

Study on Topological Relationship Construction and Automated 3D Modeling of Rainwater Pipe Network

Wangqiang Xu*

School of Geomatics and Urban Spatial Informatics, Beijing University of Civil Engineering and Architecture, Beijing, China

*Corresponding Author: Wangqiang Xu (2108160322005@stu.bucea.edu.cn)

Abstract

Underground pipe network is an important infrastructure of the city. At present, there are problems in the three-dimensional pipeline modeling, such as chaotic pipeline topological relationship and imprecise pipeline model. For example, rainwater pipes are all at the same horizontal position, and do not have slopes like real pipelines. Therefore, this paper focuses on the construction of point-line topological relationship of rainwater pipe network, and the rapid realization of the automatic construction of three-dimensional rainwater pipe model with slope. This study uses the two-dimensional pipeline data shapefile as the data source, and names the pipe segment and pipe point with unique values as the primary key; and creates a method to quickly add the starting point name and the end point name of the pipe segment in the pipeline attribute table as the pipeline table, so as to achieve the purpose of quickly establishing topological relationship for a large amount of pipeline data. Then, based on the Feature Manipulate Engine (FME) platform, the two-dimensional pipe network data with completed pipe network topological relationship construction is parametrically modeled according to the attributes of the pipe network. Taking the Shangqiu ancient city data as an example, the construction of 614 pipelines and 621 pipe well models was completed within 5.3s, and the pipelines all have real slopes. This shows that the method proposed in this paper effectively improves the accuracy of the model and is superior in efficiency, and can play an important role in smart city management.

Keywords

Pipeline Network Topology Construction; FME; 3D Pipeline Modeling.

1. Introduction

Urban underground pipelines are an indispensable infrastructure in urban construction, and they provide an important guarantee for the normal operation of the city[1]. Underground pipelines are large in scale, diverse in types, widely distributed, and complex[2]. Knowing the exact number and spatial layout of underground pipelines is the basis of urban management and planning, and is also an important means to prevent disasters and reduce pipeline accidents[3]. In addition to providing necessary infrastructure support for citizens' lives, the construction and management of underground pipelines are also directly related to the future development of the city.

Traditional underground pipelines are mainly expressed with CAD and Shapefile, which makes it difficult to effectively describe and express a large amount of pipeline information[4]. With the continuous advancement of 3D visualization technology, 3D visualization of underground pipelines has gradually become the focus of attention[5]. Through 3D visualization, the geometric shape, location and spatial relationship between underground pipelines can be presented intuitively and

clearly, providing strong information support for the planning, design and management of underground pipelines[6, 7].

Ren Lifu[8] used Bentley software to build a model based on survey data, achieving the visualization and information management functions of the pipeline network model. Tang Xiaoli et al. [9] successfully implemented automatic pipeline modeling based on the SuperMap platform. Zihé Hu et al.[10] extracted modeling parameters from pipeline network survey data and constructed three-dimensional pipeline segment and pipeline point models using parametric modeling algorithms.

At present, three-dimensional pipeline modeling faces the problems of unclear pipeline topological relationship and insufficient pipeline model accuracy. Therefore, this study uses the two-dimensional pipeline data shapefile as the data source and proposes a method to quickly add the start and end point names of the pipeline segment in the pipeline attribute table, so as to quickly establish the topological relationship between the pipeline point and the pipeline for a large amount of pipeline data. Using the FME platform, the two-dimensional pipeline network data is parametrically modeled through the pipeline network attributes, and the construction of the pipeline network topological relationship is completed. The underground rainwater pipeline data of Shangqiu Ancient City was successfully applied as an example.

2. Materials and Methods

2.1 Pipeline Network Original Data Structure

If the original data of the pipe network is in CAD format, the CAD data is first converted into shapefile format using FME software, and the missing attributes of the pipe points and lines need to be supplemented. The pipe network data can be clearly divided into two categories: pipe wells and pipe sections. The attribute tables of pipe points and pipe segments are shown in Table 1 and Table 2 respectively.

Table 1. Pipe point attribute table.

ID	X	Y	depth	Ground elevation	Well-bottom elevation	Node shape	Node Types	Geometry Size
1	x	y	1.2	100	99	columnar/ Square	Inspection well/ Rainwater well	Diameter/ Length*Width
...

Table 2. Pipeline attribute table

ID	pipeline Types	Length	Geometry Size
1	Circular Tube	2.0	Diameter
...

2.2 Methods

2.2.1 Topological Relationship Construction of Pipeline Points and Pipelines

First, the pipe points need to be named with unique values. The naming rule is MP plus OBJECTID value. Since OBJECTID is a unique value, the point name is also a unique value, and the point name is used as the primary key of the pipe point attribute table. Similarly, the naming rule for the pipe segment is: use the Python expression "ML!OBJECTID!" in the calculation field of ArcGIS Pro

software to name it as ML plus OBJECTID value, that is, the line name is also used as the primary key of the pipeline. The advantage of this naming is that it is efficient and unique.

This study adds the starting point name and the end point name of the pipe segment in the line table as the foreign key of the pipeline table to achieve the purpose of establishing a topological relationship. Due to the large number of pipelines, how to quickly and automatically add the starting point and end point names of the pipe segment becomes a problem? The starting point of the pipe segment can be intuitively seen from the vector diagram of the pipe network point line, as shown in Figure 1.

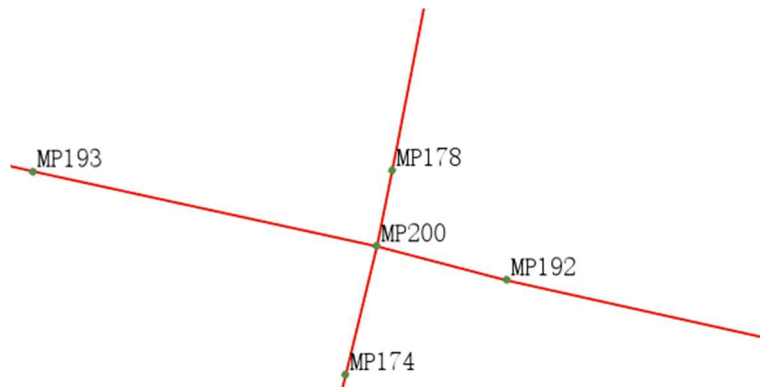


Figure 1. Pipeline network point and line local vector diagram

The attributes of the point names at both ends of the pipe segment can be added twice by applying the spatial connection under Toolbox/Geoprocessing/Analysis Tools in ArcGIS Pro. For the first merge, select the first merge rule, and for the second merge, select the second merge rule. This ensures that the two connection points are exactly the two ends of the pipe segment.

The starting point name and the end point name of the pipe section are obtained, but the order of the starting point name and the end point name may be incorrect, so it is necessary to correct it according to the size of the bottom elevation of the two ends of the pipe section. Since rainwater drainage mainly relies on gravity flow, the starting elevation of the bottom of the pipe section is greater than the end point elevation of the pipe section. That is, if the starting point elevation is greater than the end point elevation, then the order of the starting point name and the end point name is correct, otherwise the starting point name and the end point name need to be swapped. The method to correct the starting point and the end point is as follows: first, assume that the point matched for the first time is the starting point, the field is renamed S, and the elevation of the starting point of the pipe section (the elevation of the bottom of the pipe well) is SH; the point matched for the second time is the end point, the field is renamed E, and the elevation of the end point of the pipe section is EH; create a new field called "starting point name", and use the custom change function in the calculation field to get the real starting point. The change function is defined as:

```
def change (SH, EH, S, E):  
    if SH<EH:  
        return E  
    else:  
        return S
```

It is also necessary to create a "field for the end point name" whose change function definition is exactly the opposite of that of the starting point. By deleting the redundant fields in the pipeline attribute table, you can get the attribute table with the name information of the starting and ending points of the pipeline added, thus establishing the topological relationship between the pipeline point and the pipeline.

2.2.2 Parametric Modeling of Stormwater Pipelines Based on FME

(1) Construction of 2D Lines in 3D Space

According to the topological relationship between the pipe points and the pipelines, a complete pipeline attribute table is formed. The complete pipeline attribute table includes the information of the three-dimensional coordinates (X, Y, H) of the starting point and the end point. Then the two-dimensional pipeline in the three-dimensional space is generated using the complete pipeline attribute table. The entire workflow of the parametric modeling of the rainwater pipeline based on FME is shown in Figure 2.

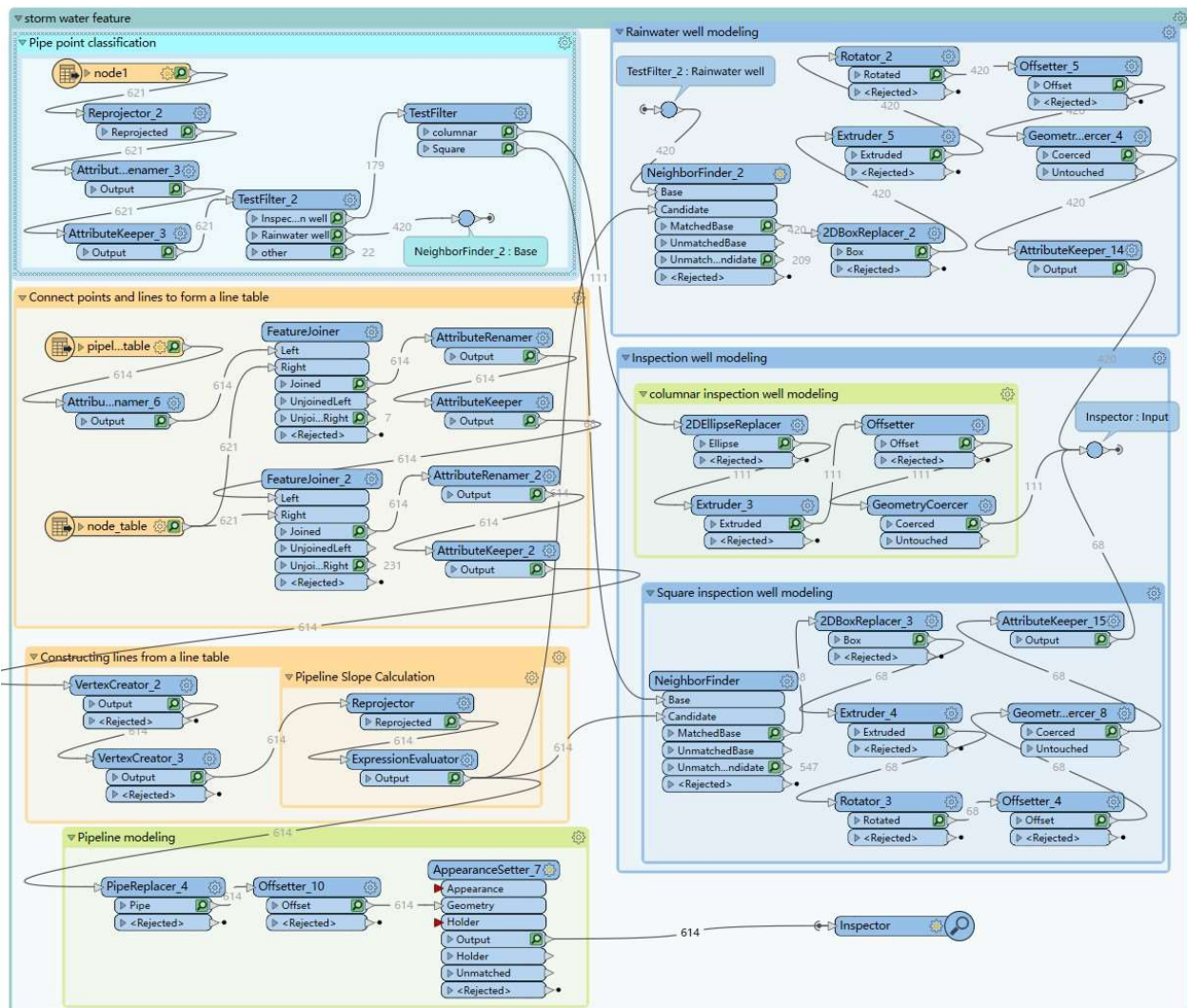


Figure 2. Pipeline Network Modeling Workflow in FME

Specifically, the FeatureJoiner transformer is first applied to match the point name attributes twice, and the attribute matching of the start point and the end point is connected to the pipeline table. Then, the VertexCreator transformer is used to divide the start point and the end point of the pipeline segment twice, and the LineBuilder transformer is used to generate a two-dimensional pipeline in three-dimensional space. The slope of the pipeline is then calculated using the slope formula.

The difference between a two-dimensional pipeline in three-dimensional space and a two-dimensional pipeline in a two-dimensional plane is that the two-dimensional pipeline in three-dimensional space expresses the elevation of the pipeline segment, rather than just expressing the elevation in the form of attributes, which paves the way for the pipeline segment model to have a real slope. With the two-dimensional pipeline in the three-dimensional pipeline, parametric modeling can

be performed based on the semantic information (geometry, location and other attributes) of the pipeline.

(2) Parametric Modeling

The modeling of the pipe segment is done by using the PipeReplacer transformer to make a cylindrical surface with a radius along the 2D pipeline in the 3D pipeline as the axis, as a circular pipe model. Since the 2D pipeline in the 3D space is already in the correct spatial position, its model inherits this point. The elevation of the pipeline refers to the elevation of the bottom of the pipeline. If the elevation of the pipeline after modeling is less than the height of the radius length of the pipe segment, the Offsetter transformer can be used to lift the radius length upward for correction.

Pipe wells can be divided into rainwater wells and inspection wells by type; pipe wells can be divided into round wells and square wells by shape. Rainwater wells are all square wells, and inspection wells are square wells and round wells.

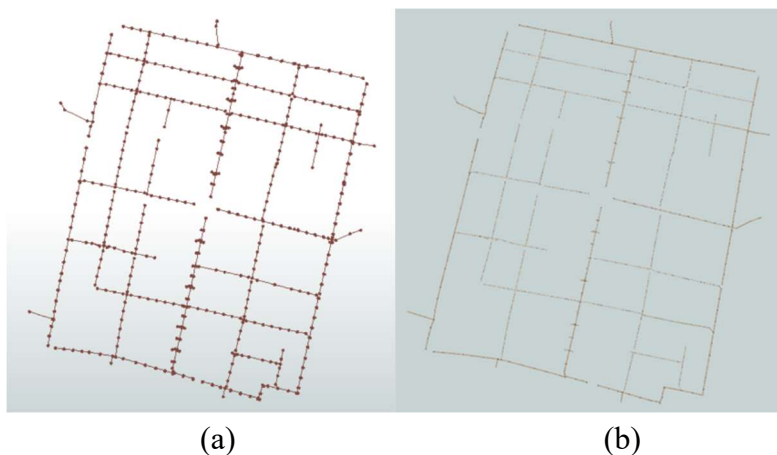
Circular well modeling: First, you need to import the pipe point data in shapefile format in FME, and filter out the pipe points with the pipe point type as circular pipe wells through conditional judgment statements. Use the 2DEllipseReplacer transformer to make a plane circle with the pipe point as the center and the diameter of the well as the size, and then use the Extruder converter to longitudinally stretch the height of the well to obtain the circular well model.

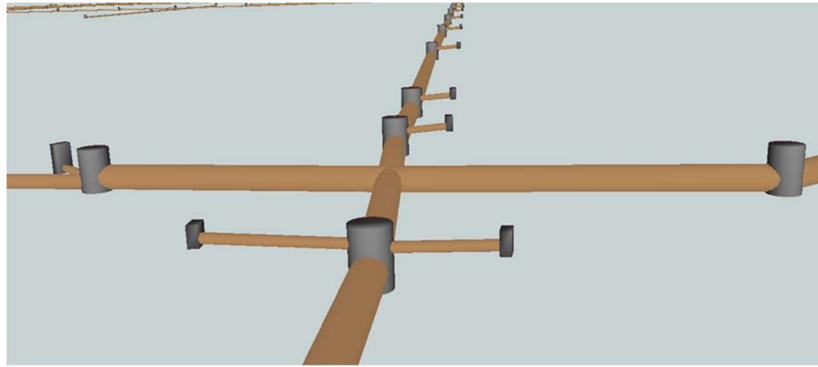
Square well modeling: The modeling of square wells is similar to that of circular wells, except that the pipe point data in shapefile format needs to be used to construct a rectangle with the pipe point as the center according to the length and width of the well through the 2DBoxReplacer transformer, and then the Extruder converter is also used to perform longitudinal stretching according to the height of the well.

In addition, the difference is that square wells have a direction distinction, while circular wells do not. The direction of the square well should be perpendicular to the direction of the pipeline so that the pipeline is orthogonal to the pipe well. The NeighborFinder transformer can be used to find the nearest pipe (Base port) to each pipe well. This transformer also adds the angle of the candidate to the base feature. Once we build a three-dimensional model of the square well, we can use this angle plus 90° as the parameter of the Rotator transformer to rotate the model so that the square well is orthogonal to the pipeline.

3. Results

This study applied the 3D pipeline modeling process designed based on the FME platform to model the underground rainwater pipelines in the ancient city of Shangqiu. The construction of 614 pipelines and 621 pipe well models was completed within 5.3 seconds. The pipeline models all have real slopes. The comparison before and after 3D modeling is shown in Figure 3, and the modeling operation is shown in Figure 4.





(c)

Figure 3. Before and after comparison of 3D pipeline modeling. (a) Two-dimensional pipe network; (b) Macroscopic view of 3D pipe network modeling results; (c) Microscopic view of 3D pipe network modeling results

```
-----  
                          Features Read Summary  
-----  
node1                      621  
node_table                  621  
pipeline_table              614  
-----  
Total Features Read        1856  
-----  
                          Features Written Summary  
-----  
Total Features Written      0  
-----  
~  
~   Feature caches have been recorded at every stage of the translation.   ~  
~           To inspect the recorded features,                               ~  
~           click the feature cache icons next to the ports.               ~  
~  
-----  
Translation was SUCCESSFUL with 8 warning(s) (0 feature(s) output)  
FME Session Duration: 5.3 seconds. (CPU: 2.1s user, 0.5s system)  
END - ProcessID: 25472, peak process memory usage: 157524 kB, current process memory usage: 116328 kB  
Translation was SUCCESSFUL
```

Figure 4. Summary of FME program operation

4. Conclusion

This study proposes a method to quickly construct point-line topological relationships, and uses the FME platform to design an automated 3D modeling workflow for underground rainwater pipelines. The underground rainwater pipeline network data of Shangqiu Ancient City is applied to this process, which can quickly parameterize the 2D pipeline and pipe point data according to the attribute information of the pipeline network. It effectively overcomes the problems of no slope in the pipeline model and disordered topological relationships between the pipe point and pipeline model.

At present, the 3D modeling of the pipeline network in this study only stays on the surface of the pipeline network, and fails to realize the visualization and analysis of the inside of the pipeline network, such as the inside of the pipe well. In the development of smart cities, detailed pipeline network models are crucial for urban emergency response.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Acknowledgments

The author would like to thank Dr. Guoyin Cai from the School of Geomatics and Urban Spatial Informatics at Beijing University of Civil Engineering and Architecture for helpful discussions on topics related to this work.

References

- [1] S. Wang et al., "A Hybrid Framework for High-Performance Modeling of Three-Dimensional Pipe Networks," *ISPRS International Journal of Geo-Information*, vol. 8, no. 10, p. 441, 2019. [Online]. Available: https://kns.cnki.net/kcms2/article/abstract?v=YvzTZTPVeK6IJEYm3BP4jgDNYDboVnNqZDr3kT3Tatbg72LC9X64JFZ5bunvbaOw6Xs-b-_Hw9mbB9jnFp5s52vW5QqHqrvePg0X2UmDZ6gITn9UrLA888NF7Rrh4vEqhV8RoBF8I8XT4RHPZmiRPY7yt6QUiVbMxFlsOUS00BDwQG3q7CLw0jY-V5nUYpW0ul9nEPwVPPxuGMpBnjIAuxw5bfspRQYn&uniplatform=NZKPT&language=CHS.
- [2] Hunter, Brooking, Reading, and Vink, "A Web-based system enabling the integration, analysis, and 3D sub-surface visualization of groundwater monitoring data and geological models," *International Journal of Digital Earth*, vol. 9, no. 2, pp. 197-214, 2016. [Online]. Available: https://kns.cnki.net/kcms2/article/abstract?v=YvzTZTPVeK7ESSxyQ5joujrjseQaes03YnNItvIy0eRqBForxbwIHeD-v1GisnoUeUza9X6FxxXC8TbG4hN-_S7ub9tObFhjqtZ3Bf1J957bQsnkdQ3CITD97TdnIMWXNmiNwP8xI43Ao-ERgUk5zDfebZ1WRwNG2nH9hYKbFgS3hz811kS4FaOXK8J43YtTts_6F8MhpUgYOxMdBtVnZcZT_A8tLWcvl&uniplatform=NZKPT&language=CHS.
- [3] C. Yiqun, S. Erfan, R. Abbas, and S. Soheil, "From IFC to 3D Tiles: An Integrated Open-Source Solution for Visualising BIMs on Cesium," *ISPRS International Journal of Geo-Information*, vol. 7, no. 10, pp. 393-393, 2018. [Online]. Available: https://kns.cnki.net/kcms2/article/abstract?v=YvzTZTPVeK4dNk8DGd8MY_2-2SgUWzxqfFsG05-pckBOFJAdQLNrd-CVqxg4y0Xpqqnl_m4dK9staDKgJLzuN-slul_QeohNCZw1Aw26f-aUsx9ud6XWLJp5mgfbrKrZvbkCvXFsmv3ZLQGQuGIDCrR-bVQu0kVZcJbN2TphLgnilISbnJOFYVOIX2nohx8tikCEVvZR547T45g96GBXm3bIIRIQA03&uniplatform=NZKPT&language=CHS.
- [4] J. Heaton, A. K. Parlikad, and J. Schooling, "Design and development of BIM models to support operations and maintenance," *Computers in Industry*, vol. 111, pp. 172-186, 2019. [Online]. Available: https://kns.cnki.net/kcms2/article/abstract?v=YvzTZTPVeK7RmsAkd2tsRW_MdyGsM4Dk8XUP0nVaOCF2RwB4IDK89-fnU794kPW3w3gjAsnYGTQVif_bkRBPeIAs-x9PS7jPzi5jpUOkfe3OPSpl174kIV0kmbJEUftlxE9PlSsRdgqscwU-1legsQnaWAB7gRgCXuN4I7BVzU7EJRS81wt48Cd9fu6UrWON80_stHEfdlUmEMA6Nufjs-EfALbH_Ffi&uniplatform=NZKPT&language=CHS.
- [5] H. M. Mehrab and A. Shakil, "Developing an automated safety checking system using BIM: a case study in the Bangladeshi construction industry," *International Journal of Construction Management*, vol. 22, no. 7, pp. 1-19, 2019. [Online]. Available: https://kns.cnki.net/kcms2/article/abstract?v=YvzTZTPVeK79nrAgw9RZeO5BLJicAeNY8VvY4xmInhCmz4fc9eke_Hwe96hxayl7c2JHHeFjSwLuanpcjmyWyp7My_LE_37YA5UPY0vfmf7jPVSwkjoN60Sz1tmD77NHvTrSonZ3zUsO6QGf1iHoS2Z8s1ghV8BrsiQjRzrJWVst5U_phXK3D891MwNFf5K9gKI86F4psFmftCgWsKM0I2S4vwMrNGD&uniplatform=NZKPT&language=CHS.
- [6] C. J. H. R. G. X. W. Feng, "Building Information Modeling-Based Secondary Development System for 3D Modeling of Underground Pipelines," *Computer Modeling in Engineering & Sciences*, vol. 123, no. 2, pp. 647-660, 2020. [Online]. Available: https://kns.cnki.net/kcms2/article/abstract?v=YvzTZTPVeK6XT9cpUm-9fRT7en28aBuOsQIU9h3YUHexEutlqOEyGc-sLCq2sa3rc8xyXWk353mr6f_s2Yosljkf7-spaTBW7ytiRsCEWMjtxIgt5UtGnVgAXQ4F3qt4_NIQL8s1IAMoT955IUjCaTCvV8206exYSB7wd0CAgGF-zBXvWJXLwuUNmFipWYWgefRGfQTuhLAMrraX_xBbjwGdYSygp85c&uniplatform=NZKPT&language=CHS.

- [7] Y. Li, J. Yang, X. Shen, and Y. Ma, "Application Research on Construction Management of Urban Underground Utility Tunnel Based on BIM," IOP Conference Series: Earth and Environmental Science, vol. 295, p. 042133, 07/25 2019, doi: 10.1088/1755-1315/295/4/042133.
- [8] R. Lifu, "Application analysis of underground pipeline modeling based on BIM technology," Bulletin of Surveying and Mapping, no. 02, pp. 149-152, 2021.
- [9] T. Xiaoli, L. Shunjie, G. Hongcao, and X. Wenqiang, "Three-dimensional Automatic Modeling of Underground Pipelines Based on SuperMap Platform," Urban Geotechnical Investigation & Surveying, no. 06, pp. 40-43, 2021.
- [10] Z. Hu, J. Guo, and X. Zhang, "Three-Dimensional (3D) Parametric Modeling and Organization for Web-Based Visualization of City-Scale Pipe Network," ISPRS International Journal of Geo-Information, vol. 9, no. 11, p. 623, 2020. [Online]. Available: <https://www.mdpi.com/2220-9964/9/11/623>.