Building Information Modeling-Based Secondary Development System for 3D Modeling of Underground Pipelines

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Abstract: Underground pipeline networks constitute a major component of urban infrastructure, and thus, it is imperative to have an efficient mechanism to manage them. This study introduces a secondary development system to efficiently model underground pipeline networks, using the building information modeling (BIM)-based software Revit. The system comprises separate pipe point and tubulation models. Using a Revit application programming interface (API), the spatial position and attribute data of the pipe points are extracted from a pipeline database, and the corresponding tubulation data are extracted from a tubulation database. Using the Family class in Revit API, the cluster in the self-built library of pipe point is inserted into the spatial location and the attribute data is added; in the same way, all pipeline instances in the pipeline system are created. The extension and localization of the model accelerated the modeling speed. The system was then used in a real construction project. The expansion of the model database and rapid modeling made the application of BIM technology in three-dimensional visualization of underground pipeline networks more convenient. Furthermore, it has applications in pipeline engineering construction and management.

Keywords: Building information modeling, secondary development, underground pipeline, 3D modeling, visualization.

1 Introduction

Building information modeling (BIM) technology has been widely used since it was first introduced in 1974 [Li, Li, Peng et al. (2018)]. BIM is an intelligent 3D model-based process that provides architecture, engineering, and construction professionals with the insights to plan, design, construct, and manage buildings and infrastructure more efficiently [Akhoundan, Khademi, Bahmanoo et al. (2018)]. It is one of the significant

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technological advancements in recent years and has been put to use in the construction industry [Smith (2007); Liu and Li (2009); Heaton, Parlikad and Schooling (2019); Charef, Emmitt, Alaka et al. (2019)]. It comprises a sharable collection of knowledge resources that provides a numeric representation of the geometric attributes of construction projects. The popularity of BIM can be attributed to several useful features such as visualization, coordination, optimization, and full-cycle application [Goedert and Meadati (2008); Sun and Zhang (2016)]. BIM allows the creation of an accurate virtual model of a building, which is first digitally constructed. This model can be used throughout the entire value chain from design to demolition, allowing all the stake holders to work collaboratively rather than in a fragmented manner [Charef, Alaka and Emmitt (2018)]. Architects and contractors use BIM to reduce document errors, improve work flows, and support coordination during construction [Franz and Messner (2019)]. The most frequently reported project benefits of BIM are related to cost reduction and control through the project life cycle. Significant time savings were also reported [Bryde, Broquetas and Volm (2013)]. The safety of the project and the construction workers are increasingly important in the process of project construction. The application of BIM in several safety-related issues has a significant impact, and it has to be developed by adopting the BIM technology [Enshassi, Ayyash and Choudhry (2016)]. Hazard identification, minimization, and fall-prevention planning are the most important safety-related applications [Hossain and Ahmed (2019)].

Underground pipeline networks facilitate the transfer of material and information within urban areas. As new construction projects involving underground infrastructure are undertaken, several new types of underground pipelines are being introduced. Pipeline engineering is one of the most important parts of a construction project. Because most pipelines are in the underground space, the relationship between pipelines and other buildings is important for the safety of the construction process and the latter management and maintenance of the project. BIM technology is increasingly being used in pipeline engineering. BIM was used in the underground pipeline construction to avoid unnecessary construction problems because of imperfection of relevant technical specifications [Liu (2018)] and realizing visualization, information, and refined management [Qi, Zhang and Wang (2019)]. By applying BIM technology throughout all stages, including design, construction, and operation, Xu [Xu (2017)] implemented real-time simulation of transportation and construction process of various pipelines and formed a 3D working scheme so as to avoid hidden danger and conflict in construction. Ruan et al. [Ruan, Guo and Huang (2016)] applied the BIM technology in the design and construction phase and provided accurate data for operation, consequently saving overall management cost. There have been studies attempting to improve the BIM technology. Liu et al. [Liu and Issa (2012)] used a combination of a graphic information system and BIM to develop an underground pipeline management model. Chang et al. [Chang and Lin (2014)] introduced an automatic management system for roads and underground pipelines. Yang et al. [Yang and Song (2015)] developed a collision detection method for urban drainage pipelines. Wu et al. [Wu and Hu (2016)] were able to reduce errors in pipeline modeling and increase the modeling accuracy by using the collision detection function of BIM software and artificial recognition. Chen et al. [Chen, Guo, Hu et al. (2018)] achieved a 3D fusion of the superficial structure and the engineering information of an underground space, creating a precise visual representation of the spatial position, material, and function of pipelines and other underground facilities.

Despite these achievements, traditional pipeline management systems are not yet adequately equipped to face the challenges due to complexities presented in modern pipeline networks. There exist no sufficiently accurate high-speed methods for modeling underground pipelines. The operational costs associated with BIM hardware and software have been recognized as the main obstacle in BIM implementation in the past [Lu, Fung and Yi (2014)]. The "B" in BIM stands for BUILDING. The initial application scope is mainly for surface building. Because BIM is used predominantly in non-underground construction, there is a lack of special cluster databases for underground pipelines. Revit and other BIM-based software are not sufficiently localized. Several design parameters do not meet domestic design specifications, and some of the clusters in the software do not conform to domestic size standards [Li, Huang and Wang (2015)]. 3D models of underground pipelines contain large amounts of data in various formats and complex spatial relationships, resulting in inefficient visual presentation [Bi and Zhou (2014)]. The core Revit software is incapable of addressing this. As a solution to these problems, this paper performs secondary development on Revit to create a high-speed 3D modeling system for underground pipelines while expanding the existing cluster database. The secondary development process is described in detail. In order to validate the system, a case of 3D visual expression of underground pipelines is presented.

2 Design of secondary developed fast visualization function

The secondary development process involved creating a dynamically loaded library (DLL) files containing the pipeline modeling functions, and then loading these files into Revit. This process combined an external application and an external command. The functionality of Revit is enhanced through an API based on the Visual Studio 2013 (Microsoft Corporation, The USA) platform and the C# programming language. Two DLL files are required to create a function expansion module: a plug-in button for the external application development and the main program for the external command development. The entire process is illustrated in Fig. 1.

2.1 External application program

This section introduces in detail the development of the Revit plug-in. The button for the 3D pipeline model is derived from the "IExternalApplication" interface. The main program adds the application of 3D pipeline modeling through IExternalApplications interface. "OnStartUp()" and "OnShutdown()" are two inner abstract functions of Revit API, which are reloading methods. The parameter types are all UIControlledApplication. First, the inner basic cluster is created using Visual Studio 2013. Then, the DLL files of RevitAPI. dll, RevitAPIUI.dll, and PresentationCore.dll are loaded into the software. This process can be completed in four steps:

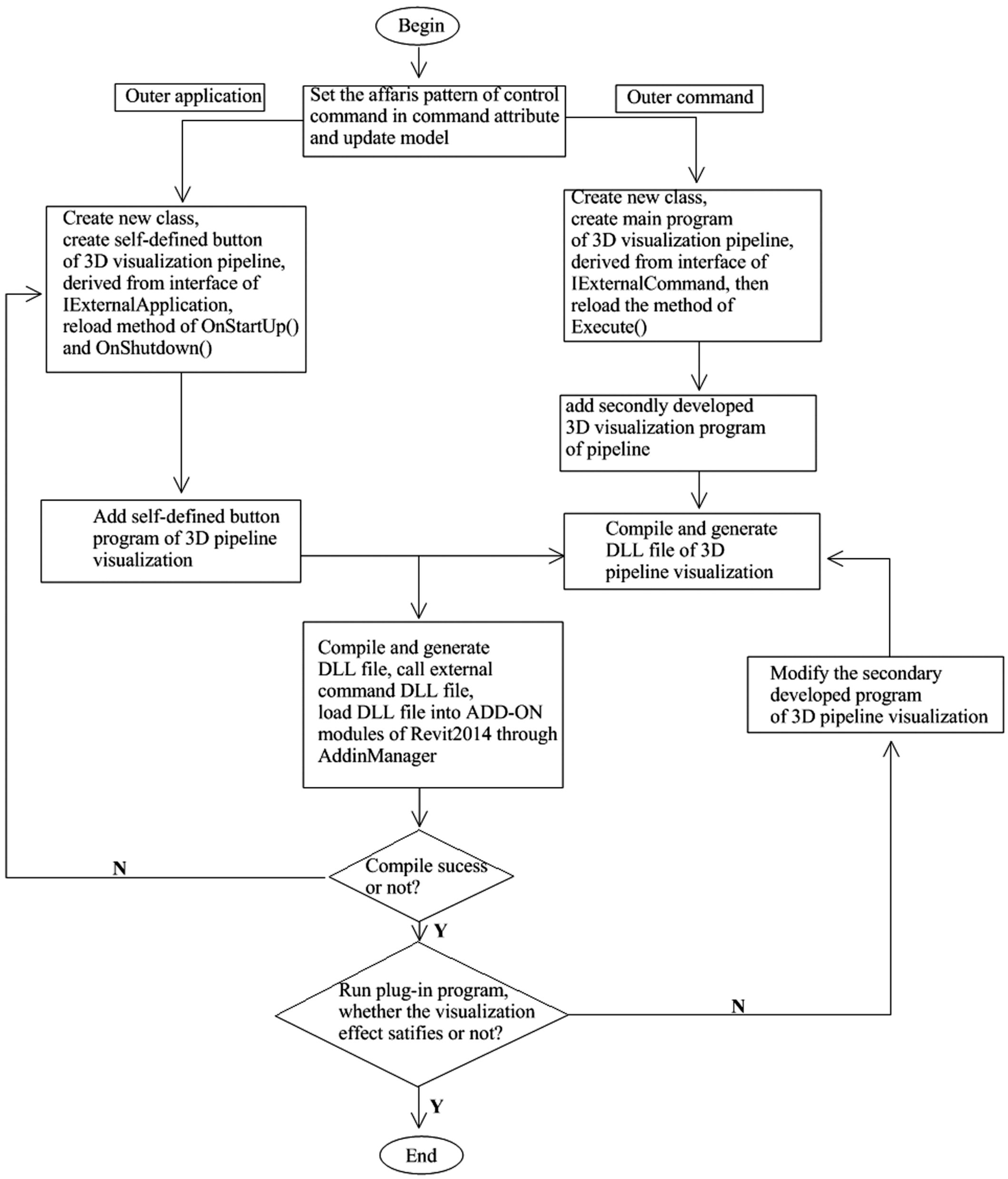

Figure 1: Technical routine of secondary development

① Quoting the name space of Revit and the related development.
Fig. 2 shows the contents that needed to be quoted in the program.

② Loading the attributes for C#.
The main attributes are the transaction attributes and the model updating attributes. The transaction attributes are needed to modify the file. The model updating attributes can modify models in Revit.

③ Using the edit function of the external command.

- create a new class of "csAddpane1" (Fig. 3), which is derived from the "IExternalApplication" interface.
- reload the "OnStartup()" method.
- add a new ribbon form and create the "3D visualization" button in the form.
- add events for the button using "Additem."
- add a prepared image for the new button using the "BitmapImage" class.
- clicking the button will call the main program of "3D visualization" to create a model.

Creating a new ".addin" file in "C:\ProgramData\Autodesk\Revit\Addins\2016" is required to add DLL files into Revit.

④ Opening Revit software, the "3D visualization" button can be found in the additional modules menu.

2.2 Main program of external command

2.2.1 Data preparation

Modeling pipelines includes work on the pipe point and the tubulation. The data required to model the pipe point include the 3D coordinates (longitude, latitude, and depth) and the pipe

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.IO;
using System.Windows.Forms;
using System.Windows.Media.Imaging;
using Autodesk;
using Autodesk.Revit.DB;
using Autodesk.Revit.UI;
using Autodesk.Revit.ApplicationServices;
using Autodesk.Revit.Attributes;
using Autodesk.Revit.Creation;
using Autodesk.Revit.Exceptions;
using Autodesk.Revit.Utility;
```

Figure 2: Contents should be quoted in the program

```
public class csAddpane1: Autodesk.Revit.UI.IExternalApplication
{
  public Autodesk.Revit.UI.Result OnStartup(UIControlledApplication application)
  {
    RibbonPanel ribbonpanel=application.CreateRibbonPanel("3D pipeline");
      PushButton pushButton=ribbonpanel.AddItem(new PushButtonData("3D pipeline", "3D
     pipeline", @"C:\Users\Think\Desktop\secondary development\3D pipeline\bin\Debug\3D
     pipeline.dll", "3D pipeline.Class1")) as PushButton;
    Uri uriImage = new Uri(@"C:\Users\Think\Desktop\3D pipeline\piple image.jpg");
    BitmapImage largeImage=new BitmapImage(uriImage);
    pushButton.LargeImage=largeImage;
           return Result.Succeeded;
  }
  public Result OnShutdown(UIControlledApplication application)
  {
    return Result.Succeeded;
    }
}
```

Figure 3: Main code of program csAddpane1

point type. The data needed to model the tubulation include the 3D coordinates of the start and end points and the pipeline diameter, material, and burying method. The detailed information of the pipeline is saved in a database, as shown in Tab. 1.

2.2.2 Extension of the model cluster

Most aspects of the tabulation model can be found in the system cluster of Revit MEP. However, some special pipe point models, such as inspection shaft, tee, and so on, should be added to the database for underground projects. Here, the external model of pipe points is first created according to the data structure in Tab. 1. Then, the new external model is saved into the external cluster database. As an example, Fig. 4 shows the basic steps to create one inspection shaft model.

① Give out the plan of inspection shaft.
② Select reference level plane and cross bisector.
③ Add control parameter information, such as size data and attribute information.
④ Preview the rudimentary model.
⑤ Optimize the rudimentary model and beautify the details. Form the final 3D model.

2.2.3 Realization of the 3D visualization function

First, the pipe point is modeled after fixing the coordinates and pipe point types. Then, the tubulation is modeled simultaneously and the start and end points are defined. The Revit

Table 1: Table structure of pipeline database

Field name	Field meaning	Type	Length	Can it be null?
P_NUM	Point number of pipeline	Nchar	10	No (major key)
X	Coordinate(longitude)	Float	8	No
Y	Coordinate(gratitude)	Float	8	No
S_Point	Start point number	Nchar	10	Yes
H	Elevation	Float	8	No
Material	Material	Nvarchar	50	Yes
S_Deep	Depth of pipeline top	Float	8	No
P_Type	type	Nvarchar	50	Yes
DN	Diameter	Float	18	No
P_C	Center	Float	18	Yes
D_Type	Bury method	Nvarchar	50	Yes
Hole_Num	Number of hole or line	Nvarchar	50	Yes
B_Code	Property unit	Nvarchar	50	Yes
MEMO	Note	Nvarchar	255	Yes

API is used to constrain and add tubulation-related attributes. The steps for designing the program for the 3D visualization function are as follows:

(1) Input data

Before modeling, the relevant data should be loaded from the database. After putting the data into a list, a Revit XYZ coordinate object point is created to save the coordinate information of the point. Because the Revit length unit is feet but the database length unit is meter, a unit transform is required when reading the data. The kernel code for data reading includes four steps:

① Read data from the database.

② Read point number and 3D coordinate, and transform the length unit.

③ Read point type, pipeline diameter, material, embedding type, and other attribute data.

④ Create a new derived type “PointInfo” to save parameter information of point number.

(2) Elevation of the project

The elevation belongs to the “Level” class in the Revit API, which is from the “Element” class. The “Element” class selection is completed using the “ElementClass” filter and “FilteredElementCollector”. The following steps are to be performed:

① Create a collector:
FilteredElementCollector levels=new FilteredElementCollector(doc).

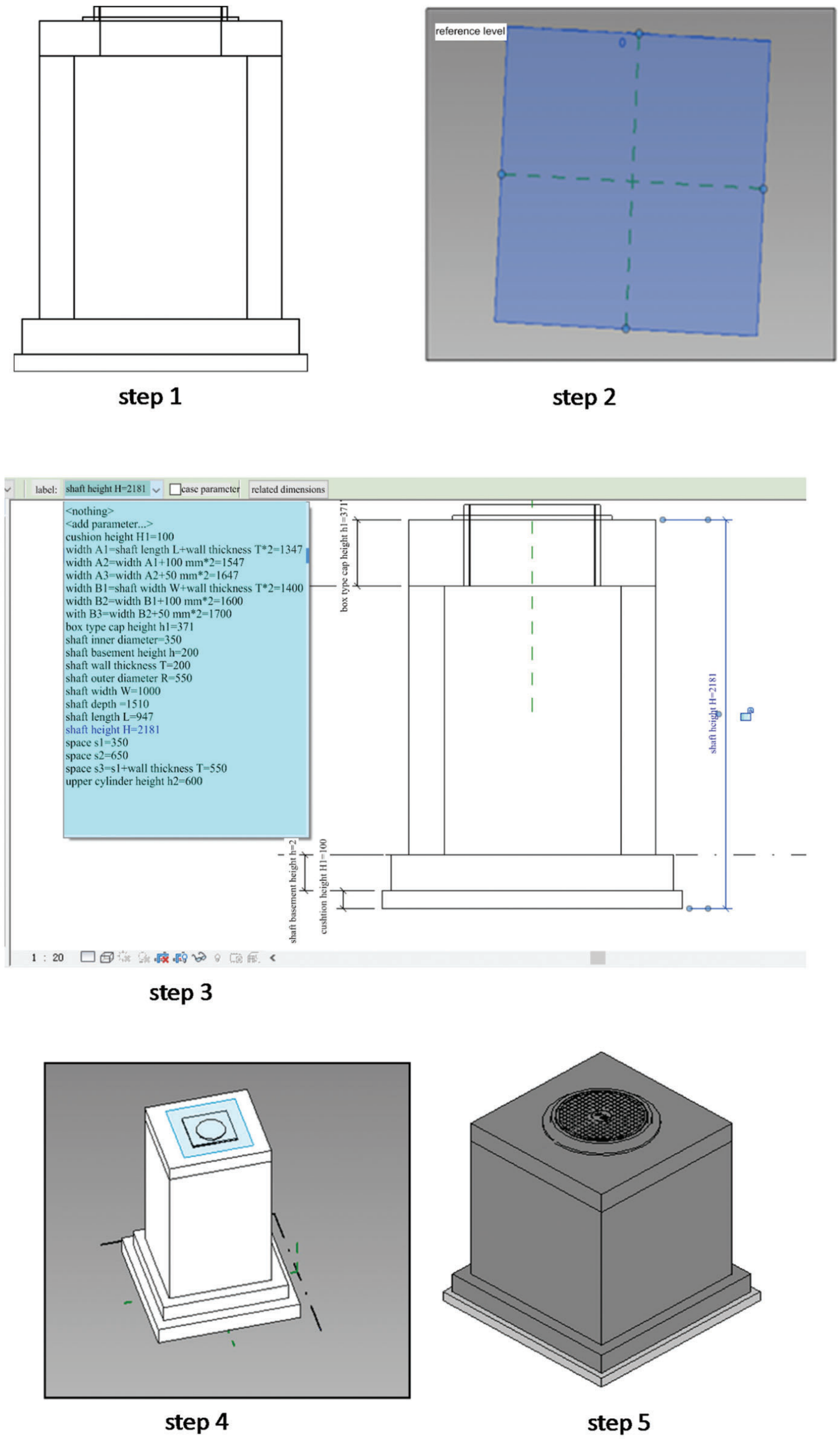

Figure 4: Basic steps of modeling the inspection shaft

② Create "ElementClassFilter" to filter all elements of elevation. The construction function to obtain elevation is defined as
var levelFilter=new ElementClassFilter(typeof(Level)).

③ Using the general method of collector "WherePasses()," add the obtained elevation element into the collector to start the filtering operation.
levels=levels.WherePasses(levelFilter).

(3) Obtain mechanical, electrical, and plumbing (MEP) system type of the project

MEP is the general name for the water, electricity, and heating systems.

(4) Obtain the loaded pipe point cluster and construct the pipe point model

The cluster type that must be established includes the inspection shaft, rainwater gate, T-shaped tube, and so on. Because external cluster building is used and reloaded into the project, the "GetFamilySymbol()" method is designed to obtain the cluster type.

(5) Obtain pipeline type and create the pipeline

The pipeline type is inherited from the "Element" class. There are several pipeline elements in a project. Hence, the element filter and element collector are needed to search for the pipe family type. The following procedures are then performed:

① Obtain the loaded pipe point cluster and determine if there is an endpoint for the pipeline (endPtr).

② Create the tabulation.

③ Set the attribute information, such as the diameter and material of tubulation, point number, endpoint number, and pipe point type.

(6) Add the attribute form of the shared parameters, and display attribute data

This includes embedding type, unit of property rights, number of pipeline holes, point number, endpoint number, and so on. This function is engaged through the attribute data of shared cluster parameters in the Revit API.

(7) Generate the plug-in file

The main program of the 3D pipeline modeling is compiled into a DLL file. The DLL file is linked to the plug-in button through the external application interface.

3 Results

A test run of the modified software was made through the following steps:

① Launch Revit.

② Create a new project.

③ Add the required pipe point model cluster into the project.

④ Click the "3D pipeline visualization" button and select the pipeline data.

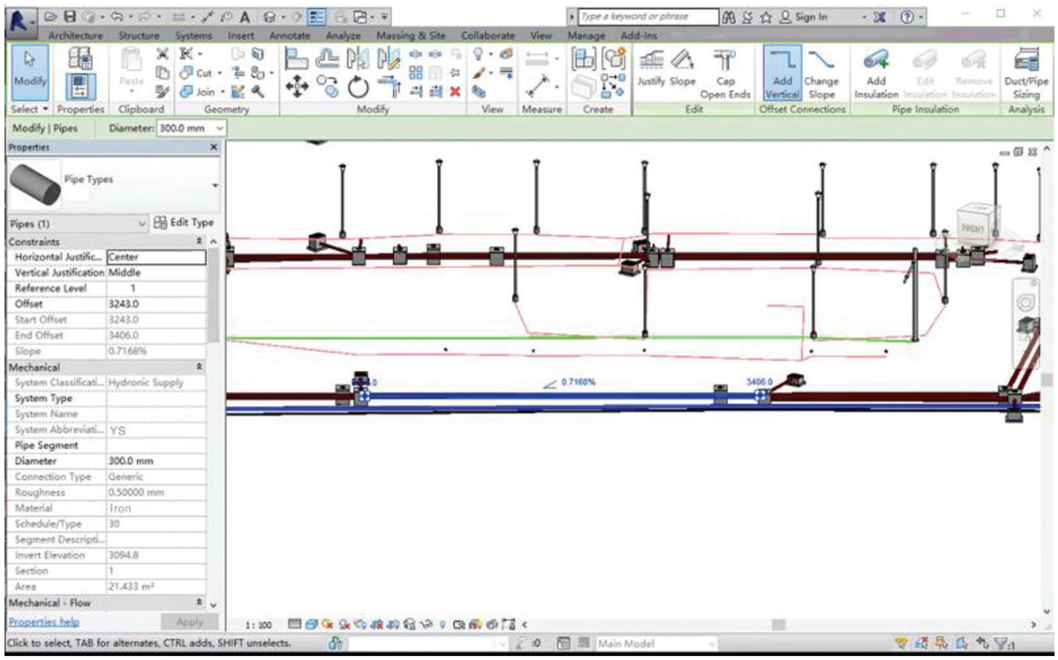

Figure 5: Test result obtained using the new 3D modeling method

The result is shown in Fig. 5. This figure shows the 3D distribution of the tubulation and pipeline points. The table in the left part of the figure is the attribute data.

The developed system was used on a subway station project (shown in Fig. 6) in Shanghai, China. The construction area was 3000 m^2. The length, width, and depth were 150 m, 18-22 m, and 10-12 m, respectively. The requirements of the project were to detect the

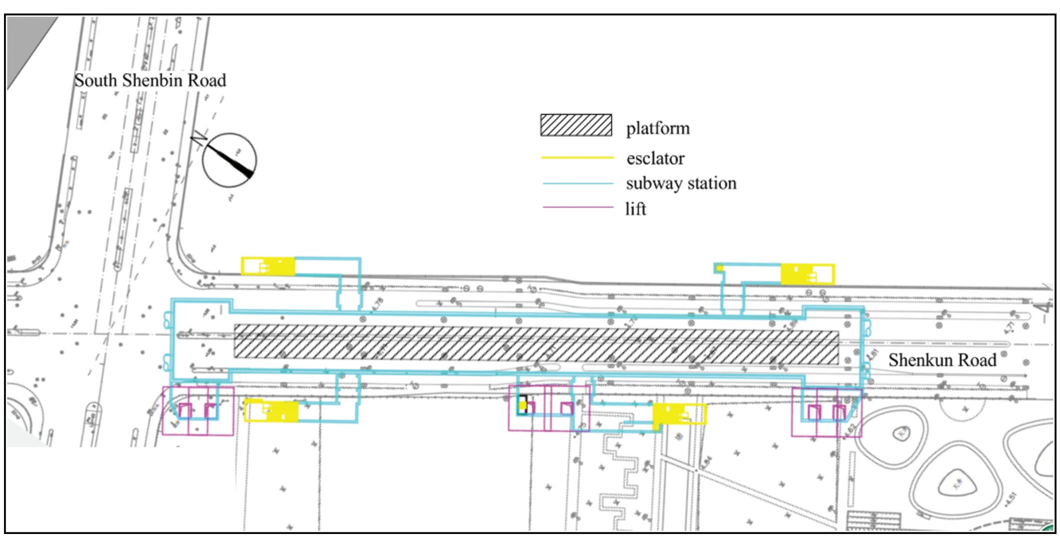

Figure 6: Work area of the project

underground pipelines in and around the work area and create a 3D visual model of the underground space and ground building using BIM series software.

All the pipeline data are from the past construction drawings and field geophysical detection results. Because the work area is in the urban area, there are a lot of pipelines. The pipelines belong to different types, such as service water, sewage and rain water, telecommunication, gas, and electrical pipes. These pipelines are positioned in a criss-cross manner. The developed system was then used to create 3D models of the pipelines. Fig. 7 presents the observation results from different perspectives. Fig. 7(a) is the result of viewing from the top, and Fig. 7(b) is the result of looking from the side. Fig. 7(c) shows the result of plain view. At the same time, Fig. 7(c) shows the integration of ground and underground facilities. The developed system provided data that included a large amount of inner attribute information, which significantly aided the project management process. The 3D visual model provides direct data, such as depth and direction, which guarantee

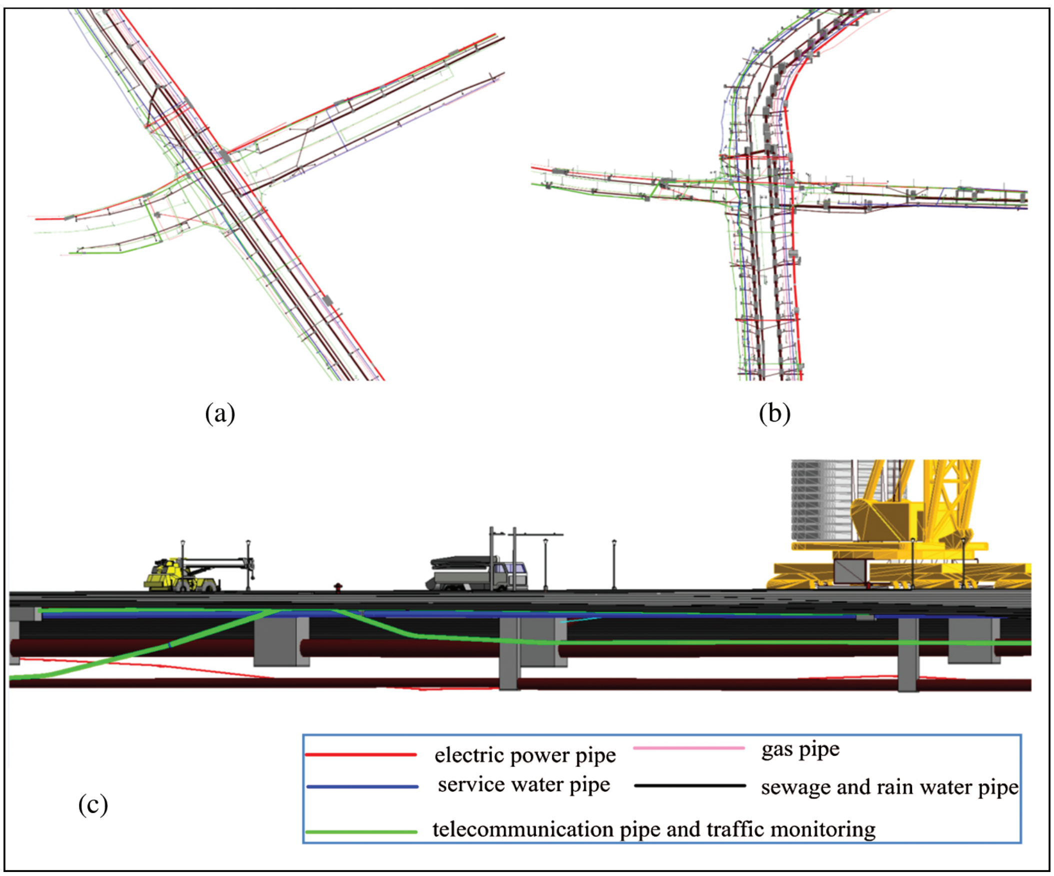

Figure 7: 3D model of underground pipeline. (a) top views, (b) side views, and (c) plan views and the integration of ground and underground facilities

construction safety. The attribute data is saved into the database of the system. All the data can be called at any time. This significantly aids project maintenance and management.

4 Conclusion

A secondary development of Revit software was used to create an efficient 3D modeling system for underground pipelines, through separate modeling of pipe points and tubulations. The developed system can clearly depict the spatial relationship among different pipelines. At the same time, it can provide visual representations of the characteristics of the pipelines. A sufficiently detailed pipeline cluster was incorporated into Revit for use in actual construction projects. The practical application verified the operational efficiency of this software system.

Because BIM technology is process-oriented, the application of BIM technology in pipeline engineering provides effective help for engineering construction and management. This software system developed on the platform of BIM improves the speed of modeling and makes the application of BIM technology more practical.

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