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AUTOMATIC EXTRACTION OF BUILDING FEATURES FOR BUILDING FAÇADES BASED ON LASER SCANNING TECHNOLOGY

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Abstract

Feature extraction on façades from unstructured point clouds is a challenging work, especially in the presence of noise. Previous studies in reconstructing the building façade are limited to traditional urban buildings. However, facade with a big proportion of windows, like curtain wall, are less explored. This research aims to propose an automatic approach to extract building features of a facade with a big proportion of windows, such as curtain wall. This approach includes automated detection of the facades, openings detection and geometry information extraction. A real case is used for testing the framework and validating the effectiveness of the approach.

Introduction

Building façades are highly related to energy consumption. Energy-efficient retrofitting of existing buildings is a key aspect of reaching the energy consumption reduction targets fixed by public authorities in different countries (Previtali et al., 2014; Sun et al., 2019). Europe has numerous historic and old buildings that face challenges, such as energy loss and higher operational costs, and need to be more energy efficient (Massafra et al., 2022). The geometry information of facades is crucial for the energy simulation.

Recent developments in generating digital twins (DTs) of buildings and point cloud techniques have the potential to obtain the geometry of building façades and improve its efficiency and accuracy (Pan et al., 2023). Geometric building models can be created based on point cloud acquisition and processing techniques (Pan et al., 2022; Wang et al., 2020). However, obtaining 3D information of façades from point cloud of existing buildings is still a challenging and costly process (Wang et al., 2022).

Previous studies in reconstructing the building façade and their openings are limited to specific types of buildings, mainly urban traditional buildings. These building facades are typically composed of concrete or brick blocks with low reflectance materials. Building façades with high reflectance materials were not considered in previous studies.

This research aims to propose an automatic approach to extract building features of a facade with a big proportion of windows, such as curtain wall. The proposed framework includes automated detection of the facades and glass windows from the building's point cloud using emerging image processing technologies techniques. Specifically, the geometric information of the recognised windows could be automatically extracted from the point clouds. Compared with previous approaches, the approach proposed in this research could be more feasible for building façades with a big proportion of windows, such as curtain wall and the outcomes could be directly employed for the other applications requiring the geometry information of façade features, such as building retrofitting and energy simulation. A laser scanning point cloud dataset of the Civil Engineering Building in the University of Cambridge is used for validation, which is an appropriate case with curtain wall and a large number of windows on the façade and the results demonstrate the effectiveness of the proposed framework.

Literature review

The reconstruction of geometric models of building façades from point cloud data has been explored by many researchers. For example, Truong-Hong et al. (2012)introduced an algorithm designed to identify building boundaries and features, employing a method that transforms point cloud data into a robust solid model through the implementation of voxels within an octree representation. This approach was deployed on the façades of three masonry buildings, exhibiting proficiency in detecting all apertures and accurately reconstructing the façade boundaries. Previtali et al. (2014) developed an automated methodology to derive highly detailed 3D vector models of existing building facades from terrestrial laser scanning data. The methodology involves segmenting the point cloud of a building facade into its planar elements and then generating 3D vector models based on the facade break lines.

The openings, such as windows and doors are always used for façade segmentation. Pu and Vosselman (2009) proposed a knowledge-based approach for façade detection, utilising walls, roofs, protrusions, and doors as features for identifying façade elements. The geometric reconstruction was viewed as a process involving polygon fitting, along with the generation of knowledge-based assumptions to address occluded parts in the proposed approach. Zolanvari et al. (2018) introduced the improved slicing method for detecting opening boundaries, including those on roofs, such as chimneys, as well as determining a building's overall outer boundaries through a local density analysis technique.

The plane fitting and clustering methods, as well as the use of a projection method to simplify a 3D scenario into a series of 2D ones, are suitable for relatively simple structures. However, when dealing with a diverse range of existing building types, such as complex architectural buildings or multi-planar building façades, these approaches tend to lack robustness in façade segmentation. For example, Hamid-Lakzaeian (2020) developed a multi-planar algorithm to detect the principal façade across the entirety of multi-planar masonry building facades. The algorithm further identifies recessed and protruded sections within each portion of the principal façade.

To identify the actual geometries for non-rectilinear openings and extract complicated facade boundaries, Iman Zolanvari and Laefer (2016) introduced the slicing method for extracting overall façade and window boundary points, enabling the reconstruction of a façade into a geometry compatible for computational modelling. It detected free-form openings and overall boundaries in building façades, even when faced with complexities and out-of-plane protrusions. Hamid-Lakzaeian (2019) proposed the Gridded-RANSAC approach to segment point cloud façade, which is particularly applicable to highly ornamental masonry buildings with non-rectilinear openings. Xia and Wang (2019) proposed a facade separation method capable of dividing connected facades into distinct building instances. This method can effectively detect complex windows, including bay windows, and identify a subset of individual façades based on dividing lines.

In addition to making reconstructions using TLS data, some studies have proposed reconstructing building façades from images. Zhao et al. (2021) outlined a BIM-based image management framework for reconstructing as-is building 3D models from fragmented images. This is achieved by registering and aligning UAV images onto BIM, matching building façade components in the BIM model with those in the UAV images. This approach primarily focuses on flat building façades with windows and doors, rather than emphasizing non-flat facades or buildings without façade components. Murtiyoso et al. (2021) proposed an approach to semantically segment building façades using deep learning, deploying the DeepLabv3+ network and training it on a database of labelled building façade images. The proposed approach facilitates the transition between 2D orthoimages and 3D point clouds. Bacharidis et al. (2020) reconstructed building façades in urban environments by establishing and leveraging a relationship between stereoscopic images and tacheometry data. This approach involves combining image and georeferenced data to extract meaningful attributes for the structural elements of the façade, including positional, appearance, and depth-related features.

Some studies have explored combinations of various techniques or features extracted from point cloud data for façade detection. By leveraging the advantages of 3D point cloud and 2D optical images, Wang et al. (2018) described a building facade feature extraction method for extracting building facade features, mainly structural information, from 3D point cloud. The proposed method involves image feature extraction, exploring the mapping method between image features and 3D point cloud data, and optimising the initial 3D point cloud facade features while considering structural information. Macher et al. (2021) investigated the use of radiometric information, specifically colour and intensity, for segmenting windows from façade point clouds. Jarząbek-Rychard et al. (2020) proposed a supervised approach for extracting façade openings, specifically windows and doors, from photogrammetric 3D point clouds, utilising both RGB and thermal infrared information.

In summary, previous studies discussed various approaches for building façade reconstruction, including deep learning for semantic segmentation in point clouds, slicing and clustering methods, supervised extraction of façade openings utilising RGB and thermal infrared data, and extracting façade features by combining 3D point cloud data with 2D images. However, these studies are still limited to building façades with rectilinear and repetitive openings or façades with multi-planar surfaces and openings in complex shapes, which are mainly urban traditional buildings. These building facades are typically composed of concrete or brick blocks with low reflectance materials. There is a lack of studies focused on building façades with a big proportion of windows, such as curtain wall, and no studies have been conducted to further extract the geometry information of the recognised windows in an automatic manner.

Research methodology

To enrich the knowledge of building façade reconstruction from high-reflectance materials, this research proposed a digital twin-enabled framework for automatically generating the geometric information for building façades. The developed modelling methodology is applicable to unstructured point clouds containing tens of millions of points. Each point is parameterised by its spatial coordinates and may also include related attributes, such as intensity or colour, but it does not share any topological relationships with nearby points. In the proposed approach, the scan registration process is conducted in the CloudCompare software, and the rest steps are implemented in Python to process the point cloud data.

The input point cloud can be generated by a single or multiple laser scan. After scan registration, scans are merged into a specific data structure. The overall procedure is illustrated in Figure 1. Once all scans are collected and registered in the CloudCompare software, it is essential to determine the windows from the façade. As mentioned earlier, the glass window is high-reflective material, therefore it is difficult to be fully scanned by laser scanners. In this case, the points reflected by the windows could be sparse and random. To detect the windows from the point cloud, it is essential to remove the points of glass as these points will influence the object detection of windows and need to be regarded as noises. A filter process is developed to identify the points reflected by windows. Usually, the intensity feature can be applied for the detection of this glass window on the façade (Macher et al., 2021). The filtering

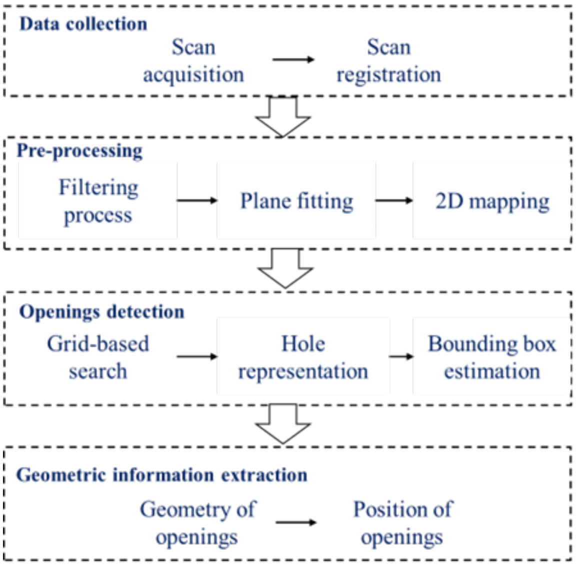


Figure 1: Pipeline of the facade reconstruction process

process is developed based on the intensity feature of the point cloud and implemented in Python.

After the removal of the glass window points, the next critical step is to detect the points belonging to the windows. The main elements constituting the façade are firstly identified by standard random sample consensus (RANSAC) algorithm. The RANSAC algorithm is an iterative method to estimate parameters of a mathematical model from point cloud data (Chum et al., 2003; Wang et al., 2021). The main plane of the façade can be computed based on RANSAC and this plane will represent the façade surface. At this stage, the point cloud data is still in 3D level. To efficiently detect the openings, including windows and doors, from the 3D point cloud data, this study adopts the mapping approach to project the 3D point cloud data onto the façade surface, which is a 2D point cloud data to identify the openings.

To detect the openings from 2D point cloud data, grid-based search for openings is performed and implemented in Python. The size of the grid needs to be determined. If the size is too big, details of the openings' boundary will be lost in the discretization and the accuracy of the dimensions could be decreased. If the grid size is too small, the grid loses its advantages over the point cloud. In general, the size will be determined by the resolution of the point cloud data and the application's requirements, which is set as 3 cm in this research.

A grid representation of point clouds for detecting hole boundaries is commonly used in previous research (Nguyen et al., 2012). The flowchart of the grid-based search approach for the openings detection is shown in Figure 2. A 3 cm × 3 cm grid is applied on the 2D point cloud to cover the whole data. Some areas may not be covered by points as they are located in the openings such as windows, therefore, the point cloud may include some holes which are regions with no points. Then, each grid is checked that

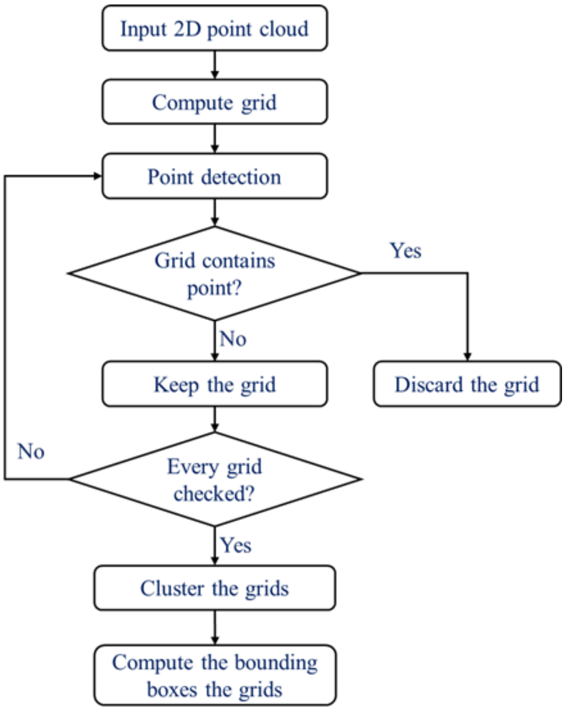


Figure 2: Flowchart of openings detection process

whether it contains point or not. If a grid has no point inside, the grid will be kept as the openings. After all grids have been checked, the openings from the façade will be detected.

Finally, the remaining grids are clustered, and each cluster represents one opening on the façade. A convex oriented bounding box (OBB) is computed and considered as the boundary of each opening. In this case, a primitive geometry of rectangles is fitted to the opening. The height and length of the opening are be calculated by their minimum and maximum x and y coordinates. Therefore, the geometry information of openings can be extracted from point cloud data and this step is implemented in Python.

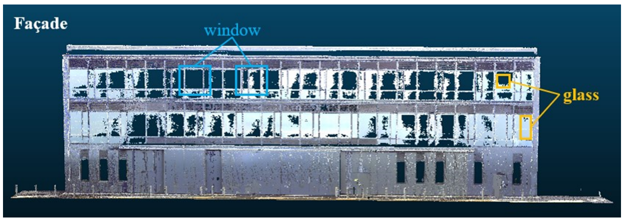
The proposed approach is capable of detecting the facades and the details, such as windows. Moreover, this research is also suitable for building façades with high reflectance materials. A real building with window façades is employed in this study to demonstrate the effectiveness of the proposed method.

Results and discussion

Case background

The terrestrial laser scanner Faro was adopted for data acquisition in this study. After the scan registration, the building façade of university building was collected. To test the proposed framework, this research cropped one piece of façade for the experiments. The picture of the building in Figure 3 demonstrates the façade is composed of glass windows. From the point cloud, it indicates that the glass windows were scanned, but few points lie on the glass because of the high reflection.

(a) Picture of the building façade



(b) Point cloud of the building facade

Figure 3: Building façade of case study

Experiment results

The filter process is adopted to remove these noise points. As proposed in methodology section, the filtering of points of glasses are based on the intensity feature of the point cloud. The scalar field image of the point cloud intensity is shown in Figure 4. The points with intensity values out of the range will be displayed in grey. In Figure 4, the range of the intensity values is from 158 to 65,535. It is obvious that the intensity values of the glass in the windows are below 158, which can be used as the threshold for filtering the noises in the windows.

The point cloud after the filtering process is given in Figure 5. It demonstrates that the filtering process has effectively remove the points of glasses in the point cloud. Based on the comparison of the point clouds of the original one and the one after filtering process, most of the points, which are appeared grey in Figure 4 have been removed. The Figure 5 shows a cleaner point cloud without the influence of the high-reflection materials on the façade. The results proved that the intensity feature of the point cloud could be capable of removing the noises caused by high-reflection materials of building's façade, such as glasses.

As proposed in the Figure 1, the cleaned point cloud was fitted with an optimal plane based on RANSAC algorithm. The plane that represents the façade surface has been identified. Therefore, the points on the façade were projected on the plane. Therefore, a 2D point cloud was generated. This 2D plane was used to detect the edge of the window frames on the façade surface. As proposed in the Figure 2, the 2D point cloud will be processed with the openings detection process to find the windows from the point cloud.

After applying the openings detection process, the openings were detected from the 2D point cloud, as shown in the Figure 6. It is obvious that all windows can be successfully detected. As given in the Figure 6, the openings are represented as clusters in different colours. By comparison with the original point cloud data in Figure 3, most of the glass windows were detected despite the high-reflection issue caused by the façade. Among them, for the second floor, all the windows were successfully identified and separated. For the first floor, on the left side of the façade, all the windows were also segmented and separated. In regard of the right side of the windows, the lower smaller windows were not successfully separated, and this is because the original point cloud was not scanned completely, and the window frames of some smaller windows were not scanned. Thus, it is challenging to separate these small windows with the detection process. This situation is caused by the quality of the scanned data.

After the detection process, the final step is to extract the geometry information of these openings as given in Figure 2. The bounding boxing method was adopted to estimate the boundaries of these openings, so that each cluster can be represented as a rectangular box. The result of the bounding box estimation is given in Figure 7(a). After that, the geometry information of each bounding box can be used to estimate the geometry information of the windows, as seen in Figure 7(b). The coordinates of the four vertices of the bounding box were computed, thus, the location, width and length of each window were obtained. In summary, with the proposed framework, the geometry information of the openings in the façade can be extracted automatically.

Discussions

According to experiments using real case point cloud data, the effectiveness of the proposed framework was validated above. In contrast to prior studies centred on general facades, our research pioneers a novel method for detecting facades with high-reflectance materials. The filtering process successfully removed points related to glass by utilising the intensity feature, allowing for the identification of openings. The results demonstrated the successful detection of glass windows from the point cloud, with approximately 94% of openings detected correctly.

The grid size used in this case is 3 cm for the openings detection, as defined in the method section. However, based on the alignment between window clusters and the point cloud before the detection process, some variations were observed among window boundaries and the facade. This might reduce the accuracy of the extraction of the geometry information. Therefore, it is suggested that the grid size used might be too large for accurate detection. For more precise geometry information generation, the grid size needs to be set smaller, or further experiments need to be conducted to determine the optimal grid size.

According to the Figure 7(b), it indicated that some small windows were merged as one window. However, it is because that they were not completed separated. A filtering algorithm could be developed to filter these windows

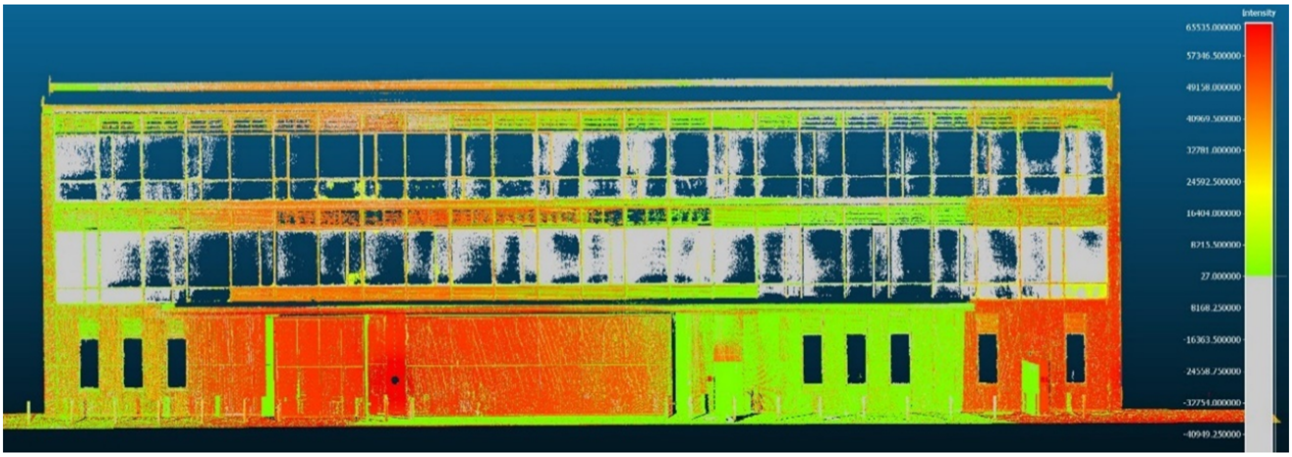


Figure 4: Scalar field of point cloud intensity

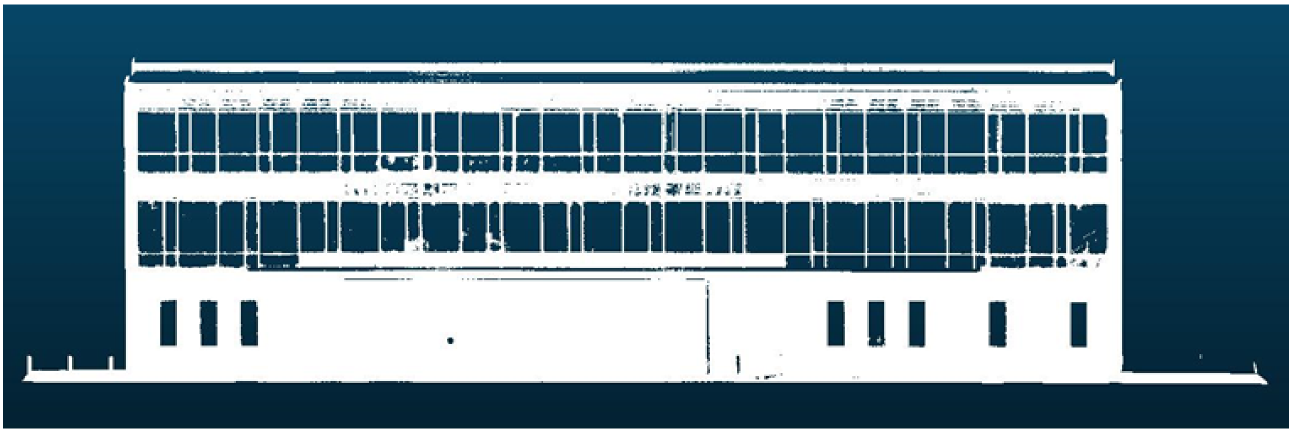


Figure 5: Point cloud after noise filtering process

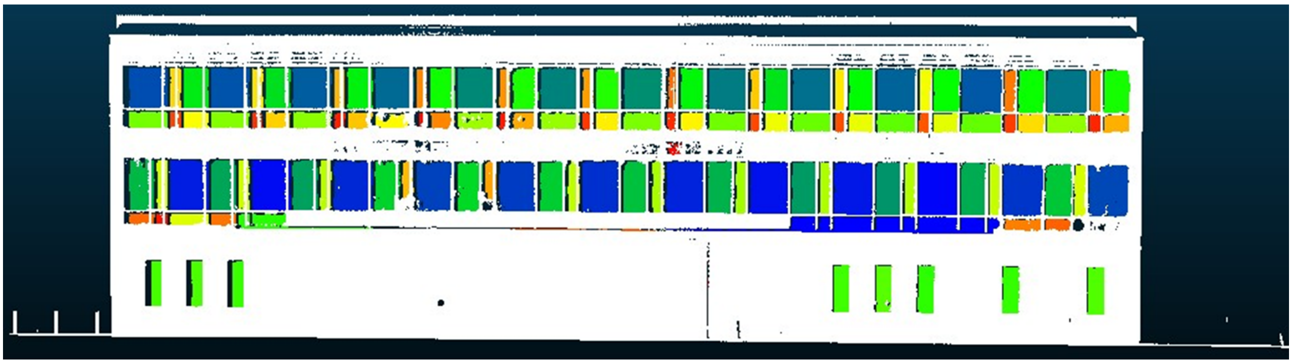


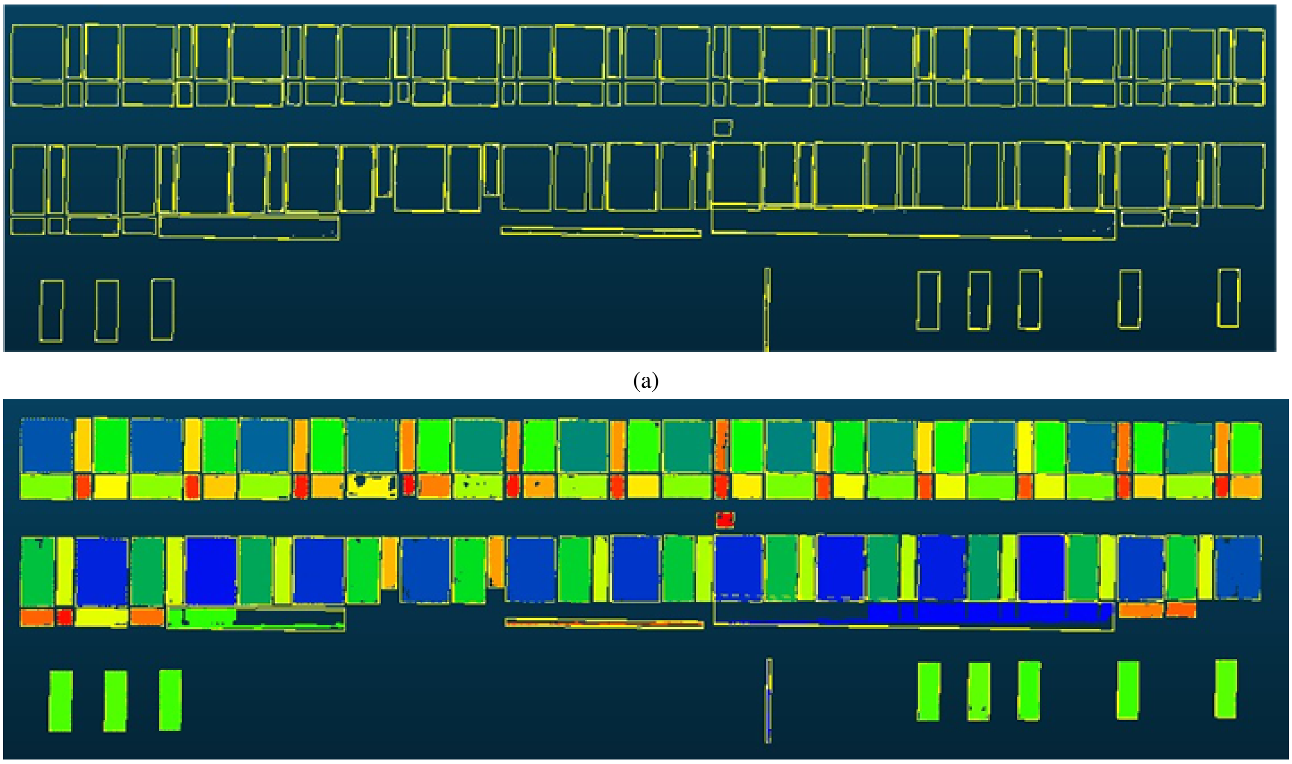
Figure 6: Point cloud after openings detection process

which need to be recognised as errors. Based on prior knowledge of building, some limits could be set for the width and length of the windows that can be used as criteria for filtering the errors, therefore improve the accuracy of the detection.

Regarding geometry information, this research assumes that windows are regular rectangular shapes, which aligns with actual practices in real cases. The extracted geometry information can be directly applied to future building energy simulations. This study opens the opportunity to automate the process from the point cloud to energy simulation, and further investigations could be conducted for this purpose.

Conclusions

The main contribution of this study is the development of the approach to extract building features of a facade with a big proportion of windows, such as curtain wall. The framework includes automated detection of the facades and glass windows from the building's point cloud. Specifically, the geometric information of the recognised windows could be automatically extracted from the point clouds. The proposed framework is validated in an existing building, and the results demonstrate its effectiveness. The



(a)

(b)

Figure 7: Bounding box estimation of the openings: (a) bounding boxes (b) bounding boxes and windows

outcomes could be directly employed for the other applications requiring the geometry information of façade features, such as building retrofitting and energy simulation.

Additionally, this research has the potential to enrich a geometric digital twin of the façade with details. This automatic approach enhances the accuracy and efficiency of the point cloud process. The limitation of this research is that the proposed approach was validated only on one case study. More types of façades could be also included to validate the effectiveness of the proposed approach. Future work in this area includes the extension of this technique to capture an entire building (exterior and interior objects) and to generate more complicated structures and building elements such as roofs, free-form surfaces, internal objects (e.g. ceiling, internal walls), shading elements, façades of non-terraced buildings, and skyscrapers.

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