Using Point Cloud with GIS and Virtual Reality to Manage and Inspect Building Plumbing

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ABSTRACT: The research develops a visual building plumbing management system (VBPMS) for effective system maintenance and supervision. The study combines a geographic information system (GIS) and a virtual reality (VR) program to manage and inspect a building plumbing system. The GIS uses point cloud retrieved from a 3D scanner as raw data to record plumbing shapes and locations, to assign serial numbers, to classify types, and to create databases. Because plumbing can be seen in 3D by ArcScene of ArcGIS, a plumber can find a pipe's location and retrieve information via serial number and database. On site seek and test time can be reduced during maintenance. The system also allows a building manager using to supervise plumbing information as well as to locate and fix problems in a timely manner.

Conference theme: Construction and materials
Keywords: 3D scanner, point cloud, GIS, building plumbing

INTRODUCTION

The research combines a geographic information system (GIS) and visualization method to manage and inspect a building's interior plumbing. The GIS uses a 3D scanner to record building plumbing shapes as 3D point clouds to support the information required in maintenance, assiging serial numbers, classifications, and databases. The system allows a building manager using GIS to retrieve the location and the product information of the plumbing in a building, as a way to help fixing plumbing problems in a timely manner.

Building plumbing consists of intricate network of systems. In the past, system is maintained mainly based on design drawings with very limited modification made before being filed as as-built records. Whenever plumbing needs to be maintained, manager usually has difficulty in finding information in a handy manner. As a result the maintenance can hardly be conducted efficiently. An appropriate management model for maintaining the plumbing infrastructure is therefore needed expecially under an as-built form.

Plumbing shop drawings hardly repesent the accurate construction site information by integrating the most updated system modification. Plumbers must coordinate with the other contractors prior to installation (Ambrose 1992). Plumbing is usually configured at site with higher priority on function than the location. When the plumbing is installed, usually no complete record of as-built configuration exists yet, neither does the accurate plumbing layout (Shih and Wang 2006). The uncertainty of old records and the still innoience of new constructions makes it difficult to find the pluming layout information which is fundamental for management. It wouldn't be surprised when plumber must reconfigure a new pipe slightly off the original design location for an easy installation and yet not be recorded in as-built drawings. On-site adjustments prevent plumbing records from being manageable and durable for future use. Over a long period of time, the plumbing system will become too cumbersome and difficult to maintain. So when maintenance is necessary, it is always easier to install new facilities upon existing ones than to be removed for no correct information regarding the system is still function or not.

The research uses a 3D scanner to record the shape and location of plumbing during construction process, instead of after installation. Data in terms of point cloud were used to justify if construction follows the design of the building's plumbing system. Point cloud is useful not only for creating as-built drawings, but also for plumbing management in post construction stage.

In the point cloud plumbing record, every dot has three-dimensional coordinate which initially does not show any information. A value is then assgned to each pipe to represent its layer name and the linking number between point cloud and database. A plumbing identification number is assigned to each pipe that identifies its position and function. Every pipe has its own number associated with the layers to be shown in the computer program. Under the layer framework, a plumbing database in accordance with the layer number is created.

After the point cloud's .dxf file is imported to GIS, the building's plumbing can be viewed in a 3D environment so a plumber can understand system layout easily. If a pipe does not function anymore, the pipe also can be retrieved in the database with all the information stored pertinently. Since the plumbing can actually be "seen" in the 3D environment, the plumber can retrieve the pipe's location and information via its number and the database. The information is useful for effective maintenance and management of a plumbing system. In the mean time, if a plumber needs to know the location of a pipe, the database information can be retrieved to calculate the distance between two pipes, or between the pipe and a wall or ceiling. This retrieve function is very helpful to reduce the on-site seek and test time during maintenance.

1. 3D SCANNER AND GIS

1.1. 3D laser scanner

A long-range 3D laser scanner can retrieve the surface geometries of remote objects as point clouds. 3D scan of small objects at short range has been widely applied to industrial design as part of the reverse engineering process. Previous industrial applications were not suitable for data retrieval of large objects like buildings until recently when the long-range laser scanner was developed. This study used a Cyrax 2500 (Figure 1) to scan a building site in order to record construction progress. Originally, a building's construction process was recorded with text, photos, and videos. The 3D scan data could be used as a type of supplementary record for the analysis and evaluation of construction quality and quantity.

Figure 1: 3D scanner (left) and registration 0targets (right)

3D scans retrieve the configuration of the plumbing that is visible to the scanner as construction records (Figure 2). These records are useful for work quality check. Since the clouds consist of x-, y-, and z-coordinates, as-built geometric information can be compared with original 2D shop drawings. A building's plan can be shown on a computer screen to verify any possible difference between the two sources of data (Shih and Wang 2002; 2004).

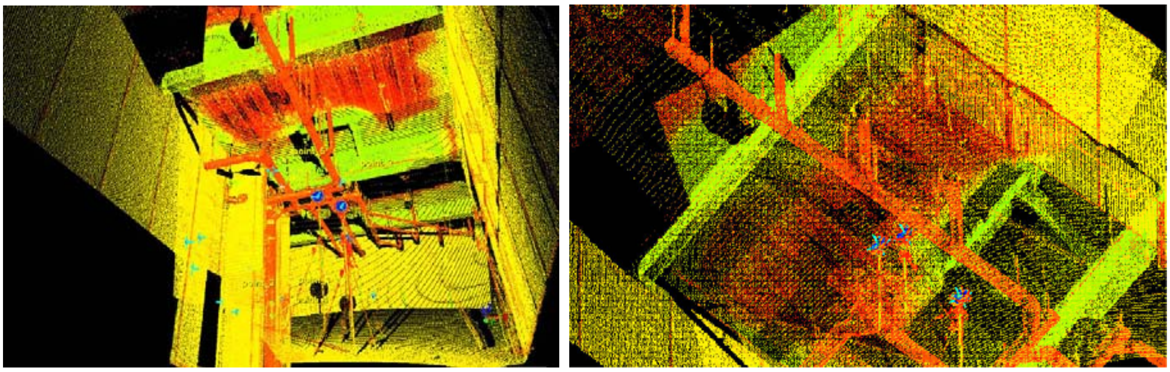

Figure 2: Point clouds of toilet plumbing

A single scan can contain up to a matrix of 999 points in width and length to figure the shapes of objects' surfaces that are exposed to the scanner. The building is scanned from different orientations to create an "omni view" that allows a building manager to observe the plumbing from any angle. The research team scanned and recorded plumbing locations from more than four orientations in each room. This system allows for modifications of scan density and enables the juxtaposation of multiple scans in one scanworld. Scans can be registered using reference points (or targets) shared by adjacent scans. The size and boundary of the scanworld is virtually unlimited.

Scanned data are stored in Cyclone .imp format, which is translated into .xyz or .dxf files to be used by other applications. Most GIS supports the .dxf format. When point cloud data are imported to a GIS and linked to other data, plumbing information is co-related and available to the plumber and building manager.

1.2. GIS and pipes database

GIS works well with most databases. The system can use different databases to display necessary information. The research expects to use GIS to create links between point clouds and plumbing database for the cloud's attributes display. GIS has been developed for more than 30 years. The system can integrate digital maps, databases, remote sensing, and GPS to serve many functions (DeMers 2000). GIS uses special information and attribute databases to measure, represent, operate, and transform objects (Chirsman 1997), by translating data into a multi-attribute information system and searching interface for measurement, mapping, monitoring, and modeling (The Four Ms) (Star and Estes 1990). Users can obtain information to coordinate and operate projects as needed.

The development of GIS not only makes it possible to perform the previously mentioned functions, but also contributes to great research using databases. For example, recently there was a serious debris flow problem in Taiwan. GIS was used to forecast the effects of rainfall using an advanced measuring device and efficient translation interface. Forecast and monitor items, such as weather conditions and debris flow, becomes easier and more efficient (Yu et al. 2006; Lin et al. 2002; Lin 2001). Moreover, the system can use different layers to stack multiple maps as defined by a theme. For example, a user can create any information needed for his research. Since it operates based on union, intersection, difference, and determination functions, it can analyze and compare many complicated information and data attributes.

GIS can coordinate drawing information and databases. Previously, plumbing diagrams only indicate approximate plumbing configurations. The disgram does not associate with any accurate information, such as construction organization, installer, contractor, telephone number, and warranty. With the GIS coordinating capability used, all plumbing information is available via search functions. So the plumbing contractor can work quickly and efficiently. Traditional shop drawings are limited by the physical size of drawing paper. Now GIS can connect files and information beyond the limitation of drawings.

This research interviewed contractors and building managers to understand why it's difficult to determine a pipe's location. Apparently, only the plumber knew the actual plumbing configuration. Since the plumbing shop drawings were referenced by contractors and building managers, other people found the on-site plumbing configuration difficult to understand and to perform follow-up maintenance. The plumbing illustrated by GIS should benefit the community by providing complete configuration information of local plumbing systems.

2. BUILT TO PLUMBING CODE

2.1. Plumbing classification framework

If every pipe has an ID number from the framework, it can easily be assigned in a database. The research assigns an appropriate code to each pipe according to pipe attribute, location, and branch. This allows the plumbing contractor to manage plumbing efficiently.

General building plumbing is divided into water supply, drainage stack, and sewage stack. Each division becomes a field listing the attribute of a pipe with the plumbing code making it easy to recognize. Besides shaft plumbing has vertical pipes while most plumbing has a horizontal configuration. The research assigned the code, "V", with vertical pipes; other pipes are coded by connection location from a major trunk. This GIS database not only can control and understand the subordinate relationships between the pipes, but also their arrangement location. For example, with regards to plumbing code D1120, the "D" represent drainage stack, "1120" represent the second pipe in the first branch of the first major trunk. For this plumbing code framework, one can ascertain pipe location. Plumbing configuration is complicated in buildings since the amount of space is large. It is not enough to describe plumbing location by just the forward code. The research assigns building codes and spatial codes before the plumbing code. Therefore, every pipe in a building has its own plumbing code. The building's name is Fifth Comprehensive Building, the research assigned it the code name "B5". After the building name code, a four digit code is used to describe the spatial number. For example, the plumbing code for the first branch drainage of the first major trunk for room 917 in the Fifth comprehensive Building is B50917D1100 (Figure 3).

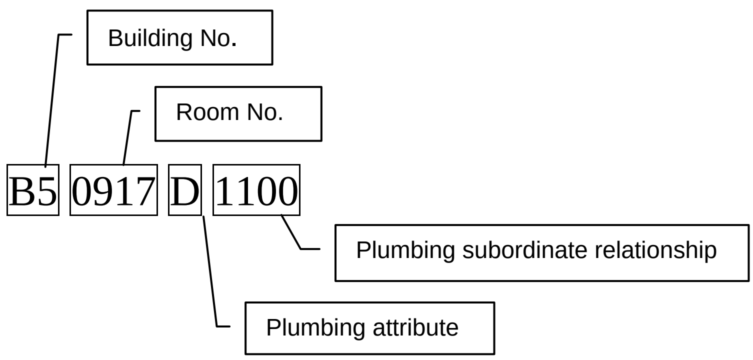

Figure 3: Contents of plumbing ID

For the research, plumbing codes need eleven numbers. The first two numbers are the building code. The third to sixth numbers comprise the spatial code. The seventh number is the plumbing attribute code. Research parameters are limited to a scan accuracy of 600*600 (maximal matrix is 999*999). The water supply pipe is thin and difficult to recognize. The research only assigned codes to drainage and sewage pipes. We use "D" for drainage pipe, "S" for sewage pipe. Other pipe systems can use this framework. The last four numbers represent the plumbing's subordinate relationships. Since the shaft pipe has a vertical configuration and the other pipes have horizontal configurations, the shaft pipes are assigned the code "V000" to indicate that it is a major trunk in the shaft. Other pipes are coded in relation to its position from the major trunk in accordance with sequence permutation. For example, the first horizontal pipe from a major trunk is designated as "1000", the first branch from 1000 is "1100", and so on. Every pipe uses this framework so that it is easy to recognize.

2.2. Set layer

In accordance with the code framework, the research uses Cyclone which is point cloud software to edit the original plumbing codes. The original point cloud only has three-dimensional coordinates values and no other attributes. The research give every point cloud image of a pipe a layer and a revised plumbing code so that it can be entered into the plumbing database.

First, peripheral point cloud data is deleted. Only the main pipe point cloud is kept. In accordance with coding framework, the pipes are recorded one by one and assigned a plumbing code. When the layer of plumbing code setting is finished, it is saved in a .dxf file format and is easily imported to other software.

3. PLUMBING DATABASE DEVELOPMENT

The plumbing database is very important for building plumbing management. Point cloud in itself does not provide any information. So it completely depends on the database to provide useful information for building maintenance.
The research, in accordance with the plumbing code framework, changed the plumbing code into ID numbers. In the database, we note information about every pipe such as attributes, completion date, warranty period, contractor, and contact information. The research uses Excel of Microsoft Office to create the database.
In the research, the pipe database has pipe IDs, attributes, diameters, materials, installation time, warranty period, construction unit, and contact information (Figure 4). All the information is saved in database file format (dBASE III).

	A	B	C	D	E	F	G
1	管線編號	管線屬性	ϕ管徑(mm)	材質	施工時間	保固年限	施工單位
2	B50917DV000	管道間排水立管	125	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
3	B50917D1000	主排水管	100	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
4	B50917D1100	排水管	100	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
5	B50917D1100	排水管	100	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
6	B50917D1110	排水管	100	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
7	B50917D1120	排水管	100	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
8	B50917D1121	排水管	50	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
9	B50917D1122	排水管	50	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
10	B50917D1123	排水管	50	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
11	B50917D1124	排水管	50	環氧樹脂粉體塗裝鋼管EIE	92.3	一年	○○水電
12	B50917SV000	管道間污水立管	150	Cast Iron Pipe	92.3	一年	○○水電
13	B50917S1000	主污水管	100	Cast Iron Pipe	92.3	一年	○○水電
14	B50917S1100	污水管	80	Cast Iron Pipe	92.3	一年	○○水電
15	B50917S1110	污水管	80	Cast Iron Pipe	92.3	一年	○○水電
16	B50917S1200	污水管	100	Cast Iron Pipe	92.3	一年	○○水電
17	B50917S1300	污水管	100	Cast Iron Pipe	92.3	一年	○○水電

Sheet1 / Sheet2 / Sheet3

Figure 4: Plumbing database, from left to right is plumbing ID, attribute, diameter, material, install time, warranty period, and construction unit etc.

4. USE GIS TO CONNECT THE PLUMBING DATABASE

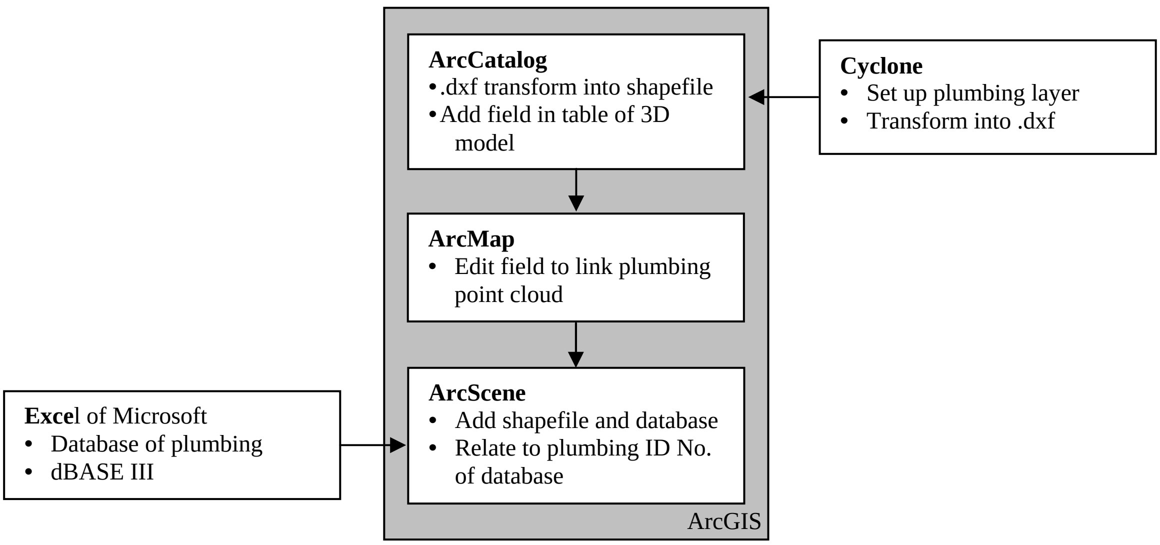

Figure 5: Information flow

The research used ArcGIS of ESRI for its plumbing management tool. ArcGIS is compatible with different application software such as ArcMap, ArcCatalog, ArcScene, ArcGlobe, and ArcReader. Every application software can operate either alone or with other software. For example, ArcMap uses data to draw, procees spatial analysis, and integrate other information. ArcCatalog reviews, manage, organize, and searches information (Figure 5). The research used

ArcScene to rotate, move, and zoom three-dimensional point cloud information. It shows a realistic view of the real plumbing using the point cloud information. The command “Identify” allows the user to point to any dot in a plumbing point cloud.

With ArcScene, plumbing point cloud is imported to a database and the “Relate” function connects the point cloud and database. When a user points to any dot in a point cloud plumbing, the pipe attribute from the database is displayed. This allows the plumbing contractor to control any plumbing information easily.

5. DEVELOP A VISUAL PLUMBING INFORMATION MANAGEMENT SYSTEM

5.1. Spatial index system

For easy accessibility to the index system, the research created a 3D structure model of the building. Every special set up is linked to a point cloud plumbing simulation. Any piece of plumbing can be connected to a GIS plumbing system. In GIS plumbing, the user can continue to search for follow-up plumbing information.

5.2. Plumbing search system

The .dxf point cloud file format includes five different types of file formats such as Annotation, MultiPatch, Point, Polygon, and Polyline. Others do not need a plumbing search system for convenient follow-up operations. This study transform .dxf file into an ArcCatalog shapefile format first. Actually, if more system contents are needed, either the whole or part of .dxf file can be transformed into a shapefile.

In this study, a three-dimensional environment is needed. The ArcGIS system uses a three-dimensional file format, but most software can only read in two-dimensions in ArcGIs. Only ArcScene can present displays three-dimensions. The point cloud shapefile and plumbing database have the same field used to describe the plumbing codes.
In the test, the three-dimensional plumbing is can be rotated, moved, and zoomed to find a specific pipe. A virtual reality display can greatly decrease plumbing problems. Plumbing contractors can actually see the plumbing on site via the 3D display. Users can easily point to any plumbing, and connect and display all of information on a particular pipe (Figure 6). Plumbers do not need traditional as-built shop drawings or plumbing tests to understand and control relative information of any pipe, as well as execute follow-up maintenance or service.

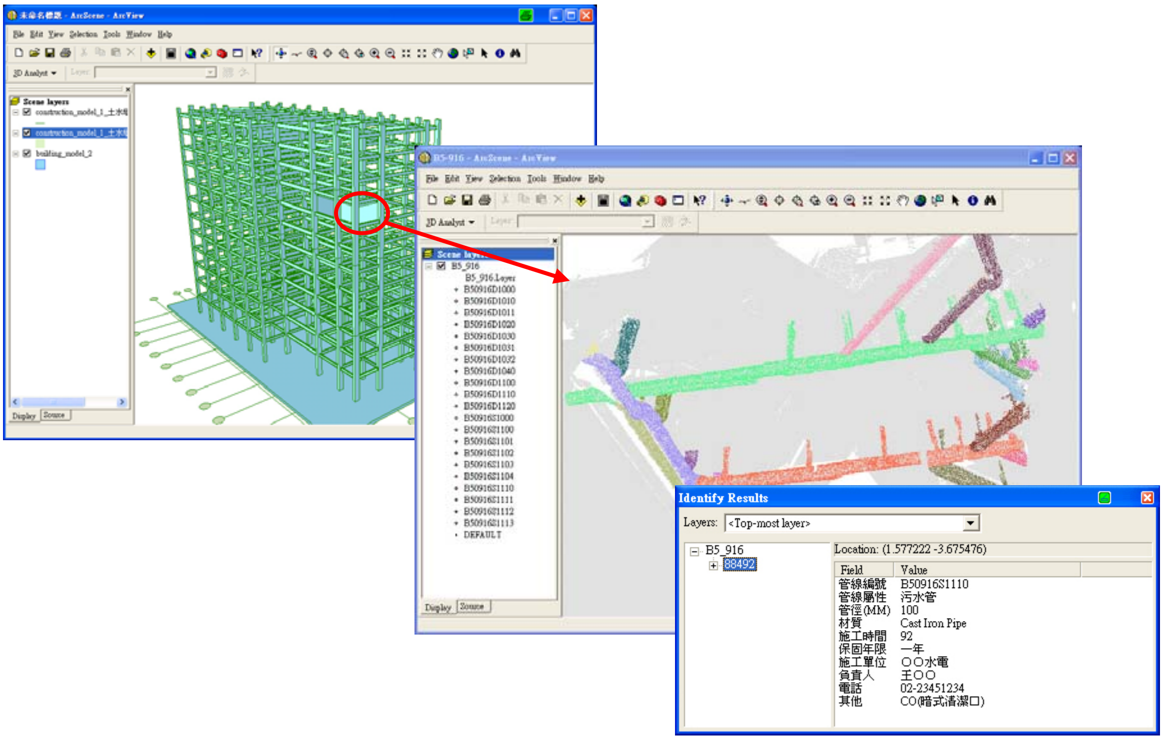

Figure 6: Plumbing management system

Plumbing in a building is intricate and, cannot adequately follow recorded configuration leading to difficulty in maintenance. This study tries to use GIS to connect a point cloud-plumbing configuration and a database. This will allow a user to easily use this system to search for the location and pertinent information for a pipe.

CONCLUSION

Building plumbing is very important to a building. But it was not efficiently managed in the past. This resulted in building plumbing having many problems related to use, management, and maintenance.

Plumbing changes as the building ages, and tenants move, or facilities increase. If a GIS plumbing system is used, checking plumbing status, function, material, construction unit, and warranty period etc is much easier. It helps the manager and plumber know how to keep the system well maintained.

A plumbing point cloud that is used with a GIS to create a database can help a building manager or plumber conveniently manage a plumbing system. Its 3D plumbing display can show the same plumbing point cloud configured on site. Moreover, the plumbing database can immediately display all attribute information of a specific pipe so that a plumber can clearly determine how to maintain and service the pipes thereby decreasing the possibility of erroneous judgment and re-configuration.

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