An overview of object detection from building point cloud data

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Abstract. 3D laser scanner, also known as LiDAR (Light Detection and Ranging), is a device that able to collect dense representation of its surroundings. Its data in point cloud form is commonly used to monitor complex environments like the highways, infrastructures and buildings. The rapid development of 3D laser scanner nowadays has assisted the process of managing complicated and huge areas, especially in building and facility management. As the advancement in architectural and civil engineering increases, building spaces change frequently, as well as renovations work which consists of several items like structures (walls, ceilings, floors) and building fixtures (doors, windows). This has contributed towards complex and huge data to be processed which usually involves tedious and complicated work. Therefore, this data needs to be handled efficiently. Object recognition and classification is one of the most important process in point cloud data since it provides a full detail of building information. Object recognition is used to recognize multiple objects in point cloud data and classification process is used to classify the objects into a class based on the criteria of the objects. These processes reduce the noise and size of point cloud data to be processed. This paper provides an overview on data processing approaches, which focused on the process of object detection and classification, especially for buildings, as part of Building Information Management (BIM) and the possibility of future research in BIM modelling.

1. Introduction

Laser scanners are the instrument that able to produce 3D point clouds of scanned environments. Point clouds are datasets that represent objects or space in X, Y, and Z geometric coordinates. Point clouds assemble a large number of coordinates into a dataset that can then represented as a whole scenery [1]. With new scanners developed through the years, the instruments become faster, more accurate and able to cover bigger areas. The technology introduces a tool for many applications and has somehow replaced traditional surveying methods since it can speed up field work significantly. For building application, the generated point cloud can be used to create a semantically rich digital facility models like 3D as-built that is very important in Building Information Modelling (BIM) [2].

BIM is a way of approaching the design and documentation of building projects [3]. BIM is developed to assist and smoothen the collaboration between architects, developers, engineers and building managers / users in a common knowledge environment to provide information sharing among these building stakeholders [4]. BIM have several advantages over the traditional way of constructing building model which uses Computer Aided Design (CAD). One of the major advantages is BIM
provides the information of the buildings, including facilities management, design analysis and more for better decision making in the building team. Furthermore, BIM supports a distributed team so that people, tasks, and tools shall share the information together to avoid data redundancy, data loss and miscommunication [3].

There are three major steps in creating building modelling, which is data collection, data preprocessing and modelling development. The techniques that can be utilized for acquisition and data collection of existing buildings include topometry, photogrammetry and lasergrammetry, also known as laser scanning [5]. Topometry is an old way of surveying which use an optical telescopic sight and a measuring system for angular direction of sight. This technique involves a lot of work to find significant structures of the object thus make this technique time consuming [5]. A comparison between photogrammetry and laser scanning has been conducted by W. Boehler et al. [6]. From the results, it can be concluded that the photogrammetry is more suitable for point or lined-based structures, while laser scanner is more suitable for complex and irregular shapes.

Due to its surface-based working principle, the objects captured by 3D laser scanners are very accurate and in full detail. The results of scanning projects also can be presented and visualized much better than the results of any other geodetic method. Figure 1 below shows an example of scanning process using laser scanner.

![Figure 1. An Example of Scanning Process Using Laser Scanner. Reproduce from [2]](image-url)

2. Data Preprocessing

After data collection, the next process is data preprocessing. Since point cloud data involves huge sizes, automated or semi-automated approaches are used to simplify the process of data preprocessing. The point cloud data from the scan is in the form of coordinates frames. Due to the big coverage area of interest, data collection needs to be done in respective stations and each station will have its own set of data. All of the data are then joined to get the complete scene of the area, using a process called ‘registration’. This process is challenging as usually, the area is full of clutter and occlusion. Data preprocessing also may contain the process of filtering the unwanted data before it is converted into triangular surface mesh for modelling the data [2].

Generally, there are four general data processes involved. The first one is feature extraction. Feature extraction consists of a single point or a group of point that helps detect certain type of point based on low-level attributes. Example of feature extraction based on low-level attributes includes planar surface and edge detection. The second process is segmentation. Segmentation is a process of grouping the point based on low-level attributes into segment or object. Next, is an object recognition. It is used to recognize one or multiple types of object in point cloud data. Lastly, is the classification process. The classification involves assigning a class or identification to each point, segment, or object to represent certain type of object [7].
Since the point cloud data contained huge data volume to be processed, we need high computer processing resources to process the data. Furthermore, point cloud data is a set of discrete data records and do not have semantic information in it. The presence of noise at scene also affects the results of data taken. These problems are reduced by using object recognition and classification techniques [7].

There have been numerous reviews on processing techniques and application of the point cloud data, but the review on the object recognition and classification is still not sufficient. This paper will be a guide for others in knowing the existing technique on recognition and classification of objects especially in architectural structures that has been conducted through the years.

3. **Point cloud data classification**

3D as-built development involved with three main aspects, which is the geometrical modelling, the attributions of categories and materials of the components, in other words classifying the objects in the building, and lastly the establishment of relationship between them. “As-built” means that the building is described based on the current state of the survey using BIM representation [5]. As of now, the process of improving the 3D as-built is still ongoing.

To simplify the point cloud data processing, the data needs to be classified into several groups to avoid time consuming and to reduce the noise in the data. The most common object classification categories found in BIM models are walls, columns, roofs, beams and slabs [8]. Since the modelled components generated from the point cloud data are dense and complex, it needs an efficient technique of architectural objects detection, such as façades, balconies, and windows [9]. The objects are then classified into the appropriate categories. The object category can be customized based on the needs of the users. Object recognition is divided into four categories, which is recognizing object instances, recognizing object classes, recognition using context and lastly using prior knowledge [2]. Detection of various shapes is complex since it involved a huge number of data. Previous research on the classification of objects, specifically for indoor building are discussed in this section.

3.1. **Object Instances Recognition**

Object instances recognition is a knowledge description, where the shapes of an object is encoded in a set of descriptors. There are two modes of object shape, which is non-parametric model and parametric model. Parametric model describes the object using certain parameters, such as height, width, radius and so on, while non-parametric model is represented using triangular mesh [2]. Parametric model also known as heuristic approach [10] used human codification to classify the shapes or objects. For example, the windows and doors are parts of the walls and roofs are above the walls. There are three steps of object recognition process. First, is the offline process. The process uses shape descriptors to recognize an object. The data of the object are then stored in the model database. Secondly, the algorithm is presented with a scene to detect the targeted object. Lastly is the verification step. The object in the database are aligned with the real scene.

One of the researches using heuristic approach has been conducted by Shi Pu et al. [11] to extract windows from building facades. Victor Sanchez et al. [12] presented an automatic system for planar 3D modelling of building interiors from point cloud data generated by range scanners. The interiors include ceilings, floors, walls and staircases. The proposed system used model-fitting and RANSAC, for detecting large-scale structures, such as ceiling and floors, as well as small scale architectural structures, such as staircases. Bohm et.al.[13] in his research used cell decomposition to model windows and doors from the LIDAR data. They used density-based edge detection to identify the vertical and horizontal lines of building facades. The resulting rectangles are then classified to window or non-window. The window frames are then further refined by photogrammetric analysis of additional image data. Figure 2 below shows the detection of edge point of planar façade polygon at horizontal and vertical window structures.
3.2. **Object classes recognition**

Since instance-based recognition cannot handle significant variation in object shapes, an object class recognition is proposed. In order to recognize non-rigid objects, the object is divided into parts and is recognized individually. Another approach is to use a descriptor that is more robust to shape changes. This approach is more robust for clutter and occlusion scenes [2].

One of the researches that utilizing part-based object was done by Daniel Huber et al. [14] who used part-based classification of 3D objects to detect a vehicle. The concept used in this research can be applied to another point cloud data, including the recognition of object inside and outside the building. Since the BIM model are always represented in solid representation, it is important to convert the surfaces to solid models. Antonio Adan et al. [15] stated that there has been little attention to the modelling of wall surfaces. In indoor environment, the wall surfaces always occluded with clutter or furniture. This scenario makes the modelling problem challenging. The research conducted by [15] focused on to recover the wall surface, to identify and model openings, such as windows and doorways, and to fill occluded surface regions. They proposed a learning-based method for detecting and modelling openings and distinguishing them from similarly shaped occluded regions and propose a method for evaluating reconstruction accuracy. Figure 3 below shows the overall process of recovering the surface shape in clutter and occluded rooms.

In addition, A.K. Aijazi et al. [16] uses ANNOVA measurements to classify the point cloud data into basic object types. After the classification, the segmented building is then projected onto a plane in order to detect the windows in the building facades.
3.3. Recognition using context
Approaches based on context used relations between components. The algorithm learns the unique features of different types of surfaces and the contextual relationships between them and uses this knowledge to automatically label patches as walls, ceilings, or floors [2]. Shi Pu et al. [11] introduced knowledge-based features to extract walls, doors, roofs, windows and so on. A polyhedron building model is combined from extracted features to form a building. Figure 4 shows the feature recognition results of extrusion, roof, wall, door and window from the research conducted by Shi Pu et al.

![Figure 4. Feature recognition results (extrusion, roof, wall, door and window). Reproduced from [11]](image)

Radu Bogdan et al. [17] investigated the problems acquiring 3D object maps of indoor household environments, particularly kitchen, such as cabinets, cupboard, drawers, and shelves using point cloud data. One of the main problems that was successfully solved in this project was the improvement of point cloud data through sparse outlier removal and resampling. The relevant kitchen objects could be recognized by classifying the object according to its features, such as hasHandle(), hasKnob(), countHandles() and so on. In prior knowledge based, the recognition is reduced to a simple problem matching between the entities of the scene and the point cloud.

3.4. Using prior knowledge
Approach using prior knowledge is a comparison between ‘as-built’ and ‘as-designed’ BIM. The approach used a CAD model or floor plan to detect any differences between as-built and as-designed BIM. Yue et al. [18] has conducted a project to detect defects on construction sites by comparing the as-built BIM to as-designed BIM. Figure 5 below shows the recognition result for building column conducted in [18]. The geometric primitives can be determined by fitting it to the as-built data.

![Figure 5. Recognition of column. Left: column design model; Center: As-built data; Right: Designed model and as-built data. Reproduced from [18]](image)
4. **Relationship modelling**

Objects extracted from point cloud data must be classified into several object classes. This is where the relationship modelling is used. The semantic information can be integrated during segmentation process to guide the process of searching the building elements.

There are three common relationship being used in BIM, which is aggregation relationship, topological relationship, and directional relationship [2]. Aggregation relationship is to describe the composition in a local-to-global way (i.e. part of, belong to, contain in, etc) [4]. Belsky et.al.[19] introduced an approach for complementing precast concrete model files. The slabs and joint aggregation concept are considered.

Topological relationship is to describe the location (i.e. connected to, inside, outside of, etc.). Topological relationship between components and spaces must be established in BIM, since it will indicate which object connected to the other, and where it is connected. Valero et.al.[20] extracted horizontal planes to identify the grounds and the ceilings. After that, they stated that walls are connected in borders of room.

Lastly, directional relationship is to describe the direction between two solid objects (i.e. above, below, north of). A research conducted by Pu and Vosselman [21] had introduced an identification of segmented planar identities based on their characteristics by combining the semantic and knowledge information. This includes the size, position, and orientation of the point cloud data.

5. **Future work**

Although many researches have been conducted on object recognition and classification of building point cloud data, there are still many research gaps that can be further investigated.

Majority of the classification modelling only focuses on simple planar surfaces. The research of details in the building, such as windows, doors and furniture has expanded nowadays and is a good sign for further improvement of more complex details, such as columns, structural steels and cove ceilings, as suggested in [2]. Windows detection itself is the most attentive topic nowadays as windows are hardly detected by laser scanner since the light can penetrate through it.

For long term goals, fine details such as decorative mouldings and lighting fixtures would be a good prospect to explore. The improvement also can be made in handling the detection and classifying the openings, such as windows, doors, or closets [15] and some obstacles like see- through walls [21]. This includes non-planar surface structure [15]. The research of fine structures recognition is very important especially for a highly detailed building facades such as historical buildings.

As the real scanning area often faced issues with clutter and occlusion, further research should be done in handling clutter, alternate part segmentations, and geometric part analysis for 3D object classification [17].

Besides that, the work also can be expanded on handling planar surface reconstruction from noisy point cloud data before a full semantic map or an as-built BIM is produced [22]. This includes reconstruction algorithms to support more complex room geometries, including curved surfaces and non-rectangular openings [8].

Finally, the area of research can be improved in obtaining reflectance information from other instruments by utilizing sensor fusion as well as data from different depths relative to the modelled surface.

6. **Conclusion**

This review summarizes the 3D point cloud data processing obtained from laser scanner for existing, in-used building to generate Building Information Management (BIM) model representing the interior building. An overview of the process of object recognition and classification in the building is discussed. There are four main aspects of object recognition, which is object instances, object classes, recognition using context and recognition using prior knowledge. The relationship modelling from the extracted object is also discussed. The relationship modelling is used to classify the recognized object into certain classes. From this review, it can be summarized that there are still many research gaps in this research area as highlighted. Thus, it is expected that the direction of this research is now towards more complex structures and fine details, which is great for future improvement.
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