3D Modeling Approach of Building Construction based on Point Cloud Data Using LiDAR

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Abstract –

LiDAR (Light Detection and Ranging) emerges as a mapping technology that provides fast, accurate, and reliable data with geometric representation of construction facilities. The technology has received high recognition especially since the importance of digital transformation in construction projects has been emphasized. However, the current state of 3D technologies including LiDAR encounters difficulty in recognizing and extracting accurate information on the as-built status of the buildings and construction sites. As a preliminary study for the development of a 3D architectural geometric representation of building and environment, this paper proposes a 3D modeling approach based on point cloud data obtained by LiDAR technology. This paper suggests a novel method for data acquisition on as-built status of construction sites and buildings during construction-operation phases. Furthermore, a field test has been performed for visualizing and modeling of the indoors of a residential house. The results of this paper are expected to inaugurate adaptation of LiDAR technology during the as-built process, and further implementation of digital technology after construction phase in construction projects.

Keywords –

LiDAR; 3D modeling; building construction; digital transformation; point cloud data

1 Introduction

The construction industry is no exception from the changes derived by the fourth industrial revolution [1, 2]. Despite the innate conservative responses of the construction industry to rapid changes, the importance of adopting digital transformation throughout the entire cycle of a construction project has long been emphasized [3]. In particular, the recent trends of applying BIM (Building Information Modeling) and AR/VR (Augmented/ Virtual Reality) technologies have triggered various efforts to revolutionize the productivity and efficiency of construction projects [4].

Meanwhile, several concerns have arose pointing out that the digital technology of the construction industry is mainly applied to the design stage [5, 6]. The main reason is that there exists technical limitations in recognizing multiple objects as separate entities in the interior buildings and external sites during construction and operation phases [7]. Thus, the current state of technologies encounters difficulty in recognizing and extracting accurate information on the as-built status of the facility and sites [8]. As the acquisition of as-built information of buildings is operated manually, digital gaps are occurring during the design phase and construction-operation phase [9]. In order to minimize the processing time of data handling and translation error of as-built data, it is necessary to upgrade the current state of digital technology adopted after the construction phase.

Therefore, as a preliminary study, this paper proposes a conceptual framework for the development of a three-dimensional architectural geometric representation of building construction after the design phase. The final and eventual output of the approach proposed in this study is an integrated platform of buildings and sites, of which the information on the exterior is acquired by using UAV (Unmanned Aerial Vehicle) and the interior by using LiDAR (Light Detection and Ranging). Considering the research process for deriving the final output, this paper focuses on suggesting a novel approach for data acquisition and processing of as-built status of the building using LiDAR technology.

What follows is an extensive literature review on the current state of related technologies, introduction on conceptual framework for 3D modeling based on the point cloud data obtained by LiDAR, applicability of the proposed method, and discussions.

2 Literature Review

There is no denying on the fact that digitalization in the construction industry has erupted a revolution in productivity of construction activities [10]. According to a survey, 93% of the construction industry players have agreed that digitalization will affect every process [10, 11]. Thus, there is no lack of studies on exploration of digital technologies for application in construction projects.

2.1 LiDAR in construction phase

Regarding the usage of LiDAR as 3D laser scanner that transmits optical laser light in pulses delivers accurate real-time 3D data, most research has primarily focused on acquiring geo-spatial information [12, 13, 14]. High-precision numerical maps of forest areas and steeply sloping roads were created based on the data acquired by LiDAR, and the displacement of the slopes was determined based on numerical maps [14]. A method to automatically extract the 2D outline of a building by merging numerical aerial photographs and LIDAR data has been developed. LiDAR technology is also adopted for semi-automatically construction 2D and 3D indoor GIS maps based on point cloud data [15].

Most, if not all of those studies have focused on extracting the structure boundary of a building or roads while excluding non-structure or any spherical and curves [16, 17]. Even though few studies have attempted to apply LiDAR and point cloud technology in the construction industry, barely any research has suggested an approach for acquiring both indoor and outdoor 3D modeling information of a building. An algorithm for independent recognition and data acquisition of multiple objects with free forms – with lines, spheres, and curves – needs to be developed in order to visualize a full indoor 3D model of a building. Insofar, however, algorithms such as Douglas Peucker have been utilized mostly for extraction of boundary lines [18]. There has been hesitant implementation of digital technologies on building sites or built facilities, especially on the interior of a space with multiple objects to be recognized. This insinuates that the construction industry needs to catch up even on the building interior and sites.

2.2 3D modeling in building construction

The potential of integrating LiDAR with Building Information Modeling (BIM) for 3D modeling has been highlighted in few studies. A framework on the level of details on modeling of a building in BIM regenerated through reverse engineering has been proposed [19]. Furthermore, a semi-automatic three-dimensional modeling has been performed by dividing point cloud data into grids and extracting outlines [20]. Nevertheless, application of BIM is recognized as 'digital planning', insinuating that the technology is first utilized during pre-design and design phases. The data acquired during the two phases does not flow easily to construction and operation phases.

Considering the application of LiDAR and point cloud technology in construction projects, few research has aimed to promote reverse highly effective and efficient reverse engineering in construction industry [21, 22].

Reverse engineering, as the process of recreating the current state of information of a part without detailed information (drawings, bill of materials, required parts specification, engineering data), is mostly applied for detection and comparison between a CAD/BIM model created during pre-construction phase and as-built model created during and after construction phase [23]. Creation of an as-built model follows the process depicted on Figure 1.

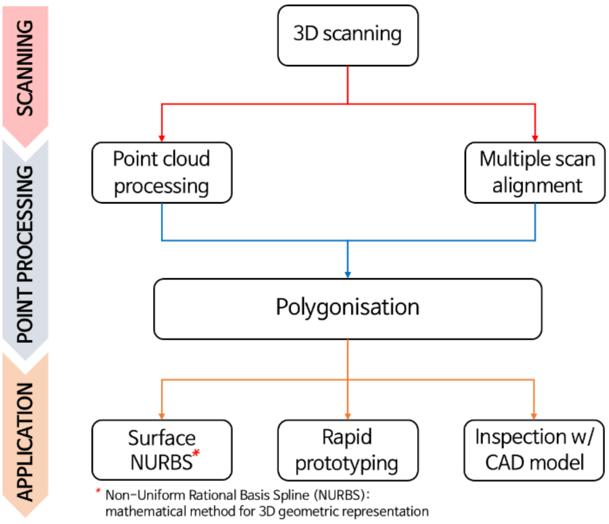

Figure 1. Process of data acquisition by LiDAR & application for reverse engineering

A three-dimensional scanning operation is performed, and then the point cloud data acquired through scanning is processed. In the case of scanning multiple targets, the merging operation of the data proceeds. After the merging work is finished, the polygonised work is applied for surface model creation, inspection with CAD model, and rapid prototyping. Throughout this process, the key element of successfully recognizing each of the multiple objects detected on the scene of scanning is developing a visualization algorithm. However, three-dimensional visualization algorithms related to construction industry are recognized as simple tools for data processing of scanning method, and the scope of application is mostly limited to earthwork construction. Most of the 3D visualization algorithms are optimized for other industries rather than the construction industry. To acquire accurate data and information on multiple objects, including structures and movable attachments, a new processing technique involving algorithms of segmenting and outlining the point cloud data are required.

3 Conceptual framework of 3D modeling approach based on LiDAR technology

As previously stated, an approach that registers, analyzes, and creates 3D models based on point cloud data delivers a reasonable source of digitalized information. To date, few studies have attempted to apply LiDAR and point cloud technology in the construction industry, but barely any research has suggested an exquisite method for acquiring 3D model of building interior with detailed information on the structure and non-structures. The current state of algorithm for visualizing data acquired as point clouds is processed for registration and surface creation. The surfaces and boundaries created by alignment of point clouds are extracted as structures of a building or infrastructure. However, a visualization algorithm that can register multiple objects independently from each other and define both the structures as well as non-structures and movable attachments is crucial for 3D modeling of an interior.

The conceptual framework of a 3D modeling approach created by point cloud data acquired by LiDAR is depicted on Figure 2.

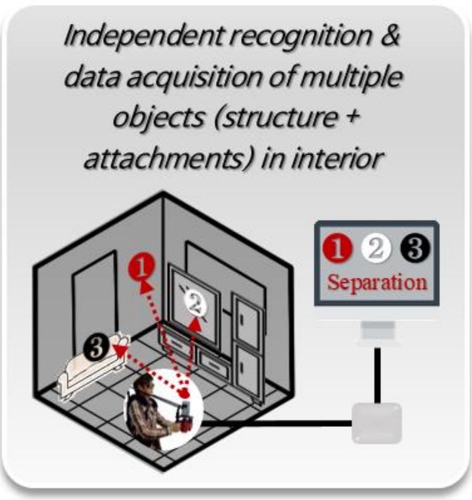

Figure 2. Conceptual approach for data acquisition

The process for ultimate modeling of building interiors based on point cloud data is defined as the following (Figure 3):

1. Data acquisition through LiDAR: 3D scanning of the interior
2. Data processing: Registration of point cloud data & segmentation by RANSAC(Random & Sampling Consensus) method, outline tracing by removing outliers & noise, surface creation based on region growing method, and input of algorithm for detection & separation of movable attachments from structures
3. Data integration & Application: Visualize the results by integrating with image processing technology, and create 3D model

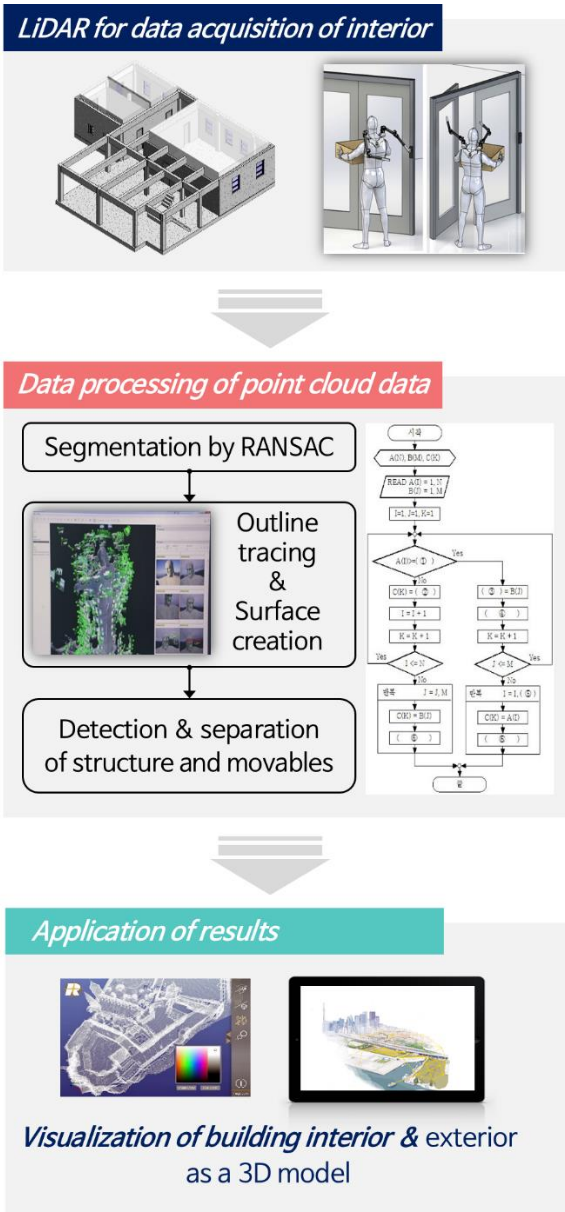

Figure 3. Process for 3D modeling based on point cloud data retrieved by LiDAR

The algorithm for segmenting the point cloud data and visualize them as three-dimensional is primarily based on RANSAC method. RANSAC is an iterative method for estimating parameters of a target model from a set of data. RANSAC is used to identify points that belong to identical planar planes from a cloud of data. Unlike the least square method, which uses all the data to estimate the parameters of the model, RANSAC includes the process of excluding the outliers based on the hypothesis and test evaluations. The outliers are removed based on SOR (Statistical Outlier Removal) algorithm.

A sample (P) with a predetermined certain range is acquired from the entire point cloud data, and then a minimum number of data (S) is selected for estimating the parameter (θ). The model (M) is determined by the function (f_m) and parameter (θ). Considering the two equations (Eq. 1, 2) for segregating the inliers from a certain threshold (δ), the Consensus Set (CS) with outliers excluded is defined as Eq. 3.

$$P = \{d \in R^2 \mid d_1, \dots, d_n\} \quad (1)$$

$$M = \{s_\text{n} \in P \mid f_m(s_n : \theta) = 0\} \quad (2)$$

$$S(\theta) = \{d \in D \mid e(d, M) \leq \delta\} \quad (3)$$

The process of segmentation for exclusion of outliers from inliers is depicted on Figure 4. Among a total of 50 points (P), three points (S) are randomly selected and aligned on a surface plane. Blue points are segregated as inliers within the threshold, while green points are considered as outliers and thus eliminated.

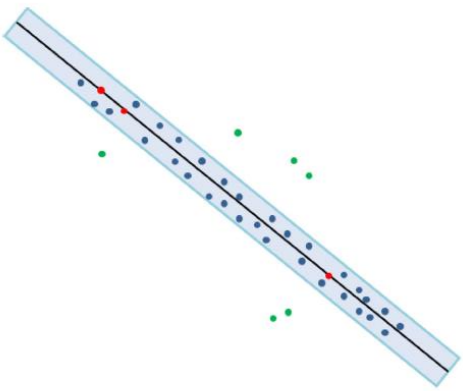

Figure 4. Process of eliminating outliers from RANSAC [20]

Point cloud data is projected under a refinement grid to verify validity for further outline tracing. During the process for outline tracing, the point cloud data is converted into a binary image using a grid as in the refinement process, and the outline is further extracted using the vectorization technique. The size of the refinement grid can be set differently according to the characteristics of the indoor environment. A cluster of planes are constructed, which results in the formulation of boundaries within 2D and 3D drawings.

When the outline extraction process ends, the binary image is inverted to extract the outline of an empty area in a segment area for visualization of the surface. At this time, the outline extraction is performed only for an empty space having an area larger than a predetermined size, and the extracted outlines are recorded in a file in the form of VRML (Virtual Reality Modeling Language). Afterwards, the point cloud data is visualized based on ICP (Iterative Closest Point) algorithm, resulting in the independent recognition of boundary structure and non-structures (movable attachments such as furniture in the interior of a building space). After the data processing phase is completed, a 3D model that provides a comprehensive information on the interior of a building and its exterior.

4 Applicability test: Results & Analysis

A field test is performed to verify the validity of the approach proposed in this study. The test was conducted mainly to secure the reliability of data acquired and processed by LiDAR technology. The interior and exterior space of a deteriorated house with all furniture properly located at its place were scanned to construct an as-built model, of which the accuracy was verified by comparing with previously completed 2D drawings. The overview of the applicability test is depicted on Figure 5.

Location:	Donae-dong, Duckyang-gu, Goyang-si, Gyeonggi-do, Korea
Area of Measurement	Basement B1 (72.48 ㎡) 1st floor (133.68 ㎡) 2nd floor (66.06 ㎡)
Number of times scanned	4 times (2 interior, 1 interior + exterior, 1 exterior)
LiDAR used	Velodyne HDL-32E

Figure 5. Overview of applicability test

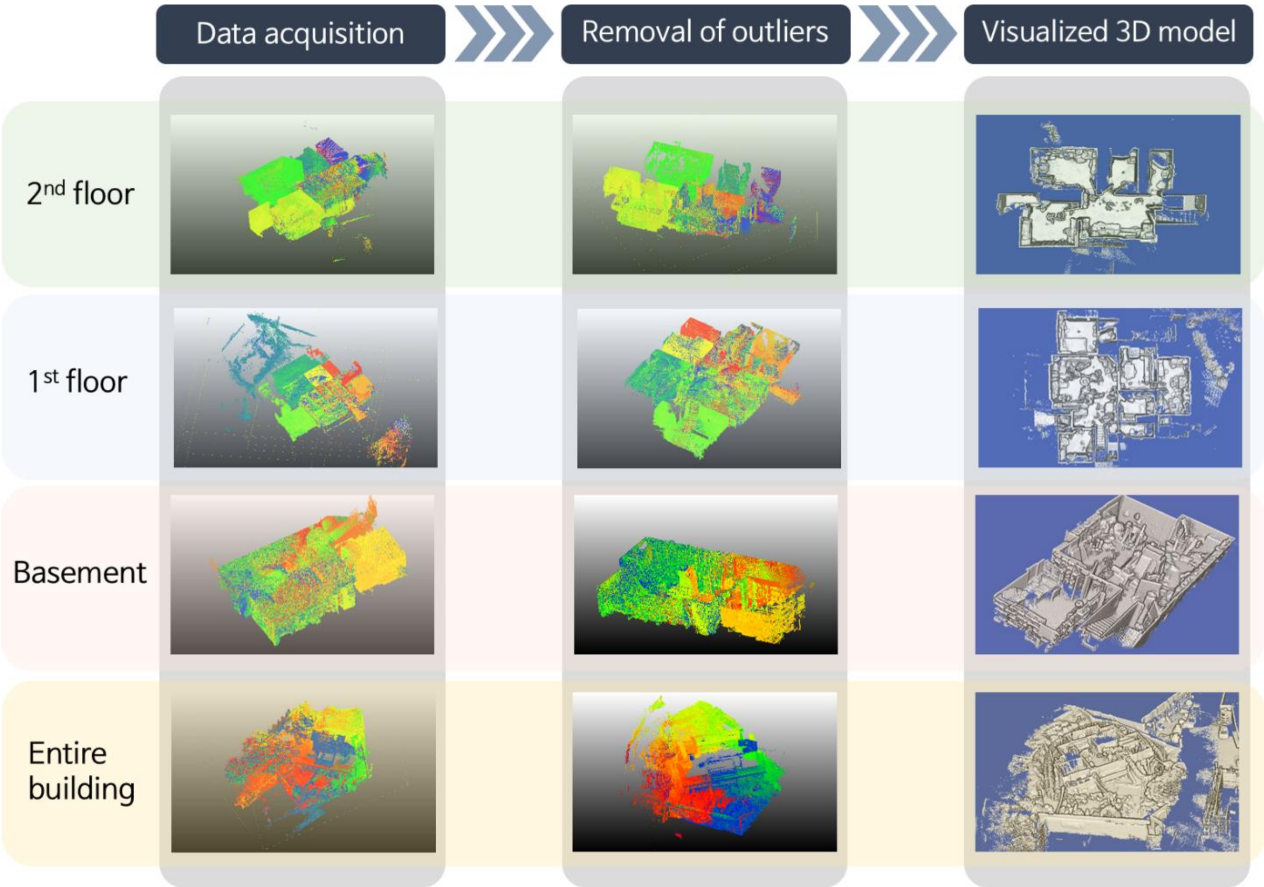

Figure 6. Results of data acquisition & processing, visualization as 3D model

The 3D scanner used for data acquisition is a backpack-type Velodyne HDL, a LiDAR scanner capable of scanning 700,000 points per second with the accuracy of 2 mm @ 200 m. The interior of the house was scanned twice; the interior was first measured from the basement to the second floor continuously at once, and then each floor was scanned separately at the second time. Also, after scanning the living room on ground floor, the scanner was moved continuously to the outside to measure the exterior. Finally, the exterior of the house, including woods, garage, and garden, was scanned. The LiDAR scanner was connected to a laptop, and thus all acquired data was accumulated on the software (Cloud Compare). Cloud Compare was used also as the software for data processing of point cloud data. As previously stated, SOR algorithm was applied within the Cloud Compare software to remove outliers, and then the processed data was visualized using ICP algorithm.

The results of acquired and processed data are depicted on Figures 6. Even though the software and applied algorithms automatically was suitable for processing the point cloud data for 3D model, some parts of the acquired data inevitable had to be modified manually. For instance, there were seven people total who conducted the field test. Five people, apart from the one who scanned the scene with the scanner while moving around and the other who held the laptop connected to the LiDAR, tried to be out of sight on the scene but were caught on some of the point clouds that were obtained after the scan. The inspectors and some of the furniture that was overlapped in some points of the scan had to be removed from the model. Additional measure are expected to be taken in case of 3D scanning.

Meanwhile, the result of data acquired on structure boundaries and non-structures is depicted on Figure 7.

As depicted on Figure 7, structure parts such as staircase, wall, and window opening are visible. All the movable items are visualized as 3D, but not easily recognizable in the current state of technology. In other words, the current 3D model simply visualizes the figures of detected object elements in three dimensions. Further studies are needed to improve precision of data processed for separating movable objects from the wall and floor of the interior. More in-depth studies are also expected to be performed for independent recognition of multiple objects.

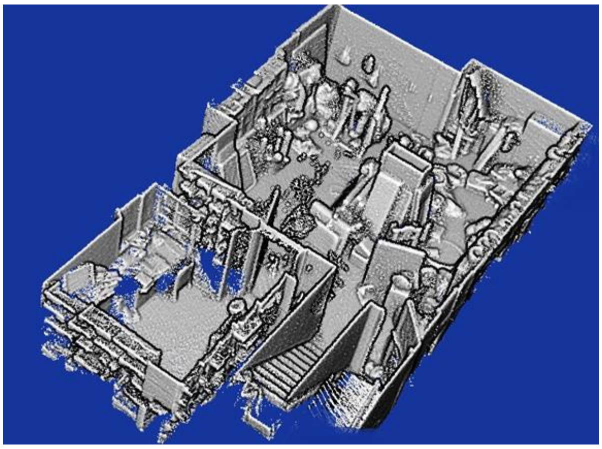

Figure 7. Scanned interior of basement

5 Conclusion

As-built data of buildings, both the exterior and interior, has been acquired manually by experts inspecting by hand using tools. However, the possibility of error arises in cases of field measurement on a manual basis, as well as the probability of safety accident occurrence. As a means to automate the data acquisition of as-built information and enhance productivity of previous work, this study proposed a novel approach for acquiring, translating, and applying as-built data retrieved under safe site conditions. The key issue of visualizing point cloud data collected by LiDAR in this study is related to the post-processing and removal of outliers for further integration with data retrieved by UAV. During this study, the outline of the building is derived through the horizontal layer division of point cloud dada based on the data acquired by LiDAR, all of which results in the creation of 3D drawings and models. In order to fully develop an automatic 3D visualization algorithm, it is necessary to consider the interference caused by the non-structure parts when setting the contour of the building. Nevertheless, the field test conducted in this study proved the possibility of adopting the novel approach in construction and operation phases.

The conceptual approach proposed in this study can provide an immediate 3D architectural geometric information visualization platform. Furthermore, the results of this study is expected to upgrade the current technology level by improving the speed and accuracy of as-built information of construction sites and buildings. Even though this paper does not address the application of UAV for measuring the exterior of buildings and the integration of retrieved data with those achieved from LiDAR, further study is expected to be conducted to visualize the conceptual framework addressed in this study.

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