

Simplifying Building Structures for Efficient Radio Propagation Modeling

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Abstract—Accurate three-dimensional models for building structures play a key role in radio propagation modeling using ray tracing method in city environments. As the frequency of wireless systems increases to centimeter/millimeter bands and the application of narrow beam signals, more accurate models containing higher level-of-detail structural information are needed. Currently, digital databases represent such building structures in a manner that may be not suitable for efficient propagation modeling. One issue is the fragmentation of structures that unnecessarily increases the size of the model and reduces the computational efficiency. It also results in ray double counting problems that reduces the simulation accuracy. We propose practical methods to tackle the fragmentation to create models with much smaller sizes. We also propose strategies to treat small structures to further reduce the sizes of environmental models without affect the simulation accuracy significantly.

I. INTRODUCTION

As we are eye-witnessing the 5th generation (5G) of wireless communication systems being developed and deployed, researchers have started to think about the next generation (6G) system [1] and beyond. The newer systems tend to use higher frequency bands to achieve larger capacity, higher data rate, better reliability, and smaller latency. For example, the high-band of the 5G systems is about 30 GHz (the corresponding wavelength is 1 cm). Another trend is the use of massive MIMO antennas featuring signals with very narrow beams. These trends have significant impact on the propagation of electromagnetic (EM) waves. In this paper, we focus on the wave propagation in city environments where high-rise and complex building structures are common.

In lower frequency bands, some small structures of buildings can be ignored. As the frequency increases, these structures may play a significant role in propagation modeling and should not be discarded. Similarly, such small objects may completely block a signal if the signal beam is narrow. To guarantee accurate propagation modeling using ray tracing methods, we need digital environmental models with higher level of detail.

According to [2], building structures can have four levels of detail (LOD) as illustrated in Fig. 1. Based on our experience, for propagation modeling in the gigahertz bands, LOD1 can provide results with good accuracy compared with measurements [3, 4]. We expect that higher LOD building structures are needed for new and emerging wireless systems.

In this paper we tackle a practical issue associated with LOD2 buildings in a database: the fragmentation of structures that severely reduces the propagation modeling speed. We examine 24,000 buildings in part of New York City and develop an automatic method to defragment the structures and increase the ray tracing simulation efficiency significantly. Also, we treat

small structures that may be ignored under certain circumstances to further improve the computational efficiency without affecting the simulation accuracy.



Figure 1. Four levels of detail building structures [2].

II. GML DATA FORMAT

There are different formats for storing 3D building structures such as the DXF and GML format. The geometry arrangement is also different. In this paper we focus on the GML (geographic markup language) format [2]. Specifically, we examine the GML data for the buildings in New York City.

The data in this GML file are grouped for each of the 24,023 buildings. For each building there are three types of shapes: the grounds, the roofs, and the walls, all represented by 2D polygons. In almost all cases, there is only one ground-polygon for each building. Roofs are above the ground polygon. The walls are polygons between the roofs and the ground or between different roofs. An example, a typical building is illustrated in Fig. 2. The ground is a polygon with 27 vertices. There are four roof polygons. The largest one is similar to the ground with a dent and it has 29 vertices. The three small roof polygons are all rectangles. One of them is on the same plane of the largest roof.

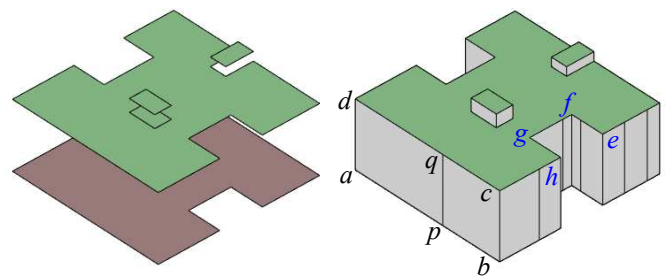


Figure 2. A typical building geometry composed of one ground polygon (right, bottom), four roofs (right, in green), and 33 walls (in gray).

All three types of polygons are defined by their vertices ordered in counterclockwise sense with respect to the usual definition of normal to a surface. It should be noted that there are no indices associated with the vertices. Thus, a polygon of n vertices will be represented by $3 \times n$ real numbers: each vertex has three coordinates. A vertex's coordinates will show up in all the polygons sharing the vertex. The advantage for this data

format is that each polygon can be directly imported to a ray tracing engine without any further processing if computational efficiency is not a problem.

III. FRAGMENTED STRUCTURES

It is evident from Fig. 1 that some walls are fragmented. For example, the two walls in the front, $apqd$ and $pbcq$, are on a common plane $abcd$. It is reasonable to combine them into a single surface $abcd$. The defragmentation has at least two very useful consequences. First, reduce of the number of surfaces (or vertices). This directly gives us more efficient propagation modeling using ray tracing method. For example, for the building in Fig. 2, there are 33 walls before defragmentation. The number of walls is reduced to 21, about a 36% reduction, after defragmentation as shown in Fig. 3 (b).

Second, avoid ray double counting. As discussed in [5], we developed a surface-based algorithm to solve the ray double counting issue. If the two adjacent surfaces are co-planar, ray double counting is possible if a ray is hitting the neighborhood of the junction (line pq in Fig. 2) of the surfaces. Thus, defragmentation can also improve the accuracy of propagation modeling.

Besides the fragmentation of the walls, we can also observe from Fig. 2 that the two small structures on the rooftop may be removed if the frequency is low and the beamwidth of the signals is large. Also, if the transmitting antenna is below the rooftop, these two objects are insignificant to affect the propagation results and can be ignored too. This will further simplify the building structures from the one with LOD2 to LOD1, as shown in Fig. 3 (c). The number of surfaces is reduced from 38 to 14.

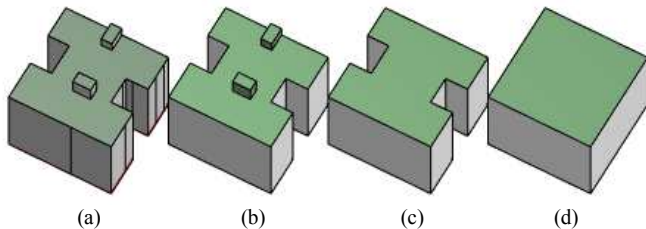


Figure 3. Simplifying buildings: (a) the original building from the GML database; (b) after wall defragmentation; (c) with small structures removed; and (d) with major propagation features only.

We can simplify the building structure one more time if the transmitter is facing the wall $abcd$ (see Fig. 2). This is because the two inward structures represented by $efgh$ in Fig. 2 will not contribute appreciable power to the receivers and can be straightened and aligned with the outer surfaces, as seen in Fig. 3 (d). The simplest structure only has five surfaces. Compared with the original 38 surfaces, this is a significant reduction (more than six times).

It is evident that by defragmentation and careful treatment of insignificant features of buildings, we can simplify a building structure without changing its LOD values or obtain lower LOD structure if the frequency, the beamwidth, and antenna locations allow. According to our experience [6], under certain circumstances buildings with low LODs can increase the computational speed significantly while not affecting the accuracy of the results. The decision process for simplification can be accomplished automatically.

IV. SIMPLIFYING BUILDINGS

There are different ways to defragment. A widely used curve simplification method, the Ramer-Douglas-Peucker (RDP) algorithm [7], can be adopted for this purpose. The RDP method simplifies a curve without changing its shape. This fits our need because the major propagation features are contained in the shape, such as reflection planes and diffraction edges.

On the other hand, for the defragmented walls in Fig. 2, a simpler method can achieve the same goal with less computational cost. For example, to determine if the two surfaces in Fig. 2, $apqd$ and $pbcq$, can be combined to one, we need to know if these two polygons are aligned. This can be done using their normal directions. If the normal vectors are parallel, the two surfaces are coplanar and can be merged. Thus, we can check the dot product of the two normal vectors. If the result is close to 1, the two surfaces can be combined. A threshold value for the dot product can be established based on experience such as 0.99 or 0.999. An important case is for a circular object and its cross section is usually represented by an inscribed polygon. Depending on the number of edges of the polygon, the angle between two edges can vary in a wide range. An inadequate threshold can eliminate the entire object.

For small structures in a building, we use a different procedure to determine if they can be ignored. The criteria include the cross-section area or volume of the object, their heights, orientations, and so on.

V. CONCLUSION

The digital databases for geospatial resources including building structures need preprocessing to be useful for the efficient propagation modeling in urban environments. The defragmentation procedures and other considerations proposed in this paper significantly reduce the number of redundant structures leading to better propagation modeling efficiency. The simplified buildings also help avoid ray double counting issues and improve the simulation accuracy.

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