated using methods like weighted summation or fuzzy comprehensive evaluation.

GIS software aids in spatial analysis by categorizing the cells into levels—such as very suitable, suitable, less suitable, and unsuitable for development—using different colors and symbols. This visual representation clearly displays the spatial distribution of attributes across the region, helping decision-makers accurately determine optimal locations and strategies for underground space development.

2) Vector element method

Based on the vector data model, the vector element method presents geographic entities and their spatial associations with the help of geometric objects such as points, lines and surfaces, which is used for engineering geological evaluation.

In data organization, point elements can mark specific locations such as drilling holes and monitoring points, with attributes such as drilling depth and stratigraphic lithology, which helps to analyze the surrounding geological conditions. Line elements show linear geological structures, such as fault lines with type and activity intensity attributes, and rivers with water volume and flow velocity attributes, whose attributes are related to the impact assessment of underground space development. Surface elements are used to delimit geological units, land use areas or underground space planning areas, and the types and thicknesses of rock and soil masses contained in them are important for the study of regional engineering geological conditions.

In terms of the evaluation process, firstly, the data of field geological exploration and existing geological maps are integrated, and the vector model is built accordingly, such as the fault line vector according to the fault information and the plane vector according to the geological unit boundary. Then, the GIS spatial analysis function is used to operate vector elements, and the spatial relationship between surface and line elements is calculated to judge whether the underground space development is affected by faults or not. Through vector superposition, geological units and groundwater level and other elements are integrated to calculate new attribute values such as the range of buried depth of groundwater level. Finally, based on the results of attribute and spatial analysis, the evaluation results of engineering geological conditions in underground space development area were output in the form of map (suitability level was distinguished by color) and report form (scores and main factors were listed).

3) Vector cell rasterization method

This method fuses the advantages of vector and raster data. At the beginning of the development, the grid resolution should be determined, and the unit size should be determined according to the research accuracy and data detail. For example, small units of 1 m × 1 m can be selected for fine exploration of groundwater level changes, and units of 10 m ×10 m or even larger can be used for rough evaluation of large regional geological structures. Then the vector feature transformation was implemented, the point elements (such as drilling points) were assigned to their raster values according to their positions, and the final attributes were determined according to the rules (mean, maximum value, etc.) when multiple points fell into the same cell. Line elements (such as fault lines) pass through the grid and are assigned relevant attributes by the algorithm. The line width defines the influence range according to the actual or default one-grid width. Surface elements (such as geological unit areas) let internal grids inherit their attributes, and boundary grids are assigned accurately by special algorithms. After conversion, the engineering geological suitability index is calculated by grid analysis method and grid calculator according to preset rules. The final results are visually output by the map, and the evaluation details are displayed with different colors and symbols, which helps decision makers clarify the distribution of regional geological conditions and provides support for the choice of underground space development.

3.3. Overall rating level

In order to show the evaluation results more intuitively, the values of each participating index are the values after standardization, and the geological suitability of underground space development is divided into five grades according to the principle of equal score, as shown in **Table 1**. Here, the principle of equal score is adopted, which means that the score interval is evenly distributed to determine the different levels of underground space development assessment. This method is suitable for the suitability evaluation of geological environment of underground space development in most cities. In practical application, it can be adjusted according to the characteristics of specific resources by combining the most unfavorable level judgment method.

Table 1. Grading of geological environment suitability for underground space development.

Level	**Suitable (Grade I)**	**More suitable (Grade II)**	**Less suitable (Grade III)**	**Limit construction (Level IV)**	**Prohibition of construction (Grade V)**
Overall score	0.8–1.0	0.6–0.8	0.3–0.6	0.1–0.3	0–0.1

4. Application of model

4.1. Dataset

The data selected in this paper are from a city in south China, and the basic data include Geological fault zone, geological sensitive element, Soil condition, and soil condition. Engineering geology and Electronic background. The basic data and types are shown in **Table 2**.

Table 2. Data sources for the suitability evaluation of underground space development in the study area.

Evaluation data	**Data source**	**Data types**
Geological fault zone	Hydrology Engineering Geology Brigade	grid
Ecologically sensitive element	Urban system planning and master planning	grid
Soil condition	Hydrology Engineering Geology Brigade Special projects for the development and utilization of urban underground space planning	grid
Engineering geology	Special regulations for the development and utilization of urban underground space draw	grid
Electronic background	General background electronic map for urban underground space planning and management	vector

4.2. Analysis of suitability influencing factors

In the development area of urban underground space, in view of the fact that many factors such as natural ecology, geological environment and geological disasters have different action mechanisms and influence degrees, the suitability evaluation factors of underground space development can be classified into two categories: One is the limit factor, which has the nature of "veto by one vote". As long as it is in the restricted area, the underground space development is not feasible, and its influence is constant, and it will not be replaced or changed by other factors, which completely locks up the development possibility. The second factor is the degree factor, which only exerts a degree influence on the development and utilization of underground space. Even if its own value reaches the limit, it cannot completely block the development process by itself. After all, the final development is limited by the comprehensive effect of all factors in the region, and its negative impact may also be "neutralized" by other factors, which does not constitute an absolute obstacle.

For the limit elements, the exclusion method is usually used to show its restriction, that is, to investigate and eliminate each limit element one by one, so as to define the development restriction area. When evaluating the impact of degree elements, it is necessary to rely on the data obtained from the qualitative and quantitative analysis of degree elements, with the help of the evaluation method and model constructed in this paper, integrate into the GIS platform, and use GIS technology to achieve the evaluation work.

4.2.1. Element of limit

The limit elements should not only consider the difficulty of engineering construction brought by geological conditions to the development and utilization of underground space, but also take into account the development restriction requirements based on natural environment protection and ecosystem maintenance to prevent the development of underground space from having a negative impact on the earth environment. When assessing the impact of such factors, the limit condition method is used, that is, the area affected by the limit factors is precisely locked and eliminated, and it is delimit as the forbidden development zone. After the areas containing limit elements are controlled, the remaining space can be reasonably planned and scientifically evaluated according to the regulations, and the orderly development of underground space can be assisted.

The limit elements of this paper include two aspects: first, the area affected by geological fault zone. Geological fault zone is a bad geological condition, which will seriously hinder the development of urban underground space. When carrying out the suitability evaluation of urban underground space development, the development of underground space in this area must be strictly prohibited, and it must be listed as the limit element and excluded. Second, urban planning defines areas where the development and construction of underground space are prohibited, as well as ecological protection areas and special land areas. This kind of area focuses on ecological construction and belongs to non-urban construction land. In order to avoid ecological disasters and damage, it is absolutely prohibited to carry out urban underground space development activities, which should also be set as the limit element and removed from the development consideration scope.

4.2.2. Element of degree

The degree element covers indicators such as rock engineering geology, groundwater corrosion and earthquake risk. According to their respective development degree and existence situation, the size of the impact on the development of underground space should be measured, and qualitative grading and quantitative scoring should be carried out. In the qualitative analysis of evaluation factors, with the help of expert analysis evaluation method, the gradient equilibrium evaluation level is obtained. In quantitative decision-making, the corresponding evaluation value can be determined according to the principle of equal division. If the influence degree of the factors shows a continuous linear change rule, the linear function principle is used to implement standardized evaluation and valuation of the index.

Considering the different impacts of different rock strata and soil conditions on the development of urban underground space, qualitative grade differentiation work is carried out for engineering geology, and quantitative score assessment is implemented simultaneously. As shown in **Table 3**.

Table 3. Classification and grading of engineering geology.

Level	Types	Scoring
I	Suitable construction area	0.8
II	Moderate control over construction areas	0.6
III	Moderately controlled construction area	0.1

Based on the difference of the distribution characteristics of different groundwater on the development of urban underground space, and the corrosion of groundwater has a great impact on the development of urban underground space. According to the distribution of corrosive groundwater in the region, qualitative classification and quantitative evaluation of groundwater corrosion are made. As shown in **Table 4**.

Table 4. Grade and score of groundwater corrosiveness.

Level	Types	Scoring
I	No pollution zone	1
II	Phenol, NO_3 pollution area	0.1

According to the actual impact of earthquake risk on the development of urban underground space, the earthquake hazard level is divided qualitatively, and the quantitative score evaluation is carried out simultaneously. As shown in **Table 5**.

Table 5. Seismic suitability rating and scoring.

Level	Types	Scoring
I	Low risk area	0.7
II	Sub-risk area	0.5
III	High risk area	0.1

4.3. Results and Analysis

4.3.1. Results of geological suitability assessment

The suitability evaluation results of geological environment in this study area are shown in **Figure 1**, which can provide reference for the overall planning of underground space in this city.

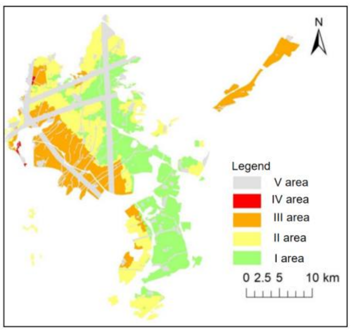

Figure 1. Distribution map of geological environment suitability evaluation results for underground space development.

According to the evaluation score classification results, combined with the actual analysis of urban geological conditions, the suitability evaluation is divided into five levels:

Grade I suitable construction area: excellent geological conditions, almost no adverse geological phenomena. The development and construction of underground space in this area does not require additional protection measures, and the cost is economical, so it is the first choice for the development and construction of urban underground space.

Grade II is more suitable for construction area: there are a small number of adverse factors in the area, but their influence is weak and not dominant. During construction, do a good job of waterproof, drainage, reinforcement slope protection such simple preventive means, can avoid the impact, the overall cost of the project is not high, belongs to the category of development.

Grade III is less suitable for construction area: there are some significant adverse factors in this area, which need to be reduced by more complex construction technology and waterproof technology, but it is difficult to completely eliminate. The process technology in the construction is complex and the cost is high. If there is no special necessity, it is generally not recommended to develop.

IV Restricted construction area: poor geology, underground construction danger zone, unfavorable factors or intractable dominant factors. Development and construction require extremely difficult protective measures, and may damage adjacent buildings and facilities. Unless there is an urgent need for development, it is usually not developed. If the special linear and network facilities are planned to be traversed, in-depth research and demonstration are needed, and comprehensive preventive protection means are prepared for development.

Level V Prohibited construction area: adverse factors contain major security risks, which are easy to cause serious harm. Once an accident occurs, it will cause a large area or even devastating blow to underground space facilities. It is strictly prohibited to develop underground space here.

4.3.2. Effect evaluation of comprehensive governance strategy

The integration of legal regulation and biomechanical considerations can not only resolve the current problem of rights conflicts, but also build a solid foundation for scientific guidance and provide strong technical support for the future development of underground space.

1) Ease the conflict of rights

In the process of high-rise building underground space development, the city has encountered many rights disputes, such as differences in underground space land transfer fees, unclear ownership of underground air defense projects, and disputes over the ownership of underground garages in residential areas. In this regard, the municipal government has actively acted and launched a series of targeted policy measures. On the one hand, the detailed content and scope of the land use right of underground space are clearly defined, and the chaos of repeated transfer and excessive charge is put an end to. On the other hand, a standardized and unified approval process for underground space development should be established to strengthen the supervision of projects such as underground air defense projects and residential underground garage, so as to make them conform to national safety standards. In addition, the biomechanical evaluation model is introduced in the early planning stage of underground space development to help improve project quality and reduce potential risks. Under the combination of various measures, the contradictions between the parties were effectively eased, and the project was promoted more smoothly.

2) Open up a new mode of development

In addition to resolving the rights conflict, the city is also based on the local situation and guided by the comprehensive governance strategy, actively exploring the suitable underground space development mode. For example, in order to deepen the value of limited urban land resources, the municipal government encourages developers to synchronously plan functional plates such as underground commercial streets and parking lots when constructing new high-rise buildings, and promotes the formation of a coordinated development pattern of above-ground and underground. At the same time, the PPP model is used to introduce social capital into the development and operation of underground space, so as to achieve a win-win situation between the government and enterprises, which not only enriches the supply of urban public services, but also raises the value of land, and reap the double harvest of economic and social benefits.

3) Help cities move forward sustainably

In the long run, comprehensive governance strategy plays a decisive role in urban sustainable development. Firstly, improve the legal system, clarify the right boundary of underground space, and build a solid system “protective wall” for the efficient utilization of urban underground space resources. Second, strengthen interdisciplinary collaboration to create a harmonious and orderly underground space environment; Thirdly, adhering to the concept of ecological protection and disaster prevention, ensuring that the development of underground space is non-destructive to the natural ecology, and enhancing the “hard power” of the city to resist natural disasters. In a word, this comprehensive management strategy of the city has provided valuable experience samples for itself and even other cities, which is beneficial to the scientific development of urban underground space resources and promotes the social benefits to a new high.

4.3.3. Enhancing governance of underground space development

1) Amendments to Legal Framework

To strengthen the governance of underground space development, it is essential to establish detailed regulations that clearly define and delineate the scope of underground space use rights. Such regulations should prevent ambiguous interpretations by clearly outlining the extent of rights associated with different levels of underground space, ensuring transparency and fairness in transactions. Standardized procedures for approving underground projects must also be introduced, incorporating biomechanical assessment criteria into the approval process. This includes mandatory pre-construction assessments and periodic reviews to ensure ongoing compliance with safety standards. Additionally, transparent mechanisms for resolving disputes related to underground space development should be developed, protecting all stakeholders' interests. Establishing mediation and arbitration services can facilitate swift conflict resolution without resorting to lengthy litigation.

2) Integration of Biomechanical Assessments

Mandatory inclusion of biomechanical assessments in urban planning stages is crucial for evaluating the impact of proposed developments on soil stability and groundwater flow. GIS-supported models can provide accurate predictions of potential risks, enabling proactive measures to mitigate adverse effects. Promoting interdisciplinary collaboration between legal experts and engineers will help develop comprehensive guidelines for safe and sustainable underground space development. Joint workshops and seminars can foster knowledge exchange and build consensus on best practices. Continuous monitoring and updating of biomechanical models based on new data and technological advancements are also encouraged to ensure long-term safety. Real-time monitoring systems can provide early warnings of any changes in subterranean conditions, allowing for timely interventions.

3) Promotion of Sustainable Development Practices

Policies should prioritize green building practices and the preservation of natural habitats to minimize disruption to underground ecosystems. Developers should be incentivized to adopt environmentally friendly techniques that support sustainability. Furthermore, research initiatives aimed at improving our understanding of the long-term effects of underground construction on local geology and ecology should be supported. Funding for such studies can lead to innovations in construction methods and materials that promote sustainability. By implementing these recommendations, cities can better manage the complexities associated with underground space development, reducing rights conflicts and enhancing overall project quality while promoting efficient land use, social harmony, and environmental protection.

5. Conclusions

By combining legal norms and biomechanical considerations, this paper systematically solves the conflict of rights in the development of underground space of high-rise buildings, formulates clear rules for the right to use underground space, avoids repeated charges, and establishes a scientific approval process to ensure the safe construction and management of underground facilities. The biomechanical evaluation model supported by GIS was introduced to optimize the underground space planning and reduce the engineering risk. Specific policy recommendations include: developing detailed regulations to clarify the content and scope of underground space use rights, introducing standardized approval procedures and incorporating biomechanical assessments, and establishing transparent dispute resolution mechanisms to protect the interests of relevant parties; Mandating biomechanical assessments at the urban planning stage, using GIS models to provide accurate risk predictions, promoting interdisciplinary collaboration and encouraging continuous monitoring and technological updating; Prioritize green building and natural habitat conservation, incentivize the application of environmentally friendly technologies, and fund long-term effects research to improve construction methods and materials. These measures not only promote the smooth implementation of the current project, but also provide valuable experience for the rational use of urban underground space resources and maximize social benefits in the future, and promote the sustainable development of the city.

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