DEVELOPMENT OF TECHNOLOGY FOR AUTOMATIC EXTRACTION OF ARCHITECTURAL PLAN WALL LINES FOR CONCRETE WASTE PREDICTION USING POINT CLOUD

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Abstract. Recently, as more and more projects on residential environment improvement in cities are actively carried out, the cases of demolishing or remodelling buildings has been increasing. Most of the target buildings for such projects are made of concrete. In order to reduce energy use as well as carbon emissions, the amount of concrete used as a building material should be reduced. This is because the concrete is the largest amount of construction waste, which the exact amount of concrete needs to be predicted. The architectural drawings are essential for the estimation and demolition of building waste, but the problem is that most of the old buildings' drawings do not exist. The 3D scanning process was performed to create the plans for such old buildings instead of the conventional method that is long time-consuming and labour-intensive actual measurement. In this study, we scanned 40 old houses that were scheduled to be demolished. The result showed that the 3D scanned drawings' accuracy - 99.2% - was higher than the ones measured by the conventional way. Through the algorithm developed in this study, the various processes of demolition, drawing measurement, and discarding quantity prediction can be solved in one process, thereby reducing work efficiently. And, considering the reliability of the research results, it is possible to reduce the economic loss by predicting the exact amount of waste in advance. After that, if the algorithm, developed in this study, can be further subdivided and supplemented to identify the materials for each part of the old buildings, it will be able to propose an efficient series of processes that distinguish between recyclable materials and wastes and thereby efficiently dispose of them.

Keywords. Point Cloud; Construction Waste; Parametric Design; Algorithm; Automatic Extraction; SDG 8.

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1. Introduction

1.1. RESEARCH BACKGROUND AND PURPOSE

Recently, as more and more projects on residential environment improvement in cities are actively carried out, the cases of demolishing or remodelling buildings has been increasing. Most of the target buildings for such projects are made of concrete. In order to reduce energy use as well as carbon emissions, the amount of concrete used as a building material should be reduced. This is because the concrete is the largest amount of construction waste, which the exact amount of concrete needs to be predicted. The architectural drawings are essential for the estimation and demolition of building waste, but the problem is that most of the old buildings' drawings do not exist. The 3D scanning process was performed to create the plans for such old buildings instead of the conventional method that is long time-consuming and labour-intensive actual measurement. In this study, we scanned 40 old houses that were scheduled to be demolished. The result showed that the 3D scanned drawings' accuracy - 99.2% - was higher than the ones measured by the conventional way. After that, if the algorithm, developed in this study, can be further subdivided and supplemented to identify the materials for each part of the old buildings, it will be able to propose an efficient series of processes that distinguish between recyclable materials and wastes and thereby efficiently dispose of them.

1.2. SCOPE AND METHOD OF RESEARCH

The research method is as follows. Firstly, we present the current methods and problems of the manual measurement to draw the decrepit building's plans, and address the limitations of current technology and methods, in accordance with the analysis of the current status of reverse engineering technology. Secondly, the preceding Authors

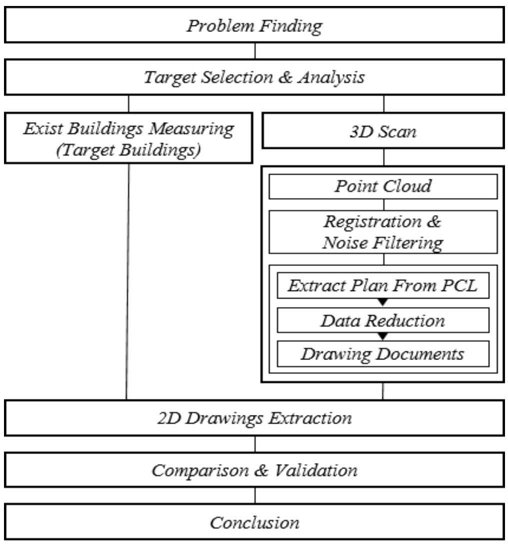


Figure 1. Research Flow

on point cloud-based reverse engineering and parametric technology research are examined. The point cloud of the target building is acquired by using a 3D scanner for the selected buildings. After going through the 3D point cloud registration process, the drawings are produced by an algorithm which is created by Grasshopper - a graphical algorithm editor integrated with Rhino 3D modelling tool. Finally, the information of the drawings extracted through the algorithm and the drawings produced by actual measurement are compared and verified. In addition, the expected amount of concrete waste is derived by calculating the concrete volume of the building using the matched point cloud data.

2. Background

Reverse engineering technology is actively applied in various fields such as shipbuilding, architecture, and MEP(Mechanical, Electrical, and Plimbing). Collecting point cloud data for reverse engineering requires a point cloud for each scanned location by employing equipment such as a depth camera and 3D scanner and a separate software that matches the various point cloud data matched to complete the building. Many reasearch on the development of point cloud-based reverse engineering technology have been conducted. Particularly, it is focused on modelling for building maintenance and restoration or recording of cultural properties.

In the field of building maintenance, there have been many studies on checking the building information, such as its location, concrete damage, and cracks in the exterior wall, on the basis of the point cloud data (Kim, 2019).

A study for point cloud-based building inspection required the process of extracting the drawing information of the building from the 3D model, and the 3D modelling had a limitation in having to align the location with the point cloud (Park, 2016). In a study to manage facilities in a BIM environment without going through manual modelling work, the point cloud was automatically mapped to objects in the BIM environment (Kang, 2019). BIM objects were created by searching for objects with a high degree of similarity in the BIM library by extracting the shape features of flat objects such as floors, walls, and doors (Yoon, 2020). As described above, studies on modelling objects derived from point clouds are in progress, but such studies are still challenging. The studies conducted so far have extracted point clouds for the 3D model, but modelling work was carried out according to the point cloud or modelling was performed based on existing drawings. Therefore, this study compares the proposed algorithm and the coherence of extracting objects as elements of geometry type by determining the reference point from the point cloud and generating drawings based on this.

Parametric design is a technology specialized in atypical design. It is actively used not only in the fields of architecture, shipbuilding, medical care, and mechanical equipment, but also mainly as a method to visualize or model objects (Koo, 2009). However, there are few studies related to extracting drawings from point clouds or parametric design.

Among them, there are several parametric studies using point clouds of buildings. One of studies implemented a method of acquiring a point cloud using lidar and projecting a 3D object observed from multiple locations onto a 2D plan. It was conducted for the purpose of visualization to inquire the point cloud as an image using CUDA-based 'Octree' and parametric algorithms, but the shape and scale of the building can be checked from the produced image. In spite of it, cross-sectional information such as the floor plan of the building cannot be known (Kim, 2016). In addition, another study developed a parametric algorithm to build a BIM library for each member for a 15th century dome building (Capone, 2019). In the other study, 3D mesh was extracted from a point cloud using 'Voronoi equations' to create a BIM model improved the model efficiency (Mesrop, 2020). As such, in the parametric field for point cloud-based modelling, algorithms are created for model creation. However, the created modelling algorithm has a structure that is difficult to fully operate when applied to other buildings.

In addition, the extracted 3D model has a problem in that it is possible to obtain information about the 2D drawing of the building only through the process of BIM modelling and drawing extraction. As such, most of the research in the parametric field using the existing point cloud is used in the medical field by creating a 3D model, or dealing with the intermediate stage process for BIM in the architectural field. Therefore, this study proposes a parametric algorithm that can be applied to various buildings as a differentiated study for extracting 2D drawings from the point cloud of a building.

3. Point cloud data pre-processing and experimental design

3.1. SELECTION AND ANALYSIS OF TARGET BUILDINGS

For the experiment to extract architectural drawings using point clouds, the buildings in the scope of this paper are located in Buk-gu, Daegu, South Korea. Although this target site is determined to conduct the residential environment improvement project, and existing buildings will be demolished or remodelled. There are many old and decrepit buildings that was built without permission and proper documentation, so that it is unlikely to find drawing materials, such as building drawings and land use plans, necessary for demolition and remodelling. Therefore, it is essential to secure digital data of buildings such as 2D drawings.

There are 51 buildings in the site, selected for this paper, they were classified into 4 based on the type of residence, structure, and number of floors. For the experiment, one building per type was selected and the point cloud of the building was acquired.

3.2. POINT CLOUD DATA REGISTRATION AND PRE-PROCESSING

First of all, consent was obtained in advance to scan the housing environment in which residents live, and the work before 3D scanning. For the point cloud acquisition, 3D scanning equipment 'BLK360' was used, which can acquire 360,000 points per second at a distance of up to 60m, and a manual measurement was conducted to obtain a comparison building measurements for this paper. In addition, 3D scanning was performed only when the roof or roof scanning environment was judged to be safe

The 3D scan was carried out for each room, interior and exterior of the building, and the higher the overlap of the scanned area, to make the pre-processing process more convenient. In the process of matching, unnecessary scans of people, vehicles, and moving objects, that are difficult to recognize, are excluded and considered noise. When the matching process is finished, the data can be reduced primarily by removing the point cloud not related to the target building, and the point cloud of the target building can be checked.

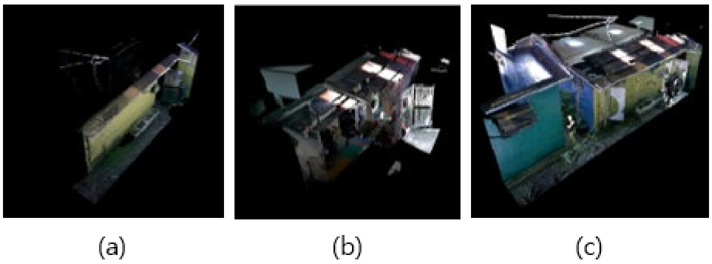


Figure 2. Original PCL (a, b) and Registrated PCL (c)

3.3. DEVELOPMENT OF DRAWING EXTRACTION PROCESS USING POINT CLOUD

Rhino6 was used for point cloud-based building drawing extraction. In this study, we used the '.pts' extension because we needed the point cloud data of the point cloud. And the parametric algorithm was written using Grasshopper.

First, through the process of section extraction of the point cloud (Figure 3), the area to create the drawing of the building is extracted. A horizontal cross section extracts the length, location and thickness of the wall, through this process the shape of the entire building plane can be realized. In this process, the point cloud of the section to be extracted is selected by adjusting the height and thickness based on the boundary circumscribed to the point cloud of the building. And by adjusting the height and thickness of the section, you can work while visually checking the height of the wall where objects do not cover it. Wall openings can be realized at the points extracted from different x, y, z axis coordinate values.

Second, the data is lightened to enable smooth operation of the extracted point cloud

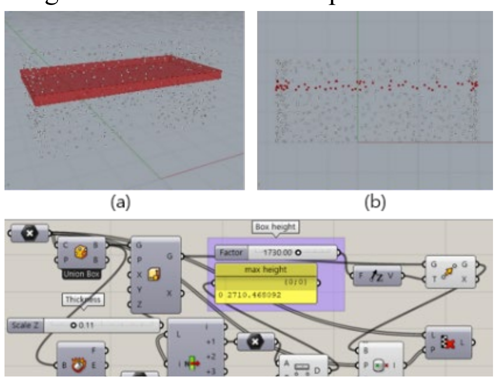


Figure 3. Section Bounding Box(a), Front View of Extracted Section(b), Section Extraction Algorithm(c)

in Grasshopper and the z-coordinate is deleted (Figure 4). If the x, y, z coordinate values of the point cloud are replaced with x, y, 0 values, the point cloud is changed to points on the x and y planes, making it easier to create drawings. And the z coordinate value becomes 0, and overlapping points are generated, and the plane point cloud is reduced in weight by erasing them. Through this process, the weight of the point cloud has been reduced to about 30%, but the shape is maintained, so it is possible to extract drawings.

Third, the drawing process is carried out by creating the centre line of the wall based on the lightweight planar point (Figure 5). By selecting points forming a straight wall, the centre line can be extracted by calculating the average distance of the points. At this time, if there is an opening in the wall, the process of erasing the centre line by selecting the point of the opening portion is performed, and the centre line of the wall is extracted. After that, the floor plan of the building can be extracted by inputting an interval so that the generated centre line matches the thickness of the wall. In the extracted drawing, the centre line and the wall line with the openings can be confirmed.

Through this algorithm, it is possible to extract the cross-section, light weight, and

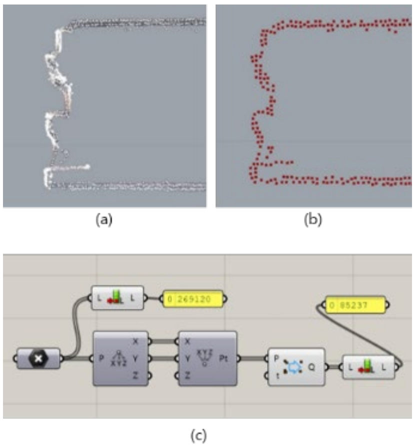


Figure 4. Original PCL(a) and Data Reducted PCL(b), Data Reduction Algorithm(c)

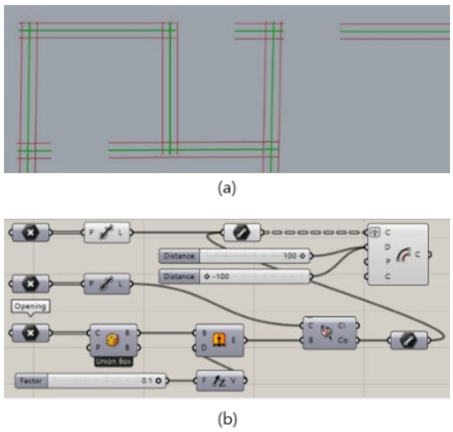


Figure 5. Generated Centre-line, Wall line, Opening(a), 2D Drawing Extraction Algorithm(b)

drawing of a building from the point cloud regardless of the size or number of floors of the building. However, since Rhino is not a software that handles point clouds, but a 3D modelling was conducted in 'Nurbs' format, there is a problem that the calculation time is extensive in Rhino and Grasshopper due to a high amount of point cloud consisting of about 20 million points or more. Therefore, it is necessary to reduce the weight as much as possible in the pre-treatment process. To reduce amount of the points, the values of the z-axis are adjusted using parameters for plane extraction. At this time, the corresponding height value must be adjusted manually, since the height including all the flat walls must be adjusted. Points included in this range are possible even as 0.1% of the total points, so pointer data can be lightened.

4. Extraction of architectural plan wall lines using point cloud for concrete waste prediction

4.1. EXTRACTION OF ARCHITECTURAL WALL LINES USING POINT CLOUD AND VERIFICATION

In the process of extracting a drawing from a point cloud through an algorithm, task such as drawing and length input was omitted, unlike the method of creating a drawing by actually measuring it. In addition, although the number of 3D scans varies depending on the size of the building or the number of rooms, the time and task of drawing up drawings have been simplified. The results extracted from the point cloud of the target building (Figure 6) are as follows.

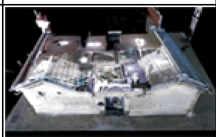
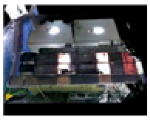
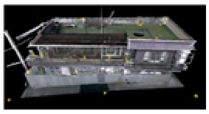
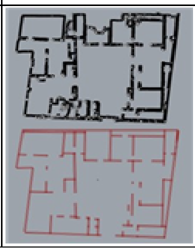
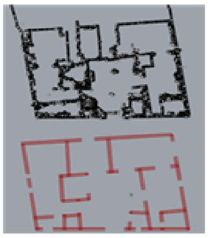
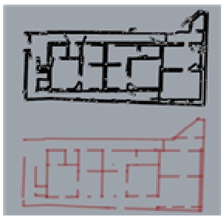
Type	A	B	C	D
3D Scan Count	50	18	11	43
Point Cloud				
Extracted Cross Section & Results				

Figure 6. Cross Sections and 2D Drawings Extracted from Point Cloud

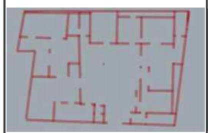
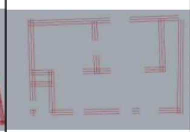
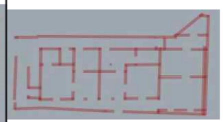
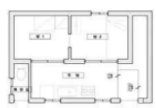
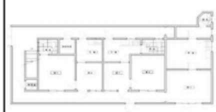
Building A is an unused, abandoned house with one side of the building adjacent to another building. It could be seen that some spaces were flat, not at right angles, and drawings could be extracted without the process of drawing. Due to the missing point cloud, it was possible to extract the intermediate planes of some walls by calculating from adjacent points.

Building B is a house in use, and it was not possible to acquire a point cloud for one side of the exterior wall. In addition, since the structure of the interior room is mostly at right angles, it was not possible to recognize the inclined square-shaped plane at the site, but it was possible to create an accurate drawing by grasping the shape of the building plane from the acquired point cloud.

Building C is a house inhabited by residents, and it was impossible to acquire a point cloud of the exterior wall because the two sides of the building were in contact with the neighbouring buildings. In addition, hidden spaces such as the plumbing room inside the wall of the bathroom could be found from the point cloud, and could be confirmed through the drawing process.

Building D is a two-story villa building that is scheduled to be demolished on a sloped site. Among the two floors, the drawings of the first floor with 3 out of 5 villas were extracted through an algorithm. Because the exterior of the building was partially used as the yard of an adjacent house, it was impossible to measure it, but it was possible to acquire a point cloud through 3D scanning from the outside of the second floor. Inside, only minimal furniture such as built-in cabinets remained, making it possible to extract a flat point cloud during the cross-section extraction process of the algorithm. Since the wall of the building was refracted in the process of extracting the drawing, the centre line of the wall was extracted by dividing it twice. Also, the space between the building and the retaining wall could be found in the inner room in the direction of the elevation of the site.

The difference was derived by comparing the drawing extracted from the point cloud through the parametric algorithm with the drawing prepared by actual measurement (Figure 7). The difference in area was compared to compare the difference in the overall size of the building.

Type	A			B			C			D		
Extracted Drawing												
Measured Drawing												
	M	E	D(%)	M	E	D(%)	M	E	D(%)	M	E	D(%)
Wall Length(m)	13.3	13.1	1.5	7.61	7.54	0.9	6.05	6.07	0.3	7.24	7.33	1.2
Depth of Space(m)	2.85	2.80	1.7	2.62	2.59	1.1	2.6	2.58	0.7	3.20	3.16	1.5
Square Measure(m^2)	226.8	220.6	2.8	74.3	75.0	0.9	24.2	24.1	0.04	127.9	140.1	8.5

● M : Measured, E : Extracted. D : Difference

Figure 7. Comparison of Measurement 2D Drawings and 2D Drawings Extracted through Algorithms

4.2. BUILDING WASTE PREDICTION

The area of the wall can be calculated from the extracted drawings. The currently developed algorithm is at a stage where the expression of openings included in buildings is not performed. When the z-axis is 0, the area of the x and y planes can be calculated. At this time, since there is a possibility that all the wall lines are not straight, the area can be automatically calculated using the ‘area’ command from the extracted file.

$$\text{Concrete Waste Volumn } (m^3) = \text{ wall area } (m^2) * \text{height } (m)$$

And to obtain the volume, the height degree can be obtained from the point cloud registration data, and the volume of the wall can be obtained by multiplying the area obtained through the drawing by the height. Through this height information, the volume of the wall at the location of the opening can be obtained. Creating a BIM model is convenient because it is possible to automatically calculate the quantity for each material.

Figure 8. Height extract form 3D point cloud registration

5. Conclusion

Due to the residential environment improvement project, drawings of buildings are needed to proceed with the demolition and remodelling of old buildings. Recognizing the limitations of drawing extraction from point cloud through 3D modelling process through reverse engineering and parametric design related technical research to create drawings from buildings that have been carried out so far, and in the modelling process, 3D object modelling and reference drawings for placement This necessary problem was identified. In this study, we created a parametric algorithm that performs the process of section extraction, weight reduction, and drawing from the point cloud for buildings that require drawing. Through this, we tried to extract 2D drawings and construction waste, especially the amount of concrete, and the results of the derived study are as follows.

First, the method of extracting drawings from the point cloud did not require any work on the drawing unlike conventional method such as drawing plans through actual measurement. Moreover, it was possible to accurately create the refraction of the wall according to the shape of the road or site. Furthermore, by accurately creating a plan in which two different walls do not form a right angle, this algorithm was possible to extract the plan shape of the entire building within the legal tolerance range.

Second, it was easy to find the plumbing room that is difficult to see with human eyes when making drawings by measuring the actual measurements. Also, this method can find easily the hidden space between the building and the wall. As can be seen from the actual experiment in this study, a space that human eyes could not find was found, and the wall that was slightly curved could be reflected in the drawing.

Finally, it was possible to predict the amount of concrete on the wall of the selected target building by using the derived architectural drawings and 3D point cloud data, due to the fact that the volume is easily found by multiplying the area by the height. This is because the area can be easily derived by extracting the drawing, and height information can also be easily obtained from point cloud.

The architectural drawing extraction algorithm using the point cloud presented in this study can increase the drawing accuracy for buildings that require drawing, and can reduce errors that occur when drawing drawings. Additionally, by predicting the amount of building waste in advance, it is possible to plan in advance for building waste during demolition and remodelling of buildings. However, algorithm developed in this study, is limited in its application to buildings containing various materials, such as insulation materials included in walls in general. Therefore, it is expected that it will be able to develop highly effective algorithms and methodologies by reducing errors depending on the size of the building and minimizing the post-processing process to extract drawings that can be applied in practice.

Acknowledgements

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