PLUMBING LOCATOR IN AN AS-BUILT BUILDING FORM

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This study analyses the usefulness of 3D scanners in recording pipe locations within newly constructed buildings. With a better understanding of the pipe layout within a building, better plumbing system management should be possible. During the building construction process in the past, pipes would offset sideways or factor in other design changes. Other construction operations, such as ceiling installation, wall partitioning, and shaft follow-up, complicated the building pipe data when attempting to locate pipes or determine their future usages. The 3D scanner used in this study recorded the finished pipe layout during the building construction process. Pipe information, which was made of point clouds, accurately displayed the as-built location of the pipes on the construction site. Point clouds were checked against the as-built shop drawings to correctly control the pipes' real status on site for the building management and maintenance department. As a result, the maintenance department could more easily obtain the pipes' location and determine the functions and attributes of the pipes before maintenance was conducted.

Keywords: 3D scanner, point cloud, plumbing, facility management.

INTRODUCTION

In a building, if there is not an appropriate interior plumbing layout, users will not have the best environment for planning and design. Plumbing acts as a support supplier, linking various supply routes that are not well configured. Improper follow-up maintenance management is not good because it creates unqualified results during the building use process. There are usually several reasons for changing the original configuration, such as a change of users, spatial requirement changes, new facilities, and old plumbing. Up to the present time, information has been too limited for plumbing changes and construction equipment to function well, making maintenance and renewal difficult. Therefore, plumbing equipment is continually being added to the original building. This process not only increases route pipes and ducts to every section of the building, it makes it almost impossible to locate a pipe, trace the route of ducts and cross rooms.

Building pipes have many designated uses: for cool water, heated water, waste, power supply, gas supply, and the Internet. They are laid out in accordance with shop drawings for configuration in the building. The most important requirement for plumbing is function. On the building construction site, there are many conditions that

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are coordinated insufficiently with the rest of the production or regulated construction contents in accordance with the actual construction conditions (Ambrose 1992). Sometimes, construction contents may not conform to the original design shop drawings. Most shop plumbing drawings display the beginning and the end with the routes between them not noted. Moreover, they are built according to the constructor's desire, custom configuration, or construction environment. The result is a varied and usually unequal pipe configuration. A great amount of plumbing passes through a location that cannot be controlled during grouting or other construction operation. This leads to difficulties for follow-up maintenance and management. The change may be due to new requirements to change the plan of configuration (Ai-Momani2000; Cox et al. 1999), or finding shop drawings that cannot be made on site in order to change designs (Mokhtar et al. 1998). If recorded incorrectly, the plumbing location will influence maintenance and management.

It is now difficult to record the real location of plumbing in construction sites as there are few sufficient recording tools available. Recently, the 3D scanner has become popular for many different uses. It can record true whole 3D spatial information from a scanned body. Therefore, it greatly influences historic building and important history landmarks. Moreover, the 3D scanner is not limited to spatial conditions and easily scans bigger buildings or long ranges. Construction sites will change their recording methods when they have 3D scanner help.

This research used a 3D scanner to record as-built plumbing information when a building was being built to refer to pipe locations for future building management and maintenance. Because this information can relay the true construction site pipes' location, it is different from the shop drawing display. If it operates to draw in coordination with as-built drawings, it will let the building manager control plumbing conditions for maintenance and renewal procedures. It also allows the building manager to quickly find the real location of the pipes to ensure that they are correctly fixed and maintained, and to determine function and attribute by the as-built drawings and point clouds measurement.

In the design and as-built comparison, the research method started from an on-site scan to an overlapping inspection with construction drawings. The verification of scan efficiency was once made in a ceiling space by removing tiles to reveal the as-built situation within. Since this was a new building, no partitions had appeared yet. We used the scan data to verify design variations.

The challenge in the future would be a thorough scan of the entire building interior. This compares to the current work where about 35% of the facility was scanned before partitions sealed the pipes. This would allow for a more efficient work schedule, especially in catch-up situations.

APPLICATION OF 3D SCANNER ON CONSTRUCTION RECORD

In the past, construction sites used photos or/and videos with text to record related work. Its record mode remained as 2D information. This mode failed to display the three-dimension relationship, and also made it easy to make a mistake based on vision. So a three dimension spatial record modes like photogrammetry were gradually developed to record the construction site or real building environment and transformed a photo image into a 3D model.. A real building environment can be recorded with a photogrammetry model (Powers 1996; Heuvel 1998; Dorffner and Forkert 1998).

Recently, a long-range 3D scanner has been developed to finally give those who just use traditional measurement techniques or photogrammetry a new choice. It uses laser light to deliver and receive, and produces 3D point cloud information in real time. It can build a 3D model of large sculpture (Rocchini et al. 2001), urban environment (Zhao and Shibasaki 2001), and be used to analyze construction component problems with a RP machine (Shih and Wang 2002).

This research used a long-range 3D laser scanner (Cyrax 2500) that can retrieve the shape geometries of remote objects as point clouds. At maximum, it can produce 999*999 matrix points. Its scan tolerance is about 2mm at 50 meters. The point density can be regulated by detail requirements. The principle uses laser light on an object and calculates the time difference between reflection times. The collection of points features cloud-like dots that take shape in relation to location in the air. The Cyrax 2500 has a long-range scan function and can register multi-scan into a single file. It can scan large objects and register point clouds with whole scan worlds. In theory, there is no limit for the volume and range of a target object (Shih 2002).

In our research we used a 3D scanner to produce point clouds of construction plumbing and then compared the results with shop drawings to confirm the difference between CAD and the real pipe locations. The real pipe location was recorded for as-built drawings reference, which is offered by AutoCAD shop drawings by the architect. The drawings translated into MicroStation Triforma and CloudWorx which were used in this study, and the correct new pipes position in TriForma (see Figure 1).

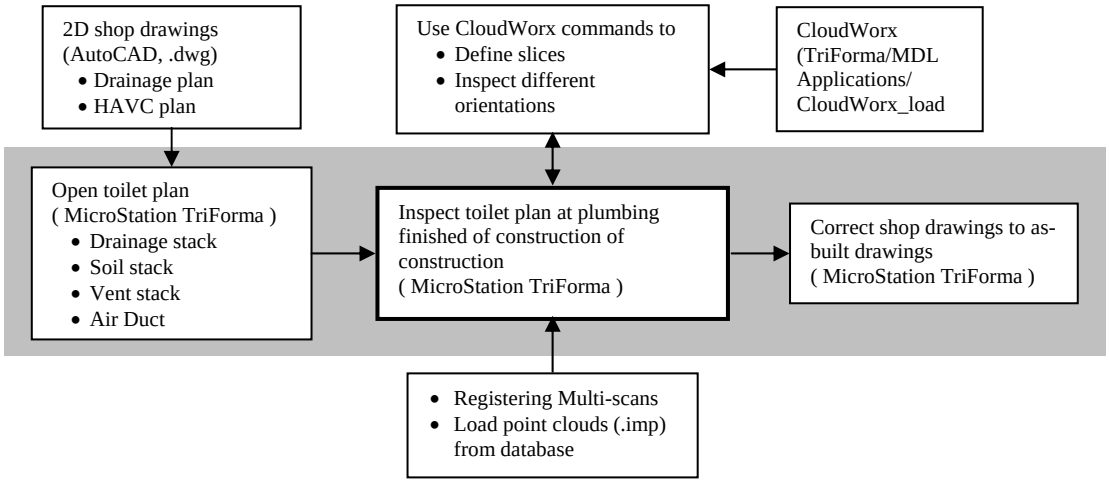

Figure 1. Information flow.

OPERATION AND PROBLEM OF BUILDING PLUMBING CONSTRUCTION AND MAINTENANCE MANAGEMENT

In general, building plumbing construction shop drawings are concerned with many different classifications, types of work in production, and professional technicians. So design plumbing and shop drawing must be integrated by the architect. Because of the extensive scope, the architects usually do not integrate before construction, waiting until the construction process when there are conflicts. Then they will coordinate the work in production with technicians. The results are usually much different from the original shop drawings. Most plumbing configuration requirements meet their major functions. It is only essential that the pipes passing in and out are configured correctly. Configuration is not necessary for pipe routes and location that do not affect

construction and structure, which are then regulated by the building site constructor. Almost all plumbing shop drawings use symbols and single lines to represent some detail of pipe configuration.

In the way of plumbing construction, shop drawings are used to give some relative conditions regarding pipe routes to configure on site. The only plumbing requirement is to solve the original function conditions. If these functions can be fulfilled, it can almost satisfy the client and to meet a standard of acceptance. The pipes must be considered in a three-dimensional environment with their pipe diameter and sluicing gradient (Stein and Reynolds 1992) and considered connection location of the surrounding environment and plumbing fixtures and equipment. Plumbing is usually hidden in the building when it is finished. It may be hidden in ceiling installations, wall partitioning, and shafts. For building construction approval, except past construction records, it only used the pipes that are functional. The quality and dimensions of pipes must be checked and recorded in materials in the site and construction process for inspection approval in the future.

For plumbing to be considered beautiful or functional in the design phase, it should be configured in concealed locations like slabs, walls or ceilings. Parts of pipes in the ceiling can be used to overhaul openings to check pipe location, and pipes that are not in their location will not be routed during grouting and seal board. Plumbing overhaul will seriously be influenced if the pipes are in a tightly squeezed area. Many problems will also occur when maintenance crews have to look for pipes that pass by in little openings and have a complicated plumbing configuration as well as in determining a pipe's function. This will greatly influence pipe searches, especially since many pipe locations are different than the original shop drawings and as-built drawings.

Pipes in shop drawings that express major requirement are a function. Configuration location can be changed when needed on the construction site. The pipes in the as-built drawings must be drawn by real site configuration. However, the reality is that they are not. The major reason is due to the reach of the pipe's function. Pipe routes are not important when it does not influence their function and operation. In shop drawings of pipes, configuration is only signal diagram. That being the case, the pipe's configuration is regulated in accordance with the construction site. If all the pipe locations must be measured and recorded, a lot of time and work are required, which won't be economical. Usually as-built drawings are used to record changes to plumbing design correctly, and they rely on as-built drawings to display the location of the pipes from the beginning to the end.

Building plumbing management must depend on original shop drawings and as-built drawings of the finished building to maintain it properly. Plumbing shop drawings and as-built drawings usually only display signal diagrams recording the pipes beginning and end points. When a building needs to be maintained, it only uses this limited clue from the pipes beginning and end points to determine their location and function. If it needs maintenance, work will increase/decrease since no one can determine the location of the pipes. Most solutions require creating a new pipe, because that removes the need to consider the location and relation attribute information of the old pipe. But following the buildings of the past, an increased number of pipes in the configuration will create more disorder. Many functions and pipe routes will have no way of being checked. More and more pipe problems will follow, causing an increase in management and maintenance costs.

It depends on the reliability of the as-built drawings and relation check information to prevent persecution of management and maintenance. In the past, there were deficiencies in pipe record tools, so locations couldn't be recorded clearly. The 3D scanner can record from as-built plumbing in the construction process. It can translate quickly from original shop drawings to accurate and detailed as-built drawings by shop drawing inspection. Since 3D pipes' spatial information can be displayed, pipe maintenance crews can rely on correct information for their work.

USED 3D SCANNER TO RECORD BUILDING PLUMBING

This research used a 3D scanner to record when the pipe configuration was finished at the construction site. The scanned building is L-shaped and is twelve stories above ground and three stories below. The building interior plumbing is multifarious. Due to limited time and manpower, we chose a complicated area to scan, which was the main toilet plumbing and air ducts in the discourse hall which hid the location of the pipes after ceiling construction. Since it focused the scan range in the interior pipes scan, we couldn't use a single scan to record, and instead used multi-scans to record and register a scanworld of interior pipes point clouds information (see Figure 2). Therefore, we had to consider the location of scanner and targets. With the point clouds, the relation of the toilet plumbing and the discourse hall air duct around wall and slab is clear (see Figure 3).

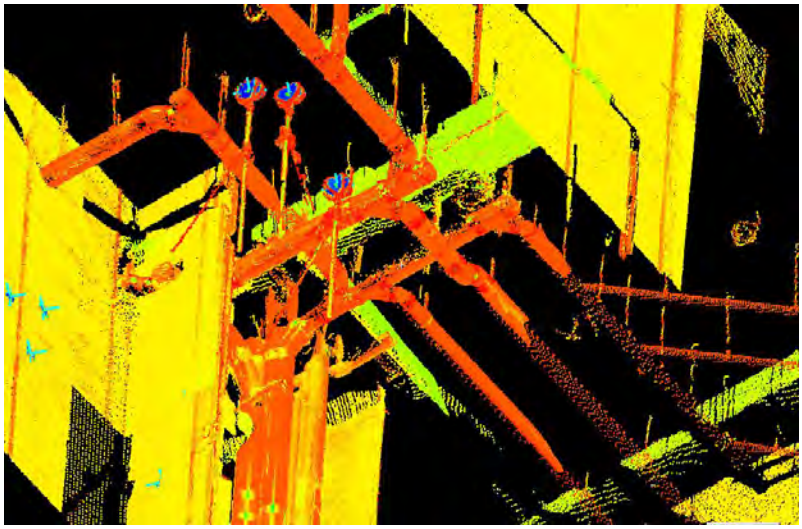

Figure 2. Register multi-scans point clouds of 10F man toilet plumbing.

By using the 3D scanner to record the plumbing point clouds and Cyclone to register them, one can clearly see three-dimension point clouds, and use measurement tools to immediately observe the relation dimensions between the pipes and building. This is very important information for the non-construction site shop drawings illustrator and maintenance worker. The illustrator can use shop drawings and point clouds for inspection, and easily and correctly draw the shop drawings to as-built drawings since they do not need to take measurements on site. Pipe maintenance workers can determine pipe locations from point cloud measurements and as-built drawings first. Then they can control information about the pipes and their location.

The point clouds of the on site scan is a 1:1 scale of real spatial information, so we can use MicroStation TriForma and CloudWorx to maintain shop drawings and observe the differences between the point clouds and shop drawings (see Figure 4). If one used

shop drawings and the naked eye to observe and measure the on-site pipe location, the workload would be enormous. Since the location of pipes is difficult to measure, it will affect the data. In addition, it must measure the data of every side of the pipe, which is difficult. If point clouds are used, one can search for data relating to any distance to a wall, slab, or another pipe.

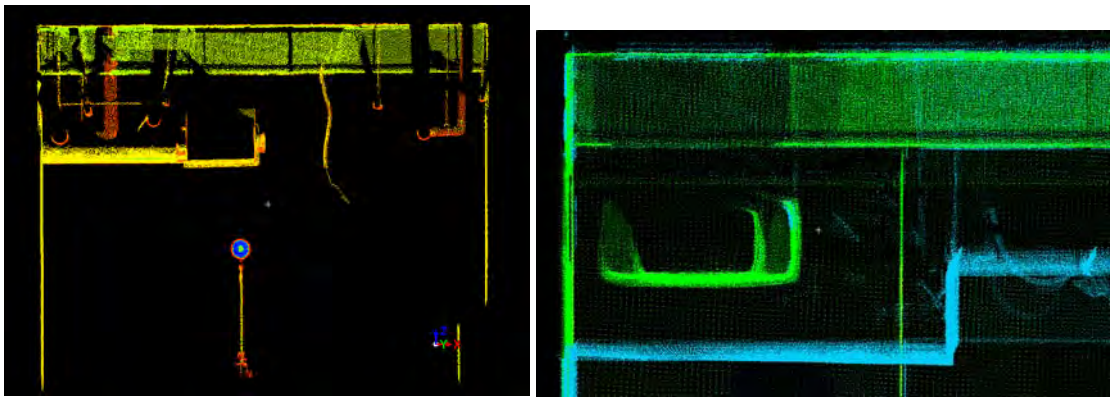

Figure 3. Plumbing and air duct relationship of wall and slab by section; to the left is the toilet, and to the right is the discourse hall.

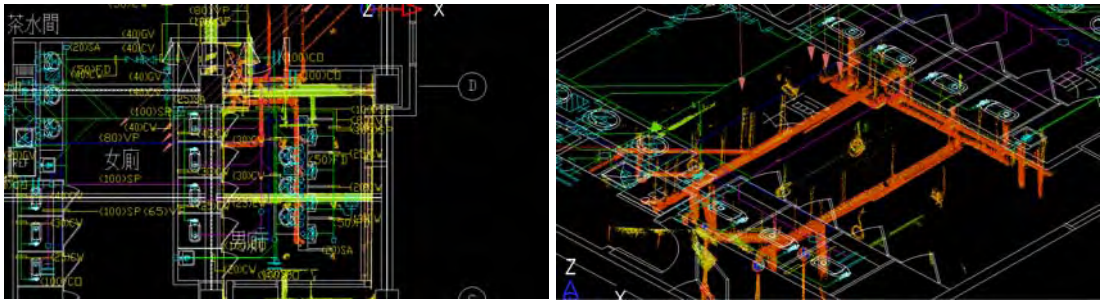

Figure 4. Inspect point clouds of toilet with pile of toilet plan, left is man toilet, and right is perspective of woman toilet.

Because building plumbing is intricate, many pipe designs and location changes will affect the real location of pipes. Inspecting the point clouds and shop drawings for the final construction result is much more different. We will not discuss the contents of design change for the present and focus on the pipe location regulations and pipes whose routes vary greatly from original shop drawings. Therefore, we can rely on as-built drawings (see Figure 5).

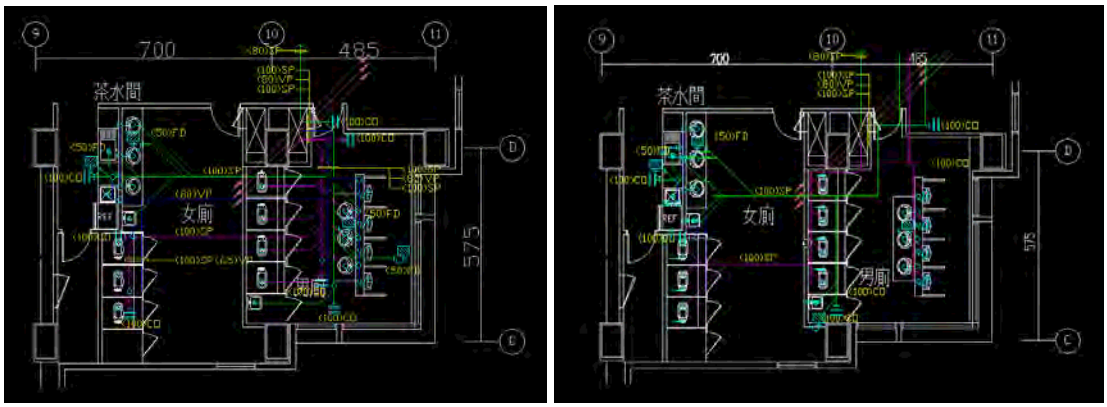

Figure 5. Correct shop drawings to as-built drawings, it is toilet of 10F, left is original drainage shop drawings, and right is as-built drawings after correct which was not finished vent stack in scanning.

DETERMINING PIPE LOCATION WITH POINT CLOUDS

On the construction site, most workers use limited shop drawings and measurement tools to configure pipes. Therefore, many pipe routing problems concern configuration condition changes and design changes. Much of the operation is in accordance with environment to regulations on-site. When the plumbing is finished, it limits the height and environment of the pipes and it is difficult to measure the pipe location. In regards to the building, the owner only requires that the pipes work. This research used plumbing point clouds to match original shop drawings so that the contractor could quickly control the differences in reality and the original shop drawings in order to avoid mistakes with the drawings quote again.

In the past, most as-built drawings only displayed design changes in the construction process and emphasized redrawing the design changes on as-built drawings to show the differences with the original shop drawings. If there was no change in design, the original shop drawings are translated into as-built drawings. However, most plumbing will change routes in the construction process and not be correctly displayed in as-built drawings because the contractor did not change the location of the beginning and the end points and function. This research improves effective pipe changes in point clouds translation to as-built drawings.

Building plumbing maintenance management uses as-built drawings information for maintenance procedures. However, the pipe locations of as-built drawings are not correct and it is difficult to connect the pipes on site with the drawings. Maintenance workers try to understand the pipe function and pass route that needs to be maintained which consumes much time. Moreover, these plumbing mistakes increase the possibility for maintenance mistakes. Building plumbing maintenance management must have one system to display the conditions of the as-built drawings on site and operate in coordination with original shop drawings to correct the problem. As a result, the manager of a building will have plumbing site plan information which is the same as the on site drawings and then collocate the original plumbing information from shop drawings with the hope of aiding future plumbing maintenance.

As-built drawings still use 2D for display, but plumbing configuration is finished in three dimensions. Fortunately, plumbing point clouds can now be made if as-built drawings do not display accurate locations, to measure distance point to point from plan and section (see Figure 6). Based on this data, it will be easier to find pipes that need maintenance.

This research has found that the measurements between the construction site and point clouds are inaccurate by about 1-3 cm (see Figure 7). So, if plumbing point clouds are used effectively, they can display the location of the pipes of unknown or uncertain status in three dimensions. Therefore, no time is wasted in looking for the correct pipes. In the measurement process on-site, we find that it is difficult to locate pipes in a limited space. Fewer mistakes will be made if the fixed ceiling is taken apart.

In the past, there was no respect for building plumbing management. Plumbing was configured one way and the construction was done in another way. The result was that shop drawings and as-built drawings couldn’t satisfy the requirements of plumbing management. The only way to fix the problems of building plumbing configuration is to enhance the importance of plumbing configuration display in as-built drawings. This research method can be used to strengthen plumbing records and will produce great changes for management, maintenance, and renewal.

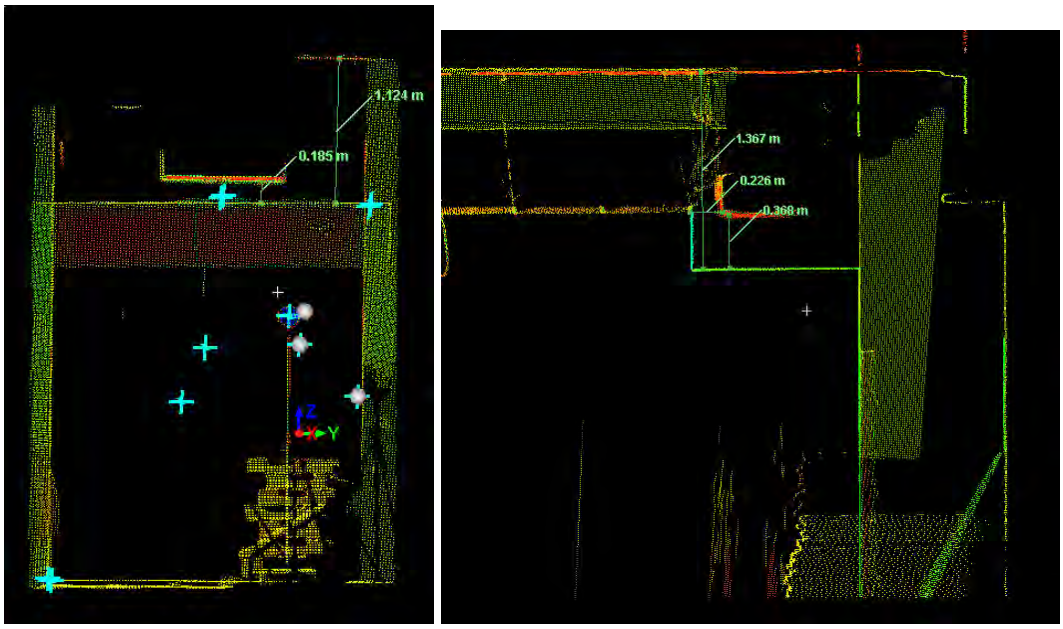

Figure 6. Measure distance point to point from plan and section, left is air duct of corridor of discourse hall to slab and ceiling, and right is interior air duct of discourse hall.

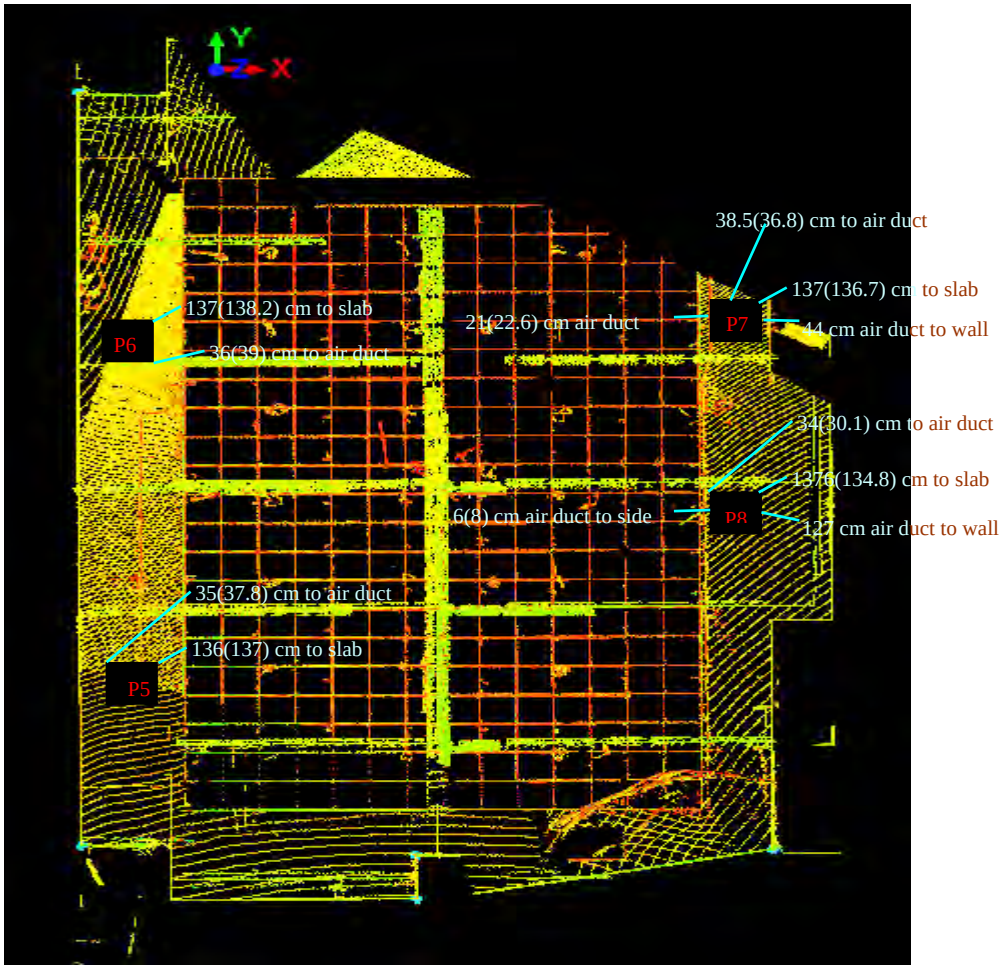

Figure 7. The result of air duct measurement in discourse hall, parenthesis is measurement from point clouds.

CONCLUSIONS

Our research has found that many plumbing shop drawings are different from the real configuration of pipes on site. Besides operating in coordination with the environment on site, there still are many changed routes and design configurations. If as-built drawings are used as they normally have been, the as-built drawing may only be an acceptance record. Not only do they not respond accurately to the real configuration of the location, but also they produce a negative effect for plumbing maintenance management for future managers.

Moreover, the research method produces plumbing point clouds information with a 3D scanner and can help as-built drawings be drawn correctly, which can help future maintenance workers search quickly for needed pipe locations. This can decrease many futile searches and decrease the probability of maintenance mistakes.

Our research finds the value of inaccuracy can rest on search plumbing for inspection of actual measurements and point clouds with correct as-built drawings and point clouds that can help the plumbing maintenance management of large buildings such as hospitals, high rise buildings, shopping malls, and oil refineries.

REFERENCES

Ambrose J (1992) Building construction: service systems. New York: Van Nostrand Reinhold.

Al-Momani, A. H. (2000) Construction delay: a quantitative analysis, I J of PM 18(1), 51-59.

Cox, I D, Morris, J P, Rogerson, J H, and Jared, G E (1999) A quantitative study of post contract award design changes in construction, CM and Economics, 17(4), 427-439.

Mokhtar, A, Bédard, C, and Fazio, P (1998) Information model for managing design changes in a collaborative environment, Journal of Computing in Civil Engineering, 12(2), 82-

Powers, R J (1996) Close range photogrammetry: the future of as-built drawings, Pulp & Paper Canada, 97(8), 17-19.

Heuvel, F A (1998) 3D reconstruction from a single image using geometric construction, Journal of Photogrammetry & Remote Sensing, 53(6), 354-368.

Dorffner, L and Forkert G (1998) Generation and visualization of 3D photo-model using hybrid block adjustment with assumption on the object shape, Journal of Photogrammetry & Remote Sensing, 53(6), 369-378.

Rocchini, C, Cignoni, P, Montani, C, Pingi, P, and Scopigno, R, (2001) A low cost 3D scanner based on structured light, Computer Graphics Forum, 20(3), C-299-308.

Zhao, H and Shibasaki, R (2001) A robust method for registering ground-based laser range images of urban outdoor objects, Photogrammetry Engineering & Remote Sensing, 67(10), 1143-1153.

Shih, N J and Wang, P H, (2002) The application of reverse engineering for building construction management, eCAADe2002, Proceedings of 20th eCAADe, 18-20 September 2002, Warsaw, Poland, 338-341.

Shih, N J (2002) An Application of a 3D Scanner in the Representation of Building Construction Site, Nineteenth International Symposium on Automation and Robotics in Construction. Proceedings of the 19th International Symposium on Automation and Robotics in Construction (ISARC 19), Washington DC, USA, pp. 337-342.

Stein, B and Reynolds, J S (1992) Mechanical and electrical equipment for buildings. New York: John Wiley & Sons, Inc