MANAGEMENT AND VISUALISATIONOF UTILITY NETWORKS FOR LOCAL AUTORITIES: A 3D APPROACH

Sisi Zlatanova[1], Fatih Doner[2] and Peter van Oosterom[1]

Management and visualization of underground utilities have been always of a great concern in many countries. Insufficient, inaccurate and unclear information about the location and depth of cables and pipelines may cause various problems and may even result in tragic accidents. In this paper we argue that 3D management and visualization of pipelines is of a critical importance for efficient maintenance (in the office and on the field), providing a better perception and understanding of the complexity of the underground networks. This issue is of critical importance for local governments or institutions responsible for utility registration, which make no use of specialised AM/FM software packages. This paper presents our approach for 3D management and visualization of pipelines using a DBMS and frontend systems (ArcGIS and BentleyMap). Additional parameters indicating diameter, height, radius, etc. are organized as attributes to the utilities. The 3D geometry for visualisation is created on the fly using the line geometry and the attributes. Various tests are performed on several case study areas.).

1. Utility management in progress

Pipelines such as water supply, sewage, power supply, heat supply, industrial pipelines and communication lines, are essential infrastructures in cities. They provide substantial material basis for cities by transporting water, energy and information. Being an important part of daily rhythm of a city, management of utility networks has always been challenging. Often insufficient documents are available describing previously existing pipelines or some of those documents are not accurate enough. This tendency has been increased in the last decade while rebuilding and substituting existing principal pipelines to fit in with increased demands of citizens and industrial development. Moreover, newly designed underground pipelines for different purposes have been built along with various engineering projects.

A large number local governments is still not able to control completely this economical booming and require new tools and approaches for management and communication ([5], [17). Responsible construction companies within engineering projects hardly wait for a complete documentation from management agencies related to existing pipelines before they start engineering projects. Insufficiently trained workers are regularly reported injured for their wrong operations during construction. Many serious accidents such as the cut-off of gas, water and heat supplies, communication lines and even the overflow of sewage were caused by blind-cutting or fault damaging. Investigations in different countries report an economic loss of up to million US dollars per year (e.g. [3], [22], [29], [25]). The increased utilization of underground space by utility companies requires more extended knowledge about the position of underground utility networks than ever before. The intensive expansion and modernization of cities (involving re-construction and re-building of streets, buildings etc.) needs also reliable information about existing infrastructures ([13], [32]). Many governments consider that a ‘centralized management’ of utilities will greatly improve the knowledge on the underground infrastructure ([6], [14], [26]). Many technical aspects related to a centralized registration of utilities have to be considered, e.g. system architecture, ownership, type of information to be stored, data model and visualisation ([9]).

GISt, OTB, TUD, Jaffalaan 9, 2628 BX Delft, The Netherlands, S.Zlatanova@tudelft.nl; P.J.M.vanOosterom@tudelft.nl

Gumushane University, Department of Geodesy and Photogrammetry 29000 Gumushane, Turkey, doner.f@gmail.com

Nowadays more and more applications such as urban planning ([15]), cadastre ([20], [8]), disaster management ([18], [19]), noise mapping ([31]), visualization ([8], [21]) and utility management ([12], [3], [34]) depend on three-dimensional (3D) data. A crucial element of utility management is visualisation. The visualisation of utility networks has always been problematic. Utility networks are usually represented as lines (segments of the networks) and points (connections, valves, etc.) predominantly with their x,y coordinates. Depending on the type of the utility networks (water, swage, telecom, etc.), the depth or (more rarely) the z coordinates (in given points) might be registered. The software (GIS, CAD, AM/FM) for utility maintenance is typically 2D, i.e. the visualisation of all the elements of the networks is on 2D maps (Figure 1). Such a visualisation usually serves the needs of a company (or state authority) that is responsible for the particular network, but can result in misinterpretation when provided to third parties. Various factors contribute to confusion and misinterpretation of the information on 2D maps:

- The major trace of pipelines or cables per network is mostly the same, i.e. under the streets, which results in overlapping lines. To avoid this overlap, many companies offset the multiple pipelines to increase the readability of the map. Such an approach, however, could mislead unfamiliar users.
- The trace of the different utility networks also overlaps. Colour and depth (depicted near a segment) of a particular pipe or cable are often the only parameters to distinguish between different networks. Integrating several networks on one map is almost an impossible task.
- A large number of important elements of the networks (such as valves, connections) are given with symbols, which might be challenging for interpretation from non-specialist and even from some of the less-qualified field workers.
- Some of the networks (e.g. sewage) contain a large amount of vertical elements, which visualisation on the 2D maps is only as points. Explanations about the vertical elements is often not included in the maps relying on the on-site experience of field workers

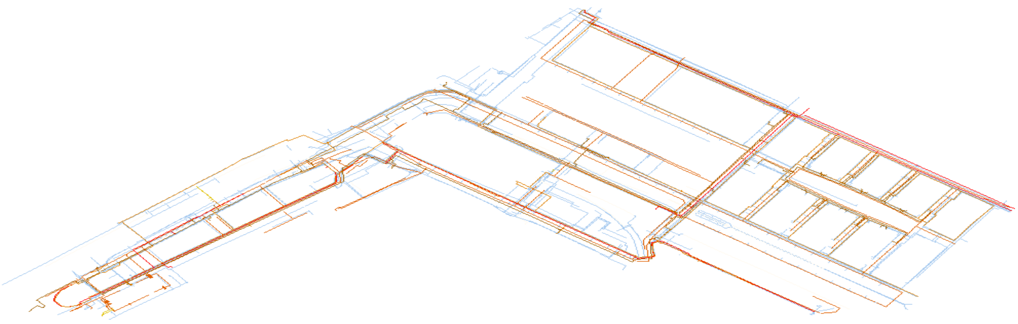

Figure 1: Visualization of utilities on a 2D map

In the last years, the need for real 3D management and visualisation of utilities is rapidly emerging. 3D visualization of utilities is expected to solve many of the drawbacks mentioned above ([34], [11],[6]). 3D visualisation allows for better representation of the absolute and relative (with respect to buildings or streets) position and better understanding of mutual relationships between different networks ([12],[38]). Research on 3D management and visualisation, however is still insufficient. [29] suggest an augmented reality system for 3D visualization of utilities (showing their position on the surface with attached depth information). [24] discuss profile creation from a utility model to maintain the pipes and the lines with their 3D coordinates. [33] proposed projection of utility networks on geo-referenced panoramic images. [34] have reported a 3D service that allows 3D visualisation of pipes on request of a user. The system however is not intended for registration and does not allow for integrated management of utility networks, cadastral data and 3D topographic data (3D City models). The new ADE for utilities of CityGML proposes a model for integrated management of utility networks, but does not discuss explicitly 3D visualisation. Given CityGML is a 3D model, the extension should be also able to support 3D.

This paper presents our approach for 3D management and visualization of pipelines, which is aimed to support local authorities and institutions responsible for utility registration. The goal was to keep as much as possible original data sets unchanged. The pipes and cables are maintained with their centrelines in DBMS and visualized in different software for inspection (in 3D) and editing (in 2D). The implementation is realized for Oracle Spatial 11g, BentleyMap and ArcGIS. The following section 2 presents an information model for management of utility networks. Section 3 presents the selected data structure. Section 4 discusses the possibilities for utility data organization and querying in Oracle Spatial together with other data sets. Section 5 elaborates on the visualization approach considering cylindrical and rectangular pipelines and construction of special connections at 3D symbols. Last section summarizes the results of the tests and addresses further research.

2. Registration of utilities

In current practice, two kinds of registration can provide information on utilities although there is no direct link between them: technical and legal registration. One of the aims of the technical registration is to protect utilities from damage in case of works by third parties. The legal registration, on the other hand, provides registration of rights, restriction and responsibilities related to these objects. In some countries, legal registration can also include geometric descriptions of under and above ground networks when these networks intersect with lands owned by another. This paper concentrates on the technical registration, but the approach used provides a basis for legal registration (as it will be discussed further).

In the Netherlands, KLIC (Cable and Pipeline Information Centre) was established for technical registration of utilities. The KLIC does not register the networks themselves, but maintain a grid covering the Netherlands. The grid cells are 500m by 1 km and the KLIC's register the network operators who have cables and pipelines in a specific cell to get easy access to the relevant parts of network maps kept and maintained by the operators. In the system, contractor contacts the center, providing the exact location of the works. The KLIC notifies all the known network operators in this area, and operators will send their own (paper or digital) map of the relevant part of the network directly to the applicant. Alternatively a network operator may also choose to send a surveyor to the location to indicate to the contractor the location of their infrastructure. The KLIC system is currently upgrading to a web-based, open-standard system under the management of the Dutch cadastre. Only municipality Rotterdam has a centralised registration of utility networks, which is caused by the great importance of Port Rotterdam ([27]).

The management of utilities in Turkey is maintained in a similar way to the Netherlands. The difference is that it is not organized at national level. Infrastructure Coordination Centre (AYKOME) has provided coordination between different network operators within 500.000+ cities since 1984. The centre determines how space is occupied by public infrastructure objects such as water, electricity, gas, telecommunication etc. When a request for excavation arrives to AYKOME, area of interest is marked on a map to determine existing underground structures. In addition, depending of existence of data, depth information can be supplied to excavator. Apart from organizing information in dedicated information centres, cadastres in some countries can provide spatial information for utility networks. In short, this happens as follows: when owner of the utility network is entitled to use the space above or below the surface parcels, limited rights such as superficies and easement rights are established on the intersecting parcels. If these rights are not applied to the full parcel, 2D drawings can be added to the deeds to describe the location of the networks. Main characteristics of the information are that drawings are only available as separate documents and show certain part of the network. Geometric description of whole network can not be obtained from cadastre. In Turkey, however, there is an exemption in case of high voltage power lines. Cadastral database can include whole geometry of the high voltage power line (see Figure 2).

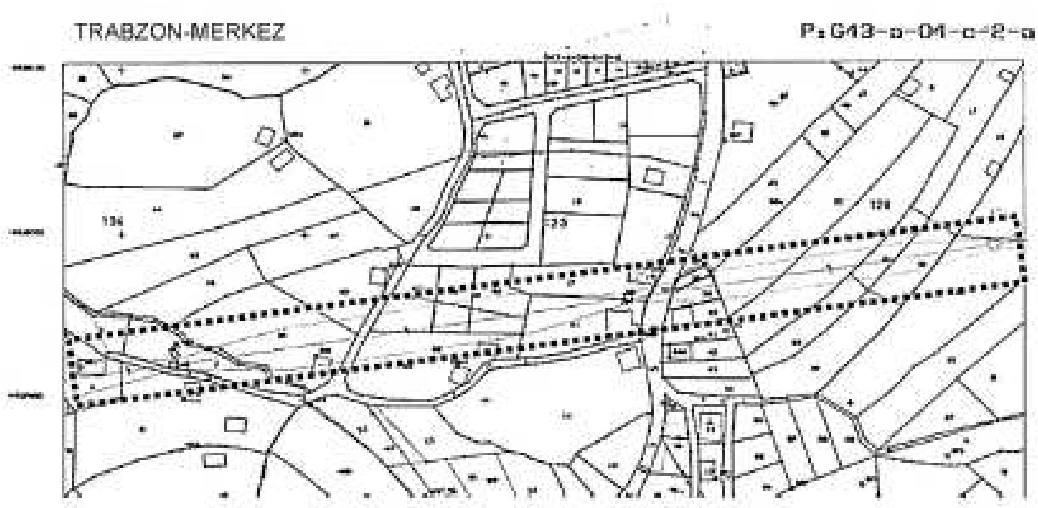

Figure 2: A cadastre map with high voltage power line (from [7])

A resent study on technical registration of utilities in China, Slovenia and Sweden ([3]) has shown similar tendencies for management of utilities. Depending on size of the country the registration can be either centralised (Slovenia) or local, organised in urban offices (China and Sweden). Each country recognises the need of a more elaborated digital system and several prototypes are already available, e.g. ArcMAP/Oracle Spatial based system in Slovenia and China.

All the countries consider 3D management and visualisation as a very important issue, but the availability of utilities in 3D is the major drawback. Generally, the information needed for registration is much simpler than the one needed utility companies to perform their daily activities. Compared to other topographic data, pipelines and cables are relatively simple types of data:

- Pipelines are generally represented by the x,y coordinates of their central lines. Depth or z-coordinate are not compulsory parameter for all networks. An approximate depth (e.g. 100 cm for water and 40cm for telecommunication) is either ‘known’ or recorded as an attribute. For example, the water company Waterleidingbedrijf Amsterdam responsible for drink water in Amsterdam, the Netherlands does not maintain any of them. In contrast, the urban offices in China have records for both depth and z-coordinate.
- Pipelines are mostly straight lines with relatively small number of turns. Very often the turns of the pipes are represented in 2D maps with one point. Relatively large turns are currently presented using short straight lines connecting successive interpolation points. The interpolation points of arc are required to be within a certain precision.
- The accuracy of points within the pipeline networks is relatively high, although it may happen that some utility companies maintain the location of pipes and cables with relative coordinates, i.e. indicating a distance to topographic objects (streets or houses). The tendency is however towards upgrading to geodetic coordinates.
- Shape and size of pipelines are relatively consistent, and materials of pipelines are rather limited. Joints of pipelines are almost the same for a single pipeline. The shape of the most pipelines is cylinder though some of them are ditch.
- As already mentioned above the vertical segments are either not represented or indicated implicitly with symbols and textual information. Accesses from the surface are also defined only by symbols.

The first four properties of pipelines make the visualization of pipes in 3D quire straightforward and easy. Long straight lines can be replaced with tiny cylinders considering the diameter of the pipe and consequently visualized as 3D objects. The real challenge is the missing information:

- absence of vertical segments,
- visualization of turns and intersection of cylindrical pipes,
- creation of rectangular pipes,
- 3D symbols to replace the 2D symbols.

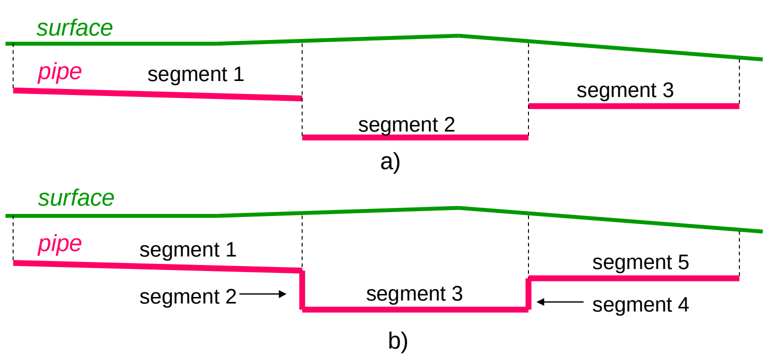

Figure 3: Conversion from a) 2D data to b) 3D (segment 2 and 4 are new)

Figure 3 illustrates the transformation from the original data to the needed representation in 3D. Starting from 3 segments in the 2D case the pipe is upgraded to 5 segments. Indeed, it should be carefully considered which and how many segments have to be organized. Practically segments 1-5 can be represented as one, but very long lines might result in a weak and inefficient indexing in databases.

In the following sections we assume that the first problem (i.e. missing vertical segments) is resolved and we concentrate on organisation of the 3D data in DBMS and the 3D visualisation in different front-ends. The database approach (versus management in GIS/CAD dedicated systems) is preferred by many local authorities since it allows flexibility for different internal and external users. The information about utilities can be accessed and used by specialised packages need for the specific work of departments or the clients. Special attention is given to Oracle Spatial since it is currently the DBMS providing the largest variation of spatial models, which could be of interest for utility management.

3. Management of utility data in Oracle Spatial

Spatial objects can be currently managed in Oracle Spatial using four different models namely *geometry*, *topology*, *Linear Referencing System (LRS)* and *Network* ([23]). Besides the data types, an extended set of spatial function and operations is attributed to each data model. The models are not equally appropriate for modelling utility networks. The topology model has *node*, *edge* and *face* data types organised in a structure similar to the well-know *wheel-chain* data structure ([25]). The major disadvantage of the topology model is that it needs area objects (i.e. faces), which are commonly not available in utility networks. The network model and LRS are typical graph data structures and conceptually very appropriate for maintenance of utility networks. However, there are few practical drawbacks. For example, LRS is not supported by any front-end application. To be able to visualize spatial objects managed as LRS data types they have to be converted to the data types of the geometry model (using Oracle Spatial function). The network model avoids this obstacle by maintaining the geometry within network data types (i.e. *node*, *link* and *patch*) and, therefore, it is readily accessible for visualization. Though very attractive, the model requires development of user-defined scripts for populating the tables and checking the consistency, which was outside the scope of this research. Therefore we have concentrated on the geometry model. The geometry model (i.e. SDO_GEOMETRY) has several simple geometry types (and collections of them) such as *point, point cluster, line string, polygon, arc line string, arc polygon, compound line string, compound polygon, circle, optimized rectangle*, and even optionally, it can be indicated that a certain geometry is *unknown*.

One option to maintain cylinders and rectangular pipes with existing data types would be to simulate them as reported in [35]. The basic idea is that a cylinder can be defined as a group of flat quadrangles connected each other. The quadrangles are in 3D and 3D vertexes represent them. Based on this idea, a rectangle pipelines can be exactly expressed with four polygons, but a cylindrical pipeline will be described with much more than four polygons. Indeed, it is quite unrealistic and inefficient to store all these polygons into Oracle Spatial.

In this paper we follow an approach, which considers the mathematical definition of cylinder, i.e. the cylinders spatial shape is only described by a centreline and a diameter. This allows us to consider that a cylinder can be created in Microstation using these two parameters. As for rectangle pipeline, it can be described with a centreline and its size considering height and width of a ditch. In this way, pipelines can be sorted in Oracle Spatial using the supported 3D line data type. The advantages of this approach are:

- Easy to manage. Line is a simple geometric type, its input, edit and update are easy.
- Easy to implement. Create, modify, validate and query of lines are a trivial operation. Moreover spatial functions such as length, overlap, intersect, etc. are readily available.
- Easy to index. Several spatial indexes are also provided by Oracle Spatial.
- Space saving. Simplified pipelines occupy less memory space, i.e. little redundant information is sorted.

The data sets used were prepared to include the central line with its x,y,z - coordinates, terrain height (or depth), diameter of pipe, width and height of ditch. The description of a pipe network can be therefore seen as a function of six parameters per pipe segment:

$P = F(x,y,z,zt,d,h)$

Since SDO_GEOMETRY supports only 4D coordinates, besides the coordinate (x,y,z), only one more parameter can be included in the SDO_GEOMETRY object. Since the terrain height is the most important value to obtain the depth, we have included it into SDO_GEOMETRY as the fourth coordinate. It is used also for preparing vertical profile and calculating insertion points within pipelines. The advantage of this representation, i.e. terrain height instead of depth value, is that pipes above the ground can be also incorporated in the model. For example, a pipeline is under ground if (zt-z) is positive, otherwise, the pipeline is above ground.

3.1 Organization of Data

Two different types of data set were organized into database for spatial query and visualisation. First data set is associated to underground utilities (pipelines and cables) while the second is related to above ground power lines. Table 1, data sets used in this study are grouped into underground and aboveground. First group was provided by Municipality of Rotterdam while the second is from cadastral database of Turkey. All data are represented with their 3D coordinates.

Table 1: Data sets used in the study

Underground	Aboveground
Pipelines Cables Buildings Cadastral parcels	Power lines Buildings Cadastral parcels

Geometry model (SDO_GEOMETRY) of Oracle Spatial was used to manage these spatial objects. The information of underground networks for pipelines and cables was stored in different tables in spatial database. The content of Pipeline table in Oracle Spatial is given in Table 2 as example. In addition to tables, metadata was maintained in Oracle Spatial by describing the dimension, lower and upper bounds and tolerance in each dimension. Finally, spatial indexes (3D R-tree) were created on the tables to speed up spatial queries. Creation of spatial index is necessary for efficient access to data after the data has been loaded into spatial tables.

Table 2: Description of Pipeline table in Oracle Spatial

Column Name	Datatype	Description
mslink	NUMBER(8)	PRIMARY KEY
start_id	NUMBER(8)	Start Node
end_id	NUMBER(8)	End Node
MATERIAL	VARCHAR(8)	Material
diameter	NUMBER(6,3)	Diameter (width of ditch)
tall	NUMBER(6,3)	Height of Ditch (null cylinder)
* Pressure	VARCHAR(8)	pressure (gas, electricity)
* Cabnum	NUMBER	Cable number (only electricity)
* Sumhole	NUMBER	Total holes (only telecommunication)
* Usedhole	NUMBER	Used holes (only telecommunication)

bdate	VARCHAR(7)	Build date
lshape	SDO_GEOMETRY	Gtype = 4002 (pipeline segment, 4D)

Asterisk (*) refer to special information for individual type of pipeline

Clearly, the data contained in the line table is sufficient to visualize the pipelines in 3D and represent their location (both with respect to other networks and the terrain). However, some points contain attribute information, which cannot be assigned to the point if it is not a separate SDO_GEOMETRY data type. Therefore those points that have specific attribute information are organized in a separate table (Table 3). Practically, all the end points of a pipeline are represented by a 3D symbol and therefore the coordinates (x,y,z) are still sorted in point table. Additional information that helps to create the 3D symbol can be height of ground, height of pipelines bottom and azimuth is also included.

Table 3: Description of Point table in Oracle Spatial

Column Name	Datatype	Description
Mslink	Number	ID of point
Component	Varchar2(6)	Attachment or Node
Top_h	NUMBER(8,3)	Height/depth with respect to the ground
Bot_h	NUMBER(8,3)	Bottom depth of pipeline
Azimuth	number(8,6)	Direction of symbol
Pshape	SDO_Geometry	x,y,z coordinates

3.2 Spatial Queries in Database

One of the benefits of using spatial data types is that a quite extensive number of spatial queries can be performed at database level. Some of the supported functions such as SDO_RELATE, SDO_FILTER, SDO_NN and SDO_WITHIN_DISTANCE also support 3D queries. For example, the SDO_RELATE identifies either the spatial objects that have a particular spatial interaction with a given object, the SDO_WITHIN_DISTANCE operator determines if two spatial objects are within a specified distance of each other and the SDO_NN operator identifies the nearest neighbours for a spatial object ([16]). Using this mechanism, queries which can be formulated as ‘’what is the vertical distance between a parcel and pipeline’’ or ‘’is a pipeline at a particular distance from a cadastral parcel’’ can be performed. SDO_GEOM.SDO_DISTANCE function was used in following SQL-statement to compute the distance between a parcel and a specific pipeline goes under that parcel. Figure 4 shows underground pipelines and above situate surface parcels and buildings.

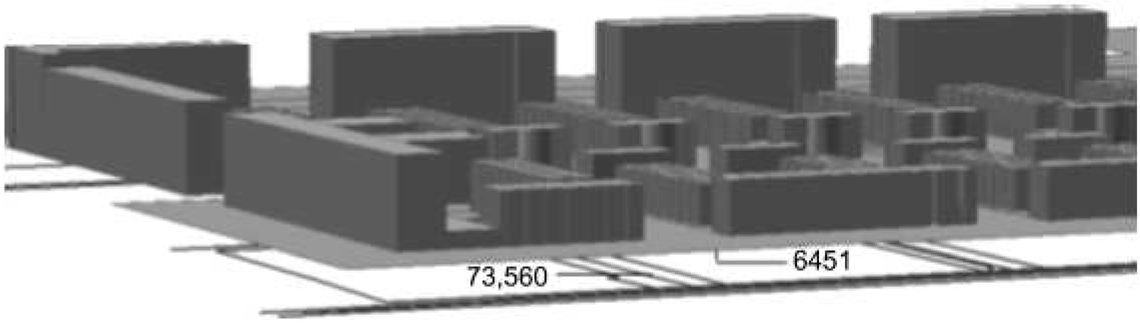

Figure 4: Underground pipeline used in the query together with surface parcels and buildings

In most application scenarios for utilities, spatial relationships of geometries such as nearest to, or within a specified radius from are needed. The next SQL shows the syntax for a query ‘find the nearest buildings and their distance to a specific pipeline’ SDO_NN operator of the OS was used to perform this query. Number of the geometries returned was limited to no more than 10 by using the ROWNUM pseudocolumn:

SELECT b.id Building_ID,

SDO_GEOM.SDO_DISTANCE(b.geom, pi.geom,0.5,'UNIT=M') Distance

FROM building b, pipeline Pi

WHERE pi.idbuis='73570'

AND SDO_NN(b.geom, pi.geom)='TRUE'

AND rownum<=10 ORDER BY Distance;

In a similar way several other important questions can be executed: ‘find all buildings within a 25-meter-distance of a specific pipeline’, ‘find all underground networks in a given region’ (see also Figure 4), ‘find all the buildings above a given pipeline’, etc. These queries are performed on underground utilities. Similar spatial queries based on distance and topological relationships of geometries are also able to be performed for above ground power lines.

The following example shows how to create a buffer around a pipeline representing a kind of restriction (e.g. on have buildings in the area or other utility lines). A typical example are the high-voltage power lines. Currently, only projection of the line on surface is represented on the cadastre map. The owners of interesting parcels still own the land under the wire, but they are restricted in the remaining use of this land. This restriction is determined by other legislation. The legislation defines minimum vertical and horizontal distances from the centre power line which imply a volumetric restriction on surface parcels. Any construction or vegetation intersecting the volume is not permitted. Figure 5 shows volumetric restriction of a high-voltage power line.

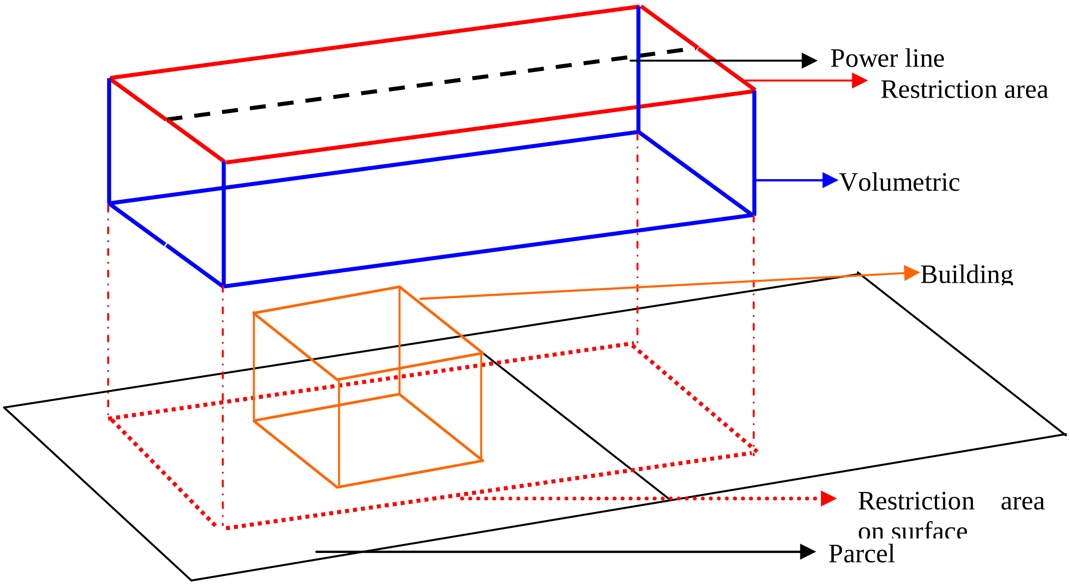

Figure 5: Volumetric restriction of power line

To construct the volumetric restriction (solid data type) in Oracle Spatial, a buffer around the power line has to be created first. The following SQL statement shows how to generate a buffer polygon with 5-meter-distance around the geometry of the power line and to store the information in table.

CREATE TABLE testbaf AS

select h.hat_id,

SDO_GEOM.SDO_BUFFER(h.geom, 5, 0.5,'arc_tolerance=0.005 unit=M') geom

FROM hat_gms3b h WHERE h.hat_id='1';

By using the polygon geometry as input, next step is to insert to solid defined with its ground height and height value in table. The following SQL statement returns the three-dimensional solid geometry representing an extrusion (using SDO_UTIL_EXTRUDE) from the two-dimensional buffer polygon geometry.

INSERT into he select id,

SDO_UTIL.EXTRUDE (geom,

SDO_NUMBER_ARRAY(1263),

SDO_NUMBER_ARRAY(1269),

'TRUE', 0.05) from testbaf

WHERE id = '1';

The last step is to check whether the buffer overlaps with existing buildings of to check the distance to it. If the 3D geometries of the buildings do not exist, the SDO_UTIL.EXTRUDE function can also be used to erect buildings from two-dimensional footprints.

4. 3D visualization

Once data has been stored in a spatial DBMS, many front-end applications (GIS/CAD) can be used to access and to visualize the data. In this stage, we used two commercial mainstream software packages, one of which is CAD and the other is a GIS application. The solution of accessing data with a CAD system offers many possibilities such as flexible tools for 3D editing, user-friendly graphic user interfaces, and exporting data in various formats as well as 3D visualisation ([4]). The GIS application, on the other hand, provides tools for 2D query of 3D spatial data ([37]).

4.1 3D Visualisation in BentleyMap

BentleyMap provides means to retrieve and visualize the data types from SDO_GEOMETRY. However, this program visualizes the pipes as they are recorded in the database, i.e. as point and lines ([2]). The display of cylinder and rectangular pipelines requires the development of new programs within Microstation programming environments. There are several development environments, such as MDL (Microstation Development Language), JMDL (Java edition of MDL), VBA(Visual Basic for Applications). Below is presentation of JMDL and 3D visualization's procedures based on JMDL (see also [28]). Three programs for visualization of 3D pipelines are developed : 1) circular pipeline, 2) rectangular pipeline, and 3) 3D symbols. The following text presents the algorithms.

3D Visualization of cylindrical pipelines is relatively simple. A cylindrical pipeline is composed of many cylinders, which can be constructed with coneElement class in JMDL according to the value of diameter and coordinates obtained from Oracle Spatial tables. These cylinders are all straight cylinders, therefore, gaps and superimposition exist at the joint between two segments (Figure 6).The size of gap may change with respect to the diameter and the turn angle of centerline. The most elegant way to solve this problem would be a torus joint, however, this shape is not available in JMDL. Another option could be a B-spline Surface ([28]). However, B-spline Surface is a rather complex shape to be used only for visualization improvements. The simplest way to close the gaps is to display a sphere at the joints of any successive segments. Sphere is the simplest surface and does not depend on the rotation matrix in 3D space. In our approach we use a Microstation shape (cellElement class in JMDL). The radius of the sphere is equal to that of joining cylinders.

Figure 6: Gaps and superimposition at joins

Thus the 3D visualization procedure for cylindrical pipelines includes the following steps: 1) build a connection with JDBC, 2) get the diameter and coordinates value of a pipeline, 3) construct a segment (coneElement), 4) construct a sphere joint (Figure 7) and 5) display in the view windows in Microstation. The steps 2, 3, 4 and 5 are the repeated for every line.

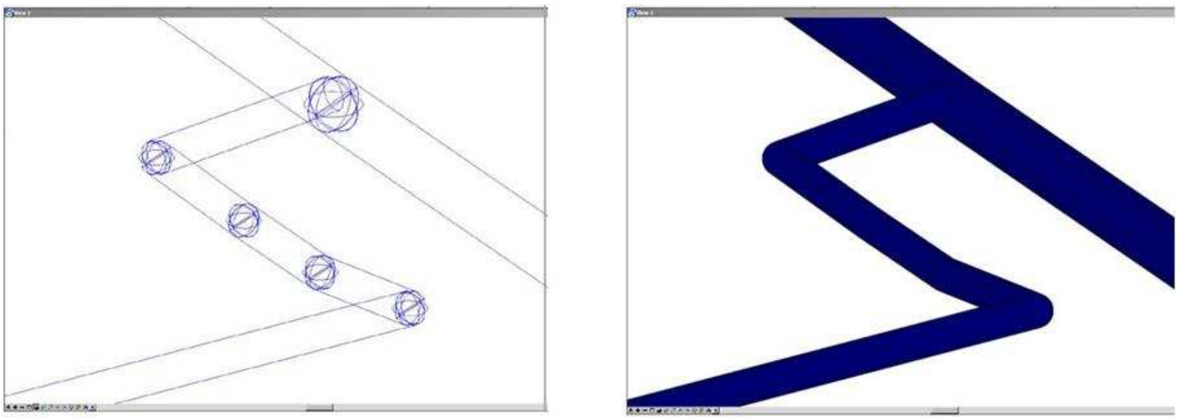

Figure 7: Creating spherical joins at the connections (from Du, 2005)

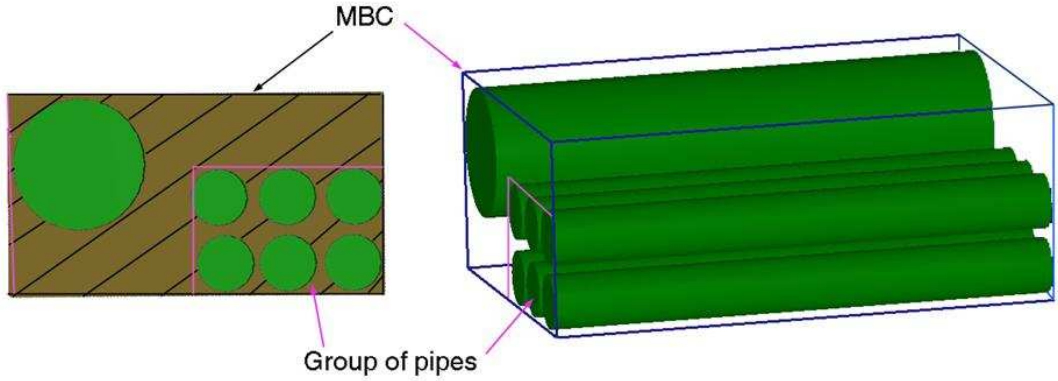

Figure 8: Rectangular pipelines as MBC of cable groups (from [11])

Rectangular pipes mainly include ditches (with cover) or the Minimum Bounding Cuboid (MBC), which minimally encloses the cables and groups of telecom and electricity, as shown in Figure 8. 3D visualization of rectangular pipelines is carried out by simulating a hexahedron which is constructed by eight vertexes and four polygons. In order to reflect the visualization impression, the polygons are restricted to be planar. Considering the rectangular pipelines in the reality, the two polygons in the right- and left-hand are required to be vertical.

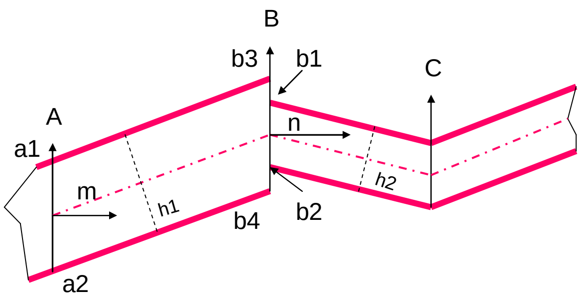

Figure 9: Section of a rectangular pipeline

The computation of vertexes of the hexahedron is the critical step of visualization of rectangular pipelines. A mathematically correct computation is quite complex but not necessary. In this paper we follow an approximated, simplified approach. The coordinates of the vertexes are determined by the coordinates of the centreline and the size of the pipeline. Firstly, a vertical section is made through the centreline. In the vertical section, two lines parallel with the central line are made by two sides, respectively. The distance with the central line is half of pipelines size (Figure 9). The cross points of parallel lines with the transects of the two ends in AB segment are presented as point a1, a2, b3 and b4. Whereas, there may be 4 points in about one central point of pipeline, i.e. b1, b2, b3 and b4 in point B. The coordinates of X, Y of the four points are the same with corresponding central point B, and Z coordinates are calculated with the help of the heights h1 and h2 and the direction angles m and n. Detailed description of the calculation steps is given in (Du, 2005 and Du et al , 2006). The result of the computation can be seen in Figure 10.

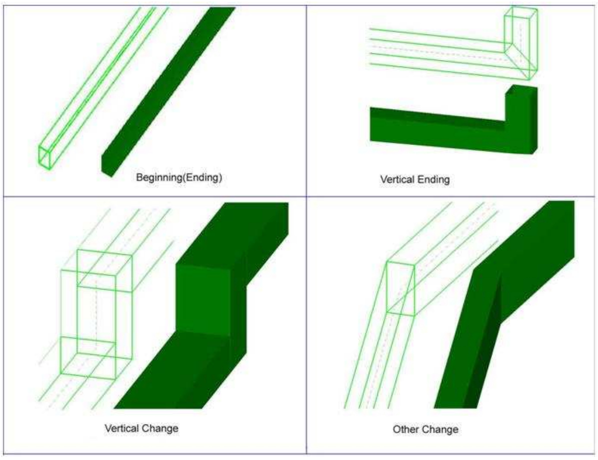

Figure 10: Rectangular pipes in 3D (from [11])

All the information required for symbolization can be drawn from the point table. The only element still to be constructed is the 3D symbol itself. A symbol is made up of series of graphic elements and can be created as any other geometry in Microstation. Each symbol has an origin, which is defined when the cell is created. We created several basic 3D symbols, i.e. valve, hydrant, well for check, manhole, hand hole and control box, as shown in Figure11. One can update and append a symbol at any time. In order to conveniently use symbols in the program all symbols are organised into a uniform symbol library.

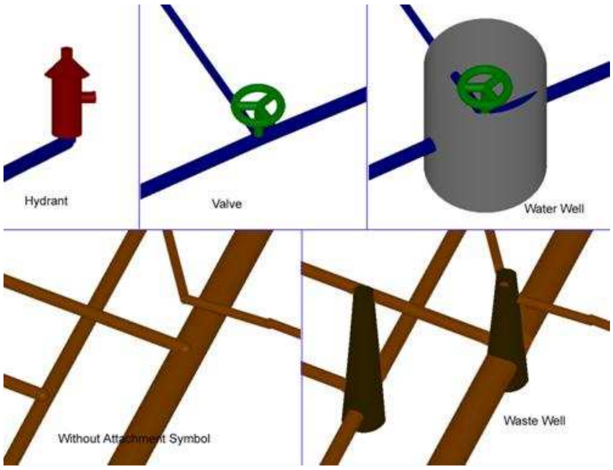

Figure 11: 3D symbols designed as cells in Microstation (from [11])

The approach was tested with data from P.R. China and the Netherlands ([6]). The utility networks were organised together (in one DBMS) with other 3D data such as terrain surface (TIN), 3D city model and cadastral parcels. These data were organised in separate tables as described by [37]. Their 3D visualisation in Microstation was completed with standard means (e.g. Spatial Viewer) to access and retrieve data from Oracle Spatial. The different data sets could be successfully integrated with the 3D representations of the pipelines and their connections. Figure 12 illustrates some of the results.

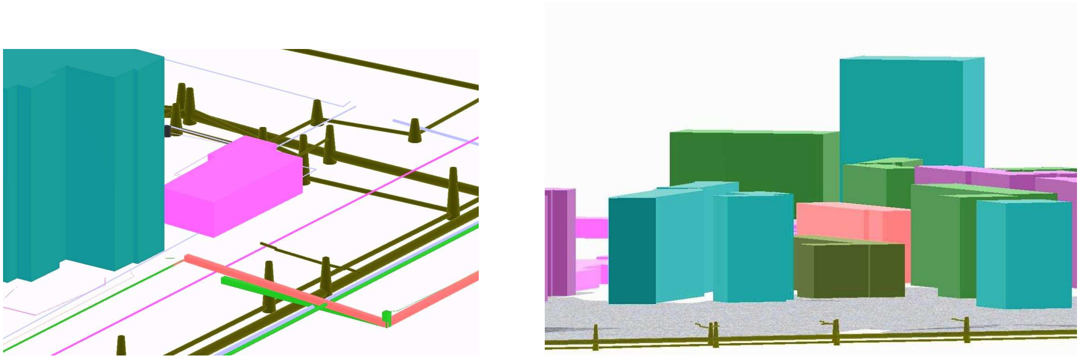

Figure 12: Snapshots of 3D visualisation of pipelines in urban environment (BentleyMap)

4.2 3D Visualisation in ArcGIS

ArcGIS is able to access data that is stored as a SDO_GEOMETRY type in Oracle with ArcSDE. ArcSDE is middleware that facilitates managing spatial data in a DBMS. Originally ArcSDE was developed for the SDE binary format, which is a format for spatial data types in the DBMS (stored as BLOBs) developed by ESRI.

Two steps must be completed to visualize data organized in Oracle with ArcGIS:

- Register the DBMS tables to SDE system tables
- Register the GeoDatabase to define the DBMS connection

In the first step geometry column, primary key in the geometry column, element type, dimension and tolerance of the layer are defined by registering as sde-layer. In the second step, spatial database connection is added by defining the name of the machine on which the database is stored, the name of the database, the user and the password of the user ([30]). After these steps are completed 2D/3D data can be obtained in ArcGIS. Although 3D solids were created in Oracle Spatial to represent buildings and restrictions of power line, this kind of 3D data types are not yet supported by the GIS application. To get volumetric representation of data stored in Oracle Spatial, an option can be to access the data stored as 3D polygons and lines and use the extrusion possibility of the application ([1]). Figure 13 shows examples of visualisation underground and aboveground 3D data stored in database together with other cadastral data sets such as buildings and parcels.

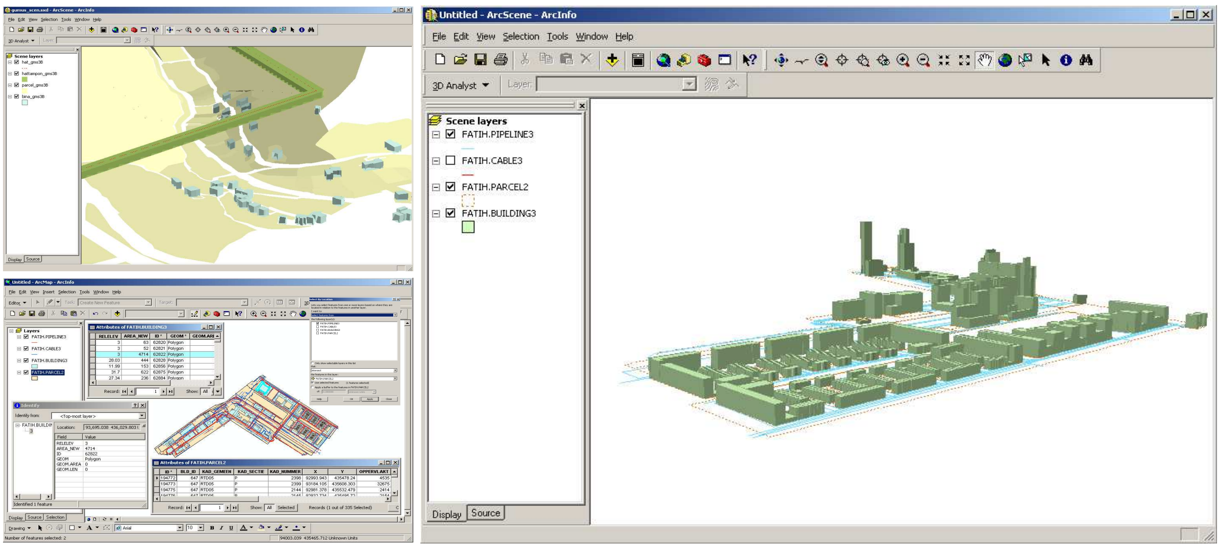

Figure 13 Snapshots of 3D visualization under and above ground utility data together with other data sets

5. Conclusion and further research

This paper reported our approach for creating 3D realistic visualization utility networks for local authorities. The utility networks are stored as simple line data types in DBMS, as quite often used in registration offices or municipalities. The experiments and test have clearly shown that 3D visualization reveals better relationships between pipes and other objects (buildings, road, terrain). Visual inspection is easier and the chance of misunderstanding is reduced to minimum. The inclusion of 3D symbols to show pipeline attachments (e.g. valves, hydrants, wells) helps to provide additional information regarding a particular pipeline, including its function, direction of flow, connectivity etc.

Besides the improved visualisation, the presented approach has the following advantages:

- The existing pipelines and cable data sets do not need to be changed besides for the creation of vertical segments (which can be automated and checked for consistency). Clearly, if existing pipeline networks do not have z coordinate, additional measurements to determine z-coordinate (depth) are unavoidable.
- Having preserved the original centre lines (stored in SDO_Geometry), editing of pipelines remains the same. If one or more segments have to be modified, the user can extract from DBMS only the centre lines and apply the usual procedure for editing using the preferred software, i.e. CAD or GIS.
- The DBMS storage of pipelines allows for performing of spatial analysis, within the network and between other data sets (e.g. cadastre parcels), supposedly other data sets are also available in the DBMS. As mentioned elsewhere, the spatial functions and operations in Oracle Spatial are currently only 2D but operations accept the 3D/4D coordinates. This means that a large number of queries such as ‘which pipelines go under parcel 11’ or ‘which telecom cables are within 100 meter from my house’, still can be performed.
- The use of Oracle Spatial data type LINE has lead to a reduction of the number records compared to the original data sets.
- Although the implementation is completed for Oracle Spatial and Microstation, the developed algorithms can be easily adapted for any front-end and therefore readily used for other combinations of DBMS and CAD software.
- The selected system architecture, i.e. DBMS for storage of utility networks and front-end (CAD or GIS) for visualisation and editing, can be considered by many local and national authorities as a promising option for a centralised registering. The spatial schema in the DBMS can be tuned with respect to the legislation of a particular country.

Utility networks are main objects in land administration systems with a 3D characteristic. These objects are often located under lands and can cross several private parcels in many situations. Therefore, legal registration of utility networks in current practice can be improved by adopting the 3D approach presented here. At this stage, however, it is important to discern between the aims of a technical (space of the physical network) and a legal (space of legal representation of physical network) registrations. It is not cable or pipeline represented in legal registration, it is legal aspect of this. Therefore, adjustments can be necessary and legal aspect has to be further investigated to apply this solution. In some countries, it is already legally possible to register utility networks as distinct real property even with their own 3D geometry. The solution of 3D management and visualisation of utility networks is best suitable for these courtiers that legal (possibility of registering utility networks as separate real property) and organizational (regulations for defining 3D information required to register utilities) issues have already been addressed to register networks.

In our approach, information of utility networks is organized into one database together with other cadastral data sets such as parcels and buildings. Another approach may be to keep information of utility networks and parcels at database of organizations (e.g. network operators and cadastre) responsible for them and refer to this information when needed. The second approach requires further studies on organisational aspect of Spatial Information Infrastructure as well as technical aspect.

Further investigations are needed to specify which utility functions are worth implementing at database level. A special attention should be given to the network model since it can add value in the organization of data. Appropriate tests have to be set up to investigate the correlation between length of pipeline segments and the building of the spatial index.

We firmly believe 3D visualization of pipelines is necessary tendency of utility public information system development and can greatly contribute to the e-government. It can clearly express the position and spatial relationship of all pipelines, and implement arbitrary displays of pipelines from any view and/or from any place. 3D visualisation can significantly reduce blind cutting and fault damaging of pipelines. This kind of visualisation can be used successfully to communicate information to none specialists and citizens.

Acknowlegements

The authors express their gratitude to the China Scholarship Council, Bentley Inc. and GDMC, Delft University of Technology for making these developments possible.

References

[1] Arens, A., 2003, Modelling 3D spatial objects in a Geo-DBMS using a 3D primitives, MSc thesis, available at http://www.gmdc.nl/publications

[2] Bentley, MicroStation/J JMDL Documentation, February 1999.

[3] Bitenc, M., Dahlberg, K., Doner, F., van Goor, B., Lin, K., Yin, Y., Yuan, X., and Zlatanova, S., 2008, Utility registration: Slovenia, China, Sweden and Turkey, GISt Report No. 49, available at http://www.gdmc.nl/punlications, 48p.

[4] Breunig, M., Zlatanova, S., 2006, Geo-DBMS: Large-scale 3D Data Integration – Challenges and Opportunities. CRCPress, Taylor & Francis group, 88-116.

[5] Budoni, A, P. Maurelli, Le. De Bonis, P.A.Frederici and M. Temperini, 2008, Integration of WebGIS and open content environments for self empowering e-governance, in (Coors, Rumor, Fendel&Zlatanova) Urban and Regional Data Management, pp. 105-118

[6] Chong, S.C., 2006, Registration of Wayleave (cable and pipeline) into the Dutch cadastre, Case study report, available at http://www.gdmc.nl/publications, 56 p.

[7] Demir, O., Uzun, B., ve Çete M., Turkish Cadastral System, Survey Review 40, No.307, 54-66, 2008.

[8] Döner, F. and Bıyık, C., in press., Modelling and Mapping Third Dimension in a Spatial Database, International Journal of Digital Earth, doi: 10.1080/17538947.2011.571723.

[9] Döner, F., R. Thompson, J. Stoter, C. Lemmen, H. Ploeger, P. van Oosterom and S. Zlatanova, 2010, 4D cadastres: First analysis of Legal, organizational, and technical impact - With a case study on utility networks, In: Land Use Policy, Volume 27, pp. 1068-1081

[10] Döner, F., R. Thompson, J. Stoter, C. Lemmen, H. Ploeger, P. van Oosterom and S. Zlatanova, in press. "Solutions for 4D cadastre – with a case study on utility Networks", International Journal of Geographical Information Science, doi: 10.1080/13658816.2010.520272.

[11] Du, Y., 2005, 3D visualization of urban pipelines, Case study report, available at http://www.gdmc.nl/publications, 44 p.

[12] Du, Y., Zlatanova, S., and Liu, X., 2006, Management and 3D visualisation of pipeline networks using DBMS and AEC software, in: Nayak, Pathan&Garg (Eds.), Proceedings of the ISPRS Commission IV Symposium on 'Geospatial Databases for Sustainable Development,' 27-30 September, 2006, Goa, India; Archives of ISPRS Vol. 36, Part 4A pp. 395-400

[13] Emgard, L. and Zlatanova, S., 2008, Implementation alternatives for an integrated 3D information model, in: Advances in 3D Geoinformation Systems, LNGC, Springer-Verlag, Heidelberg, pp. 313-329

[14] Hei, J., Li, L., and Deng, M., 2002, The design, of urban underground pipe line GIS, based on UML flexibility software developing model. ISPRS, Vol. XXXIV, PART2, Com II, Xi'an, Aug.20-23, China, pp. 169-170

[15] Kolbe, T., Groeger, G., and Czerwinski, A., 2006. City geography markup language (CityGML). In: OGC, OpenGIS consortium, discussion papers, Version 0.3.0, doc. no. 06-057.

[16] Kothuri, R., Godfrind, A., Beinat, E., 2007, Pro Oracle Spatial for Oracle Database 11g, Apress, 2007, ISBN: 1590598997.

[17] Lanza, V. and D. Prosperi, 2009, Collaborative e-governance: Describing and pre-calibrating the digital milieu in urban and regional planning, in (Krek, Rumor, Zlatanova& Fendel) Urban and Regional Data Management, pp. 373-398

[18] Lan, H., Derek, M.C., and Lim, C.H., 2007. Rockfall analyst: a GIS extension for threedimensional and spatially distributed Rockfall hazard modeling. Computers and Geosciences, 33 (2), 262_279.

[19] Lee, J. and Zlatanova, S., 2008. Geospatial information technology for emergency response. In: S. Zlatanova and J. Li, eds. A 3D data model and topological analyses for emergency response in urban areas. Balkema: Taylor & Francis, 143_168.

[20] Lemmen, C. and van Oosterom, P., 2003. 3D cadastres. Computers, Environment and Urban Systems, 27, 337_343.

[21] Marghany, M., Cracknell, A.P., and Hashim, M., 2010. 3-D visualizations of coastal bathymetry by utilization of airborne TOPSAR polarized data. International Journal of Digital Earth, 3 (2), 187_206.

[22] Ministry of Construction in China, 2005, Management regulation for engineering documents of underground pipelines and cable in city, (issued in January 7th 2005) (in Chinese).

[23] Oracle, 2003, Spatial User's Guide and Reference10g Release 1 (10.1) Part No. B10826-01 Dec 2003

[24] Peng, W., She, X., Xue H., and Znang, W., 2002, Integrating modelling for profile analysis of urban underground pipelines, based on 3D GIS, IAPRS, Vol XXXIV, PART2, Com. II, Xi'an, Aug.20-23, China, pp. 379-382

[25] Penninga, F., 2004, Oracle 10g Topology; Testing Oracle 10g Topology using cadastral data GISt Report No. 26, avaiable at http://www.gdmc.nl/publications, 48p

[26] Penninga, F., and van Oosterom, P., 2006, Kabel en leidingnetwerken in de kadastrale registratie, GISt rapport No 42, avaiable at http://www.gdmc.nl/publications, 36 p. (in Dutch)

[27] Ploeger, H.D., and Stoter, J.E., 2007, Eigendom van netwerken en het kadaster : eerste stap in 3D eigendomsregistratie. In: Bouwrecht, 44(2007)12, pp. 1019-1025 (In Dutch).

[28] Pu, S., 2005, Managing Freeform Curves and Surfaces in a Spatial DBMS, MSc thesis, available at: http://www.gmdc.nl/publications

[29] Roberts, G., Evans, A., Hollands, R., Denby, B., Cooper, S., and Dodson, A., 2002. Look Beneath the Surface with Augmented reality, GPS World, February, pp. 14-20.

[30] Stoter, J., and Zlatanova, S., 2003, Visualisation and editing of 3D objects organised in a DBMS, Proceedings of the EuroSDR Com V. Workshop on Visualisation and Rendering, 22-24 January 2003, Enschede, The Netherlands, 16p

[31] Stoter, J., Kluijver, H., and Kurakula, V., 2008. 3D noise mapping in urban areas. International Journal of Geographical Information Science, 22 (8), 907_924.

[32] Tegtmeier, W., Hack, W., Zlatanova, S., and van Oosterom, P., The problem of uncertainty integration and geo-information harmonization In: V. Coors, M. Rumor, E. Fendel and S. Zlatanova (Eds.); Urban and regional data management: UDMS annual 2007, Taylor & Francis, 2008, pp. 171-184

[33] Verbree, E., S. Zlatanova and K. Smit, 2004, Interactive navigation services through value-added navigation CycloMedia panoramic images, in: Proceedings of Sixth International Conference on Electronic Commerce, 25-27 October, Delft, The Netherlands, CDROM, 10 p

[34] Xu, L., Geng, G., Shi, M., and Lin, S., 2008, Pipe Network 3D Visualization Service Architecture, in 2008 IEEE Congress on Services 2008 - Part I, pp. 495-502

[35] Yong, Y. 2003 Research On 3D Visualization Of Underground Pipeline, Transaction of Wuhan University, edition of science information, June, 2003

[36] Zlatanova, S., 2004, Workshop on 3D city modelling, UDMS 2004, textbook, available at http://www.gdmc.nl/publications, 52 p

[37] Zlatanova, S., and Stoter, J., 2006, The role of DBMS in the new generation GIS architecture, Chapter 8 in S.Rana & J. Sharma (Eds.) Frontiers of Geographic Information Technology, Springer, pp. 155-180

[38] Zlatanova, S., Rahman A.A., and Pilouk, M., 2002, Trends in 3D GIS development in: Journal of Geospatial Engineering, Vol.4, No.2, pp. 1-10