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A Fast Method for Identifying Room Configurations from Unit Boundaries in Existing Residential Buildings

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Abstract: Prediction of interior room layout from observations on the exterior boundaries of a unit is sometimes needed in cases of emergencies when unit entry is denied. Seeing that 3D laser scanners are becoming smaller, lighter, and easier to carry around, this paper attempts to offer a fast method that can automatically reconstruct a room model relying merely on the 3D point cloud of the unit boundaries. The method first partitions the building floor space to generate the so-called "room seeds" from the intersections of lines that are extended from the detected wall segments. Then, the grammar approach compares different possible room configurations through a trial-and-error process to find the most possible one. The proposed method is tested on a real residential building case for validation. The proposed method may be useful in emergent cases when exact floor plans are not available. The method can be extended to other Manhattan-type buildings as long as the grammar rules are settled.

Keywords: existing buildings; grammar approach; prediction method; point cloud; room model; reconstruction

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1. Introduction

For existing residential buildings, room entry permission is needed from residents. Prediction of interior room layout from observations on the exterior boundaries of a unit is sometimes needed in cases of emergencies when unit entry is denied. Residential buildings usually follow the Manhattan-world style, which has rectangular-shaped rooms. In this regard, Manhattan-world indoor environments can be reconstructed without a lot of effort using a set of predefined grammar rules, combined with the knowledge inferred from the geometries and the openings of the exterior walls. Seeing that 3D laser scanners are becoming smaller, lighter, and easier to carry around, this paper attempts to offer a fast method that can automatically reconstruct a room model relying merely on the 3D point cloud of the unit boundaries.

Previous researchers have developed a lot of approaches for room layout prediction from images and point clouds [1–13]. Compared to indirect data sources such as measured distance, images and point clouds are kinds of direct sources that can considerably streamline the modeling process [11]. Although researchers have made substantial progress, many open research problems remain [12]. To most methods, the problem of predicting or estimating the room configuration is equivalent to predicting the cuboid that represents the room's spatial structure by finding all the room's edges (wall–floor, wall–wall, and wall–ceiling edges). However, the task is challenging because of complex environmental factors such as heavy occlusions and clutters, viewpoint shifts, illumination variation, etc. Consequently, existing reconstruction methods when dealing with point clouds with incompleteness and noise tend to generate low-quality results and incur tedious postprocessing [13].

Meanwhile, artificial intelligence, e.g., machine learning, neural network, and deep learning, has been popularly used to enhance algorithms' resilience to incomplete and noisy point clouds. So far, researchers have developed two kinds of learning methods: methods using a proposal-ranking scheme and methods using an encoder–decoder architecture. The first kind generates a number of proposals, in which each room configuration is represented by codewords, through vanishing point detection and ray sampling, and then selects the best hypothesis from a ranking step based on hand-crafted rules. Examples are Hedau et al. [3], Ismail et al. [4], Mallya and Lazebnik [6], Schwing et al. [7], and Zhang et al. [9]. On the other hand, the second kind extracts a set of room configuration key points and then connects the obtained key points in a specific order to draw a room configuration. The refinement process is formed as an optimization problem. Examples are Dasgupta et al. [1], Deng and Chen [2], Lee et al. [5], Yan et al. [8], Zhao et al. [10], and Wang et al. [11]. All these methods need to explore the actual space. In contrast to them, this paper proposes a method that does not have the requirement of entering the room.

We attempt to predict room configurations from hints of exterior boundaries according to the Manhattan-world assumption. The method may be useful for emergent cases when exact floor plans are not available or cannot be obtained on time. For private residential buildings, the individual unit may be locked for entry. When rescuers need a fast prediction of the indoor scene, the proposed method will be helpful. Today, the use of a portable 3D laser scanning device mounted on a helmet has become popular. While the rescuers are exploring the outdoor areas, the method can simultaneously generate the indoor model based on the outdoor scanning results. Since this is an automated and fast method, it can assist in real-time decision making. In addition, the method can complement conventional room reconstruction methods for checking and verifying their results.

Generally, indoor space can be treated as a combination of many cuboids that represent rooms. Given the bounding box of the entire building, the horizontal cross-section can be split into a single 2D cell complex. As wall directions are shared within and even across the different floors of a building, the 2D cell complex can be extended in 3D simply through stacking and vertical extrusion, resulting in a 3D cell complex. Based on the 3D cell complex, the final room model can be discovered from a set of relationships among spaces. The above procedure has been popularly used. For example, Oesau et al. [14] used graph cut to label structural components in each cell, where the final model is the union of the cells that satisfy the predefined conditions. Mura et al. [15] built a 2D cell complex from the intersections of the representative lines that are associated with the detected candidate wall patches, where its edges are weighted according to the likelihood of being genuine walls. The final model is computed through a diffusion process. Khoshelham and Diaz-Vilarino [16] presented a parametric shape grammar, in which they showed that interior spaces can be modeled by iteratively placing, connecting, and merging cuboid shapes. Tran et al. [17] also regenerated 3D models of indoor environments from the shape grammar approach.

The method proposed in this paper firstly partitions the building floor space to generate the so-called "room seeds" from the intersections of lines that are extended from the detected wall segments. Then, the grammar approach compares different possible room configurations through a trial-and-error process to find the most possible one. Such a method is considered fast, as it does not involve the tedious coarse-to-fine procedure as other reconstruction methods do. The obtained results are good approximations though not 100% accurate.

The organization of this paper is as follows: after this introduction, the overview of the proposed method is given. Then, the space partitioning method is explained in Setions 3 and 4 describes the grammar approach. After that, Section 5 provides a case study on a real residential building and gives a discussion on the result. Finally, the paper is concluded in Section 6 with limitations and application prospects.

2. Method Overview

The proposed method intends to first create the 2D cell complexes of interior spaces for each floor, and then use a grammar-based approach to generate the room model. Finally, the 2D model is stacked to create the 3D entire building model.

The method takes as input the lines of the building envelope, the windows, and the hallway boundaries as well as the permanent structure configuration detected from the accessible areas. The method consists of two main steps. as depicted in Figure 1.

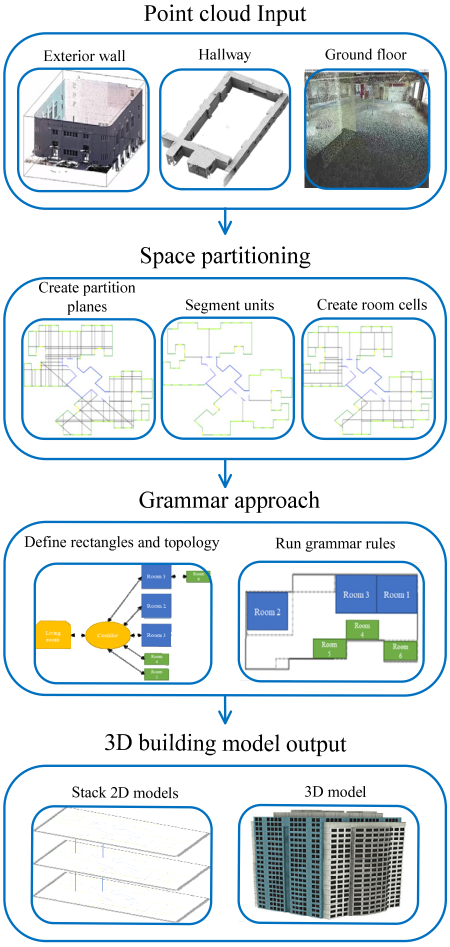


Figure 1. Method overview.

1. Space partitioning: The building's envelope defines the interiors of the building. The private accommodation spaces are obtained by subtracting the public spaces from the interiors. Firstly, the private accommodation spaces are divided into cells by the partition planes, which are generated from the wall edges and the gaps between windows. Then, the boundary cells containing windows are selected as the room seeds.
2. Grammar approach: The grammar approach is a production procedure to design the proper room configuration that meets the minimum room size and the predefined room topological relations based on the discovered room seeds. The grammar exploits the regularity of rooms. It firstly defines different room rectangles and their relations referring to the rooms in the unit with the minimum room side length. It then generates the optimum room configuration that meets the predefined topological relations by placing room rectangles into seeds and repeatedly interchanging the rooms using the computerized relative allocation of facilities technique (CRAFT).

3. Space Partitioning

All the spaces on the floors of a building are arranged in layers floor by floor. The goal of this step is to provide the 2D cell complexes. Exterior walls form a building envelope. Then, the building floor is partitioned into cells that align to the empty and filled space. Wall edges, window spacings, and features such as bay windows, air conditioning ledges, and planter boxes all provide rich information about indoor space. Together with hallway systems, they can be utilized for the prediction of interior room configuration. Take Singapore Housing & Development Board (HDB) residential buildings (a kind of public housing for over 80% of Singapore's resident population) as an example. Their ground floors are void decks designed for community activities, where permanent structures are open to see. In that case, the structure configurations observed from the ground floors give a hint of the room sizes on the upper floors.

3.1. Horizontal Slicing

In the Manhattan-world assumption, walls are assumed to be vertical and perpendicular to floors and ceilings, and permanent structures are assumed to be piecewise linear along the vertical direction. At every height where the permanent structures change, the presence of horizontal planar structures, i.e., floors or ceilings is presumed. According to the locations of floors and ceilings, the building model can be decomposed vertically into horizontal slices that contain wall feature projection. In addition to on-site measurements, one may refer to other sources, e.g., design guidelines, similar buildings, and expert experience, for confirmation. For example, in the HDB building design guidelines, floor-to-floor height is 3.6 m from the 1st to 2nd floor, and the typical floor-to-floor height shall be 2.8 m, including the topmost floor to the lowest point of the roof [18].

The building's exterior walls, the hallway systems, and the ground floor can be scanned separately with a focus placed on the boundary lines of walls and openings (i.e., doors and windows). They are then treated as independent sets of point clouds. The workflow begins with the registration of multiple point clouds of the object that are acquired from different viewpoints. The registration process can be performed by using either artificial targets or objects' features (e.g., edges or corners of walls). In practice, the registration process is performed by using the scanner's proprietary software such as Faro® Scene Software (https://www.faro.com/zh-CN/Products/Software/SCENE-Software accessed on 21 November 2022). Because the resulting registration includes a large number of redundant points, we eliminate them using the segmentation method proposed by Vo et al. [19]. After that, the data points are projected onto horizontal and vertical planes. The data points are firstly vertically sliced according to the standard floor-to-floor heights into many blocks. Each block is projected horizontally and vertically into various planes.

Structures show up as peaks in the point distribution on these planes. For extracting peaks from the point distribution, we create histograms following the steps proposed by Okorn et al. [20]. For opening detection, we applied the method proposed by O'Donnell et al. [21]. The 2D regions of the vertical planes are divided into regular cells with marks indicating their geometries and properties. Ultimately, the 2D models generated from the three sets of point clouds are consolidated into one global coordinate system. A horizontal slicing of the building is the integrated 2D model on the horizontal plane combining the projection of the building feature of the floor and the extrusion of the permanent structures from the ground floor. It should be noted that the technique described above is the conventional technique that learns from point cloud histograms. Today, more advanced deep-learning techniques are available. But since 3D reconstruction from the point cloud is not the focus of this paper, we skip a further elaboration of them.

3.2. Creation of Partition Planes for Rooms

To divide the interior building space into a cell complex for room construction, partition planes originate from the extension of the detected walls as well as the middle of the gaps between the windows and extend till reaching the building boundaries. However, this is far from over. If the partition plane reaches a window, it will be shortened to the most nearby plane perpendicular to it under the assumption that a window belongs at most to one room (Figure 2b). The perpendicular plane will be created if it does not exist (Figure 2c). In addition, due to the Manhattan-world assumption, those sections that are not orthogonal are deleted (Figure 2d). If sets of parallel planes have been detected, cells are created. We select those cells along the boundaries as the room seeds under the assumption that one room must contain at least one window (Figure 2e). The cell sizes can be adjusted to avoid overlapping and ridiculous space according to their local environments (Figure 2f). Figure 2 shows the workflow to create room seeds as above described.

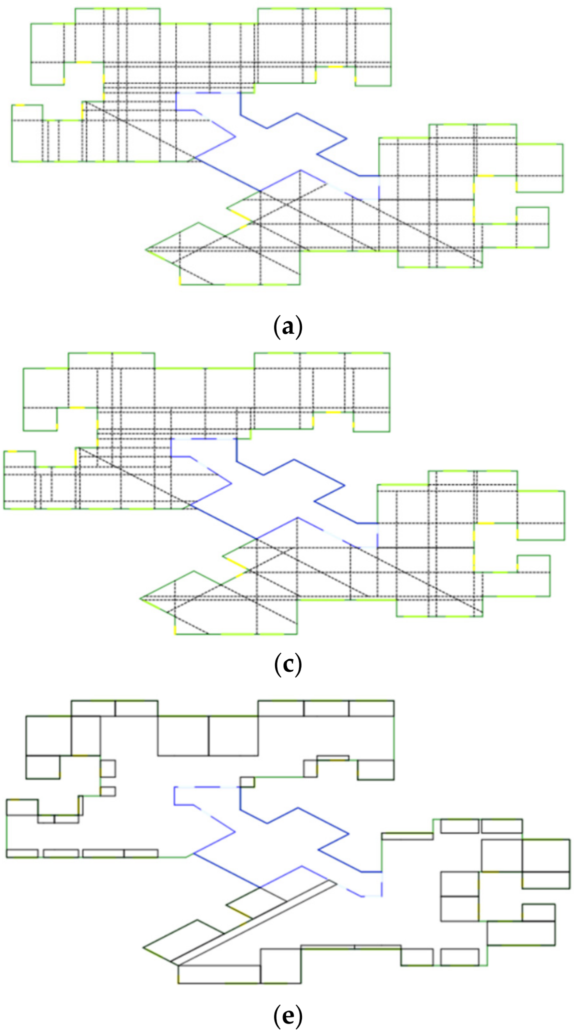


Figure 2. Procedures to create room seeds: (**a**) create partition planes; (**b**) shorten those planes that touch windows; (**c**) correct unconnected partition planes; (**d**) delete non-orthogonal sections; (**e**) select room cells along boundaries; (**f**) adjust cell sizes to local environments (Dark green lines: unit boundaries; light green lines and yellow lines: openings; grey lines: partition planes).

3.3. Creation of Partition Planes for Units

The room seeds are attached to the units. Each unit contains a door opening connecting to the hallway space. For HDB residential buildings, units are of standard types, for example, the so-called three-room unit, four-room unit, five-room unit, executive unit, etc. For each unit type, the unit size is determined. For example, the standard size of a three-room unit is about 60 to 65 square meters, the standard size of a four-room unit is about 90 square meters, the standard size of a five-room unit is about 110 square meters, and the standard size of an executive unit is about 130 square meters. Moreover, the total number of bedrooms and the total number of bathrooms are also determined. For example, a three-room unit contains two bedrooms and two bathrooms, a four-room unit, a five-room unit, and an executive unit all contain three bedrooms and two bathrooms.

Based on the prior knowledge of the units, partition planes are created to divide the interior space into several units. Figure 3 shows the workflow for creating units. The initial partition planes are created from the extension of the hallway walls and the middle of the gaps between the windows (Figure 3a). Those planes that end up with the windows are removed (Figure 3b). In addition, those neighboring planes are combined (Figure 3c). Then, among the remaining, those planes that generate a closed space without a door are further removed (Figure 3d). Finally, the resulting spaces are feasible for units. One can figure out the unit type by comparing the size of the generated unit pace with the standard unit sizes.

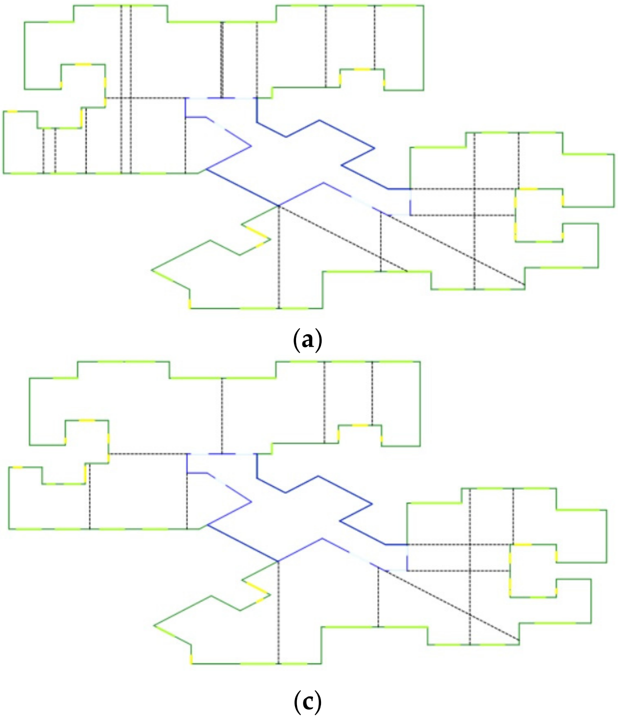

(**a**) (**b**) (**c**) (**d**)

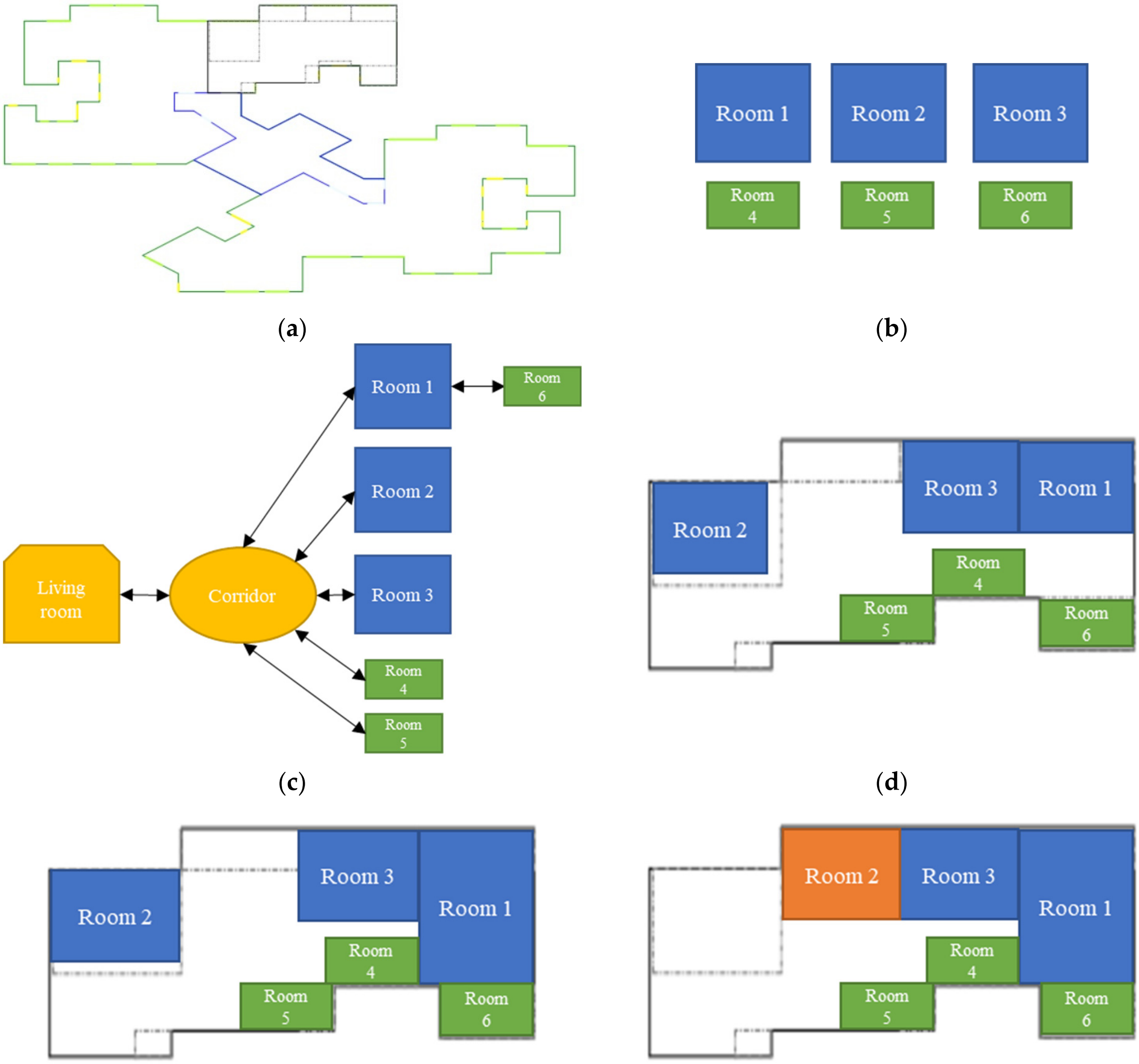
Figure 3. Procedures to create units: (**a**) create partition planes; (**b**) remove those planes that touch windows; (**c**) combine neighboring planes; (**d**) remove those planes that generate a closed space without a door.

4. Grammar Approach

The grammar approach generates the optimum room model that satisfies the predefined room size and topological relations by placing the rectangles that represent the rooms of the unit into the room seeds previously generated and exchanging them pairwisely using the so-called CRAFT technique. The placement, size adjustment, and topology evaluation as well as room exchange are governed by the grammar rules.

Figure 4 shows the workflow of the grammar approach. Based on the recognized unit type, the rooms of the unit (i.e., the bedrooms, the bathrooms, and the kitchen) except for the living room are modeled by rectangles. In this case, we design two types of room rectangles: Type I—bedroom and Type II—bathroom/kitchen. Side lengths of the rectangles follow the minimum room size requirements of each room type.

As we know in space syntax theory, the configuration of spaces relates directly to their functions [22]. Therefore, the topological relations among the rooms or the rectangles are usually quite standard among dwelling units. For instance, entering the main gate is the living room which has the greatest number of windows and is not necessarily rectangular in shape. The living room should directly connect to all the bedrooms, the kitchen, and at least one bathroom. The unit may have a master bedroom which is a bedroom containing a bathroom. From exterior walls, we can recognize window types and the window type suggests the interior room type. In Singapore, there are generally three types of windows: casement windows, sliding windows, and louvered windows. Louvered windows are commonly installed for the bathrooms. Therefore, cells containing different window types invite different sizes of rectangles that refer to different room types.



(**a**) (**b**)

(**c**) (**d**)

(**e**) (**f**)

Figure 4. Grammar approach to creating the room configuration that satisfies the topological relations: (**a**) 2D cell complex of a unit; (**b**) prepare room rectangles; (**c**) define room's topological relations; (**d**) place room rectangles into room seeds; (**e**) refine room configuration; (**f**) find the optimum configuration by pair-wisely exchanging.

At the initial, the rectangles are randomly allocated to the room seeds and their sizes are adapted to the local environments. Then, the rectangles are pair-wisely interchanged among the room seeds to find the optimal room configuration. The above procedure is repeated for each unit of the floor. Finally, we stack the generated 2D model to create the final 3D building model.

4.1. Grammar Rules

Six grammar rules (placement rule R^1_{place}, adjustment rule R^2_{adj}, connectivity rule R^3_{conn}, accessibility rule R^4_{acce}, exchange rule R^5_{exch}, and evaluation rule R^6_{eval}) are defined to produce a room model.

4.1.1. Placement Rule

The placement rule R^1_{place} places an unassigned rectangle I to an unoccupied room seed S by checking against the criteria H. H corresponds to the number of available seeds. H is set to zero if no available seed exists and the rule cannot be applied.

$$R^1_{place} : I \rightarrow S : cond(H \neq 0)$$

4.1.2. Adjustment Rule

The adjustment rule R^2_{adj} modifies the size and location of a room. The rule adapts room A to its local environment B upon the conditions.

$$R^2_{adj} : A \rightarrow B : cond$$

A room side can be moved within the room size minimum and maximum requirements as well as the window requirement in the following cases: (a) the side is not the side of any other rooms, or (b) the side is not an exterior or hallway wall, or (c) the side is an exterior or hallway wall it contains no window. In addition, a room side can be merged or in line with its closest neighboring wall. The geographical closeness of the two walls is measured by their Euclidean distance. If the distance is under an empirically determined threshold τ, for example, $\tau = 0.9$ m since the internal corridor width is 1.0 m, the adjustment rule will be triggered. Moreover, if two rooms are overlapped, the adjustment rule keeps working till it separates them or exceeds the maximum number of iterations allowed.

4.1.3. Connectivity Rule

The connectivity rule R^3_{conn} evaluates the connectivity relation between two rooms: A_1 and A_2. The two rooms are deemed as adjacent spaces if there is a common wall between them. They are accessible if there is space that permits the free flow of walking between them. In the current grammar, the modeling of doors and other details is neglected.

$$R^3_{conn} : \{A_1, A_2\} \rightarrow [conn]$$

4.1.4. Accessibility Rule

The accessibility rule R^4_{acce} establishes a corridor system C between two rooms A_1 and A_2 if they should be connected according to the predefined topological relation between them. The corridor system follows the Manhattan-world assumption and the shortest path assumption. Any impacted rooms by the corridor creation should still be able to satisfy their size requirements. The corridor system is an integral system that permits the free flow of walking. It originates from the living room to link all the rooms together. In practice, a corridor is created by perpendicularly extruding a line from the boundary of the living room to the intended room along the common side of the adjacent rooms.

$$R^4_{acce} : \{A_1, A_2\} \rightarrow C : cond$$

4.1.5. Exchange Rule

The exchange rule R^5_{exch} performs the CRAFT procedure where it exchanges the locations of two room rectangles or moves the location of a room rectangle to another empty seed. In the rule, the term $[A, C]$ denotes that seed C is assigned by rectangle A. A seed may or may not have a rectangle on it. If C is not assigned, A is set to zero. Because rectangles of the same room type are the same, we do not need to exchange the locations of the rectangles belonging to the same type. Therefore, we only need to relocate the rectangle to an empty seed.

$$R^5_{exch} : \{[A_1, C_1], [0, C_2]\} \to \{[A_1, C_2], [0, C_1]\}$$

4.1.6. Evaluation Rule

The evaluation rule R^6_{eval} gives each room configuration solution a score Z indicating the level of its preference to the designers. The score is designed as follows:

$$Z = \frac{4\delta(G_{size})\delta\left(G_{topology}\right)}{W_{edge}}$$

where $\delta(\cdot)$ is a function returning values of either 0 or 1. If the requirement of room size is satisfied, $\delta(G_{size}) = 1$; otherwise, 0. If the requirement of room topology is satisfied, $\delta\left(G_{topology}\right) = 1$; otherwise, 0. W_{edge} denotes the total number of wall edges in the living room and $\frac{4}{W_{edge}}$ reveals the regularity of the living room. If the living room has a rectangular shape, $\frac{4}{W_{edge}} = 1$; otherwise, $\frac{4}{W_{edge}} < 1$. Therefore, the score Z is a value between 0 and 1. Higher Z is preferred.

$$R^6_{eval} : \{[A_1, C_1], [A_2, C_2], \cdots, [A_n, C_n]\} \to Z$$

4.2. Production Procedure

The grammar rules are applied iteratively and in a specific order, as depicted in Figure 5. The production procedure starts by placing the rectangles into the seeds formed from the previous space partitioning step. This is performed by applying repeatedly the placement rule. After all the rectangles of the unit have been allocated to the seeds, the adjustment rule is invoked, and the rule is repeatedly applied for each rectangle till no more adjustment is needed. Next, the connectivity rule evaluates the topological relations between each pair of rooms against their predefined relations. If additional connectivity is needed, the accessibility rule is used to automatically create a corridor system. Once a room configuration is generated, it is awarded a score by calling the evaluation rule. Then, the exchange rule is applied to seek a better one. The above procedure iterates till all possible room configurations have been explored.

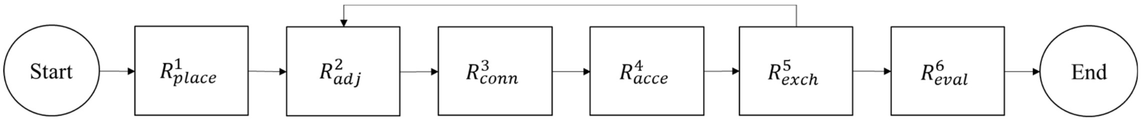


Figure 5. Production procedure (arrows on the tops of the boxes indicate iteration).

5. Case Study

The proposed method was implemented in a .NET environment on a personal computer (i7-8750H CPU, 2.2 GHz, and 32.0 GB). The conversion of the point clouds to the 3D model was conducted by a C# script executed within Eyeshot software version 2020. An experiment was carried out using real point clouds to evaluate the performance of the proposed method. An 18-floor HDB residential building with 53 4-room units and 51 5-room units in Singapore (Address: Block 311, Sengkang, Singapore) was selected for this pilot study. The whole building contains two separate blocks: Block A and Block B. Block A and Block B have the same design. So, we selected one of them. Each floor consists of several units connected by a large public corridor space. The scanner we used was FARO Laser Scanner Focus3D X 330. It is a high-speed 3D laser scanner for detailed measurement and documentation. The resulting scan resolution was chosen to be 1/10, quality was 3 times, and scan durations were limited to about 5 min each. Because the sizes of the raw point clouds were more than 100 million points, we used a voxel grid filter to downsample the data. Figure 6 shows the scanned point clouds.

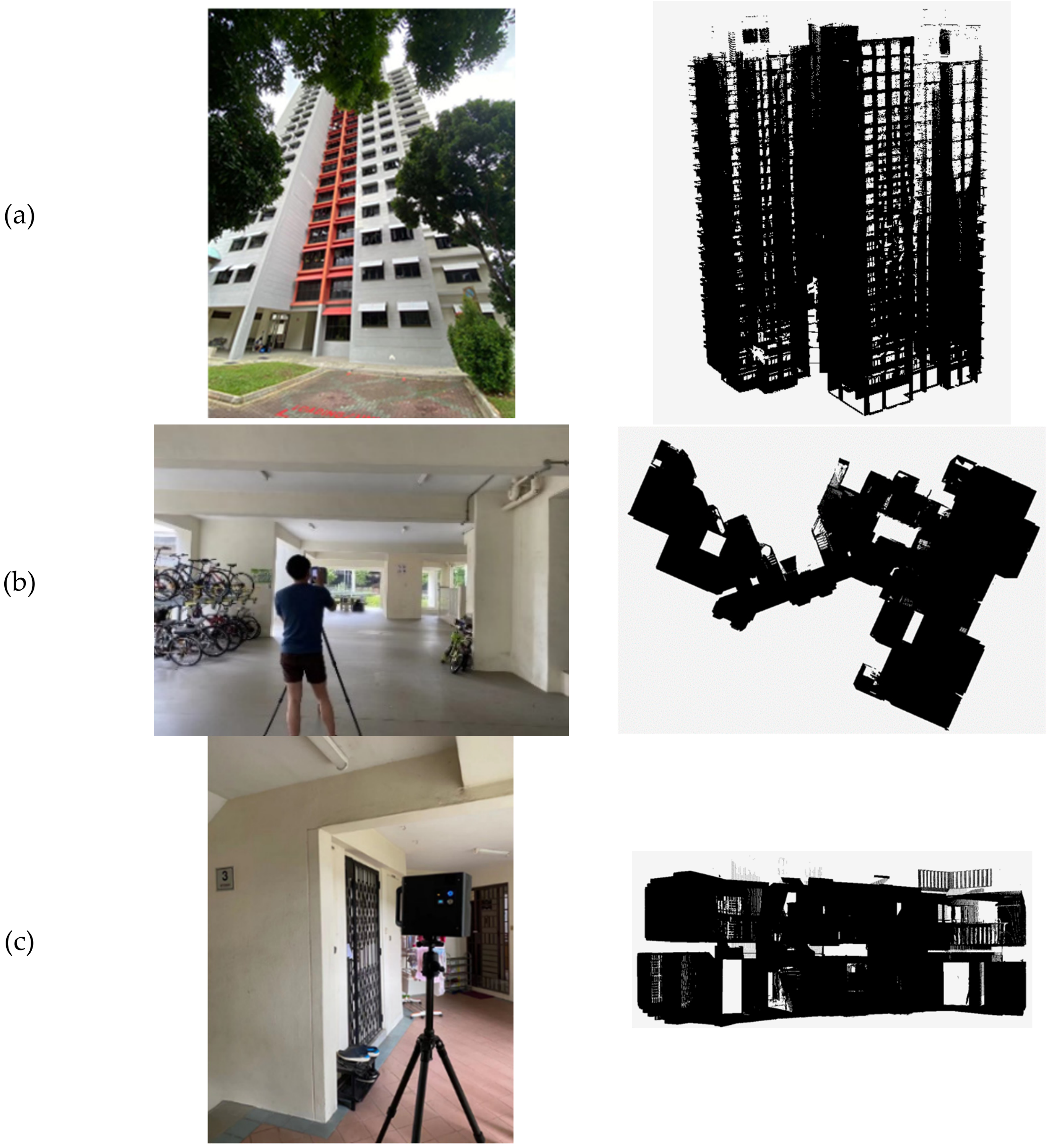
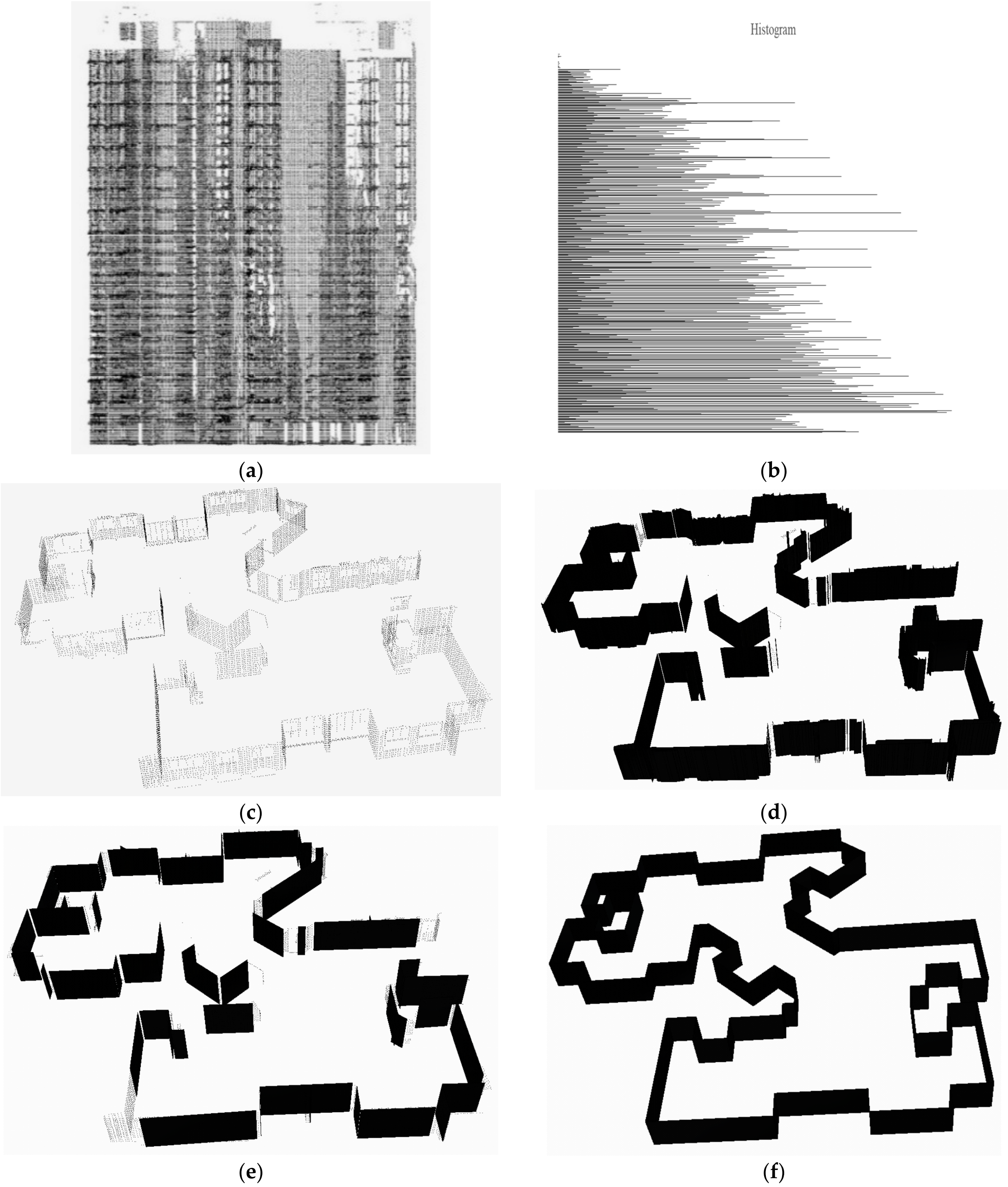


Figure 6. Scanned point clouds: (**a**) exterior walls; (**b**) ground floor; (**c**) hallway.

Take the point cloud of the exterior walls as an illustration. To extract the point cloud of one floor from the point cloud of the entire building, the raw point cloud was projected onto the vertical plane and a height histogram was created, from which the floor-to-ceiling distance was estimated. Based on the floor-to-ceiling distance, the point cloud was segmented for each floor. After that, the region-growing algorithm was applied to find planes for wall reconstruction. To overcome the drawbacks of using random seeds and thresholds, multiple tries were made, and the results were combined. At last, the boundary check was performed. Those open boundaries where points were missing were forced to be connected according to the Manhattan-world assumption. Figure 7 illustrates the whole process. Then, the same procedure was continued for the hallway section. At last, the proposed method was used to predict the interior room configuration. Figure 8 shows the generated room configuration result compared with the design drawing.

The obtained result from the proposed method can reconstruct the actual room configuration as depicted by the CAD drawing at a satisfactory level though not 100% exactly. The default room shape except for the living room is rectangular. The room types (the living rooms, the bedrooms, the bathrooms, and the kitchen) are all correctly recognized.

However, as the required minimum room size is used as the default room size when there is no additional clue from the detected walls, the generated room size is an approximation. The proposed method has no need for scanning and thus will be useful in some cases when carrying on scanning is not possible. This is the major difference from the existing methods. But by achieving such ease, the accuracy of the model is sacrificed. For more accurate modeling, the scanning process is definitely needed.

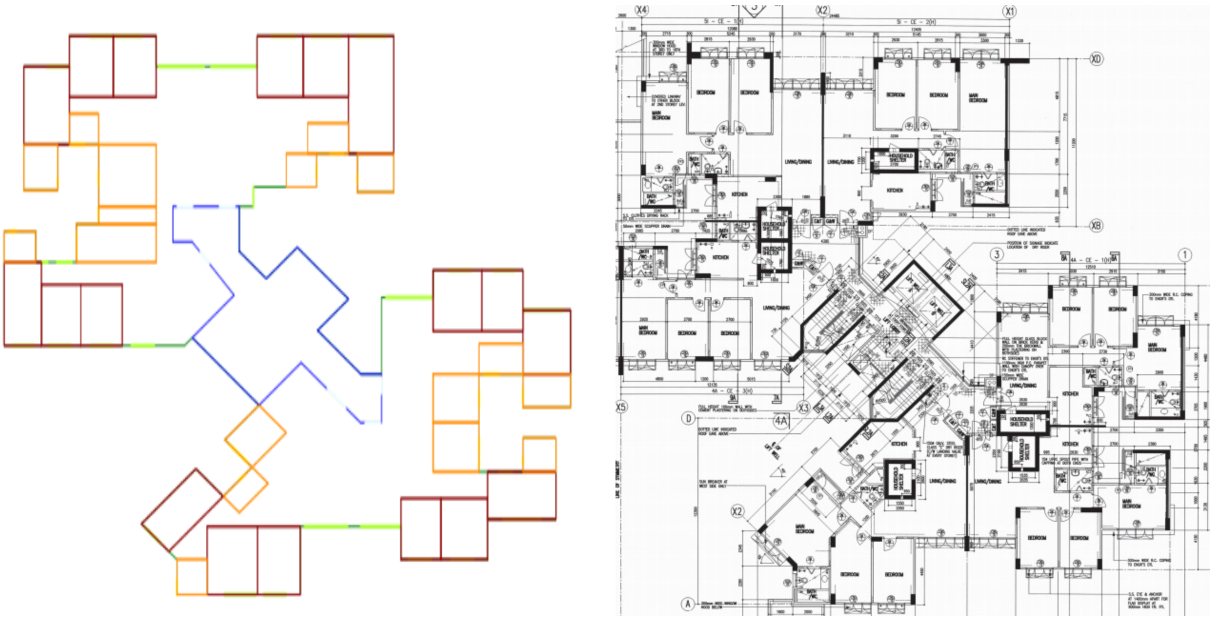


(**a**) (**b**)

(**c**) (**d**)

(**e**) (**f**)

Figure 7. Procedures to reconstruct walls from point clouds: (**a**) raw point cloud for the building; (**b**) height histogram; (**c**) point cloud of one building floor; (**d**) detected wall planes; (**e**) filtered wall planes; (**f**) reconstructed walls.



(**a**) (**b**)

Figure 8. Comparison of the predicted room configuration plan of a floor with the design drawing: (**a**) predicted room configuration; (**b**) CAD drawing.

To summarize, the proposed method is a fast algorithm that relies on the Manhattan-world assumption and six grammar rules. The Manhattan-world assumption is valid for the majority of urban buildings where architectural scenes exhibit strong structural regularities. Therefore, as long as the building is not in a peculiar design, the proposed method should be feasible.

The method consists of two steps. The first step of the method discovers all possible room locations—the so-called room seeds. The second step uses the grammar approach, which takes into consideration the constraints of room sizes and room topological relations to determine the room configuration. We propose six grammar rules. Once these six grammar rules have been defined, the room configuration can be produced through a trial-and-error process without difficulty. The procedure is fast because there is no tedious coarse-to-fine procedure. However, the design of the six grammar rules needs prior knowledge of the building. Luckily, prior knowledge of a building is easy to obtain, for example, from similar buildings, from design guidelines, from partial observation of the building, etc. According to the space syntax theory, the configuration of space relates directly to how people perceive, move through, and use spatial systems of any kind. Hence, it is unlikely that we do not have any knowledge about the building. Given the building follows Manhattan-world design and the six grammar rules, the proposed method can be extended to buildings other than the residential type.

6. Conclusions

This paper presents a fast room layout prediction method for modeling indoor environments with a Manhattan-world structure based on observations from publicly accessible areas. The proposed method may be useful in emergent cases when exact floor plans are not available. The method can be extended to other Manhattan-type buildings as long as the grammar rules are settled. The method consists of two main steps. The space partitioning step provides the room seeds of each building floor from the point clouds. Then, the grammar approach defines the room rectangles as well as their topological relations for each unit and generates the optimum room configuration by placing the defined rectangles to the room seeds using the CRAFT technique. Ultimately, the 3D model of the entire building is created by stacking the 2D models of the floors. The ability of the method to predict room configuration from the hints provided by wall edges, window spacing, etc., was shown in an experiment of a residential building case in Singapore.

Although building design documentations are probably available from a public office that grants construction permits or similar permits, they may not be timely accessible when needed in emergencies. In most cases, rescuers still get a clue about the building through their on-site explorations. Therefore, the proposed method has benefits in emergent cases when room entry is denied, as it provides a way to generate the indoor model upon the scanning results of the outdoor areas.

Moreover, a raw point cloud of an indoor scene often contains missing data due to occlusions and clutters. Some walls may be missing in the data set. This undermines the accuracy of the reconstructed models from point clouds. In this regard, the proposed method can offer supplementary information about the indoor environment to the conventional point cloud reconstruction methods for checking and verifying the latter's results.

The current method is limited to Manhattan-world indoor environments. The modeling of doors and other details is neglected. Future work will investigate the extension of the method to non-Manhattan-world indoor environments and automated modeling of more architectural details.

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