A PEDESTRIAN ACCESSIBLE POSITION EXTRACTION METHOD OF EXISTING 3D FILES FOR LARGE BUILDING EVACUATIONS

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ABSTRACT:

As the emergency evacuation research in large building area draws more attention than ever before, it is natural to fast acquire the navigation information for this purpose. Current solution for extracting human accessible area from existing data files consumes a significant amount of resource and time. Thus a better solution is required. We propose a semi-automatic plan, which introduces a conceptual model to extract and organize the accessible data of large building. This solution utilizes several spatial algorithms to extract detail traversing information from existing 3D building files and introduce spatial relationships to manage the extracted data.

1. INTRODUCTION

People need to face several challenging problems in modern society, such as natural disasters and artificial ones. Whatever the disaster is, we should find a fast responding plan to address the emergency caused by these disasters. Among this approach, the emergency responding in building-intensive area draws the attention of researchers, and the hotspot in this area is people evacuation in large building group.

The people evacuation requires a delicate plan to meet the demand of directing people out of the emergency scene fast and safely, and this can only be achieved by executing evacuation simulation with real people and environment or with software-simulated people and environment. The former solution could generate more workable evacuation plan but cost more resources than the latter one. Therefore, the promising research trend is to choose the second way that uses the evacuation simulation program to mimic the emergency situation, produce and evaluate the evacuation plan.

Under usual circumstance, the evacuation simulation program needs navigation data extracted from the real building with high accuracy and volume (figure 1); otherwise the simulation result cannot help researchers analyse the possible emergency situation. This means the supply of navigation data is crucial for evacuation simulation.

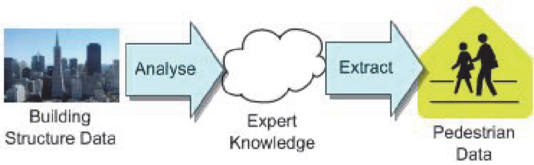

Figure 1. Concept model of pedestrian data extraction from building structure data

Researchers would face two challenges in order to acquire the proper evacuation simulation data. The first challenge is to form up a spatial relationship model to extract accessible data from existing building structure files, and the second challenge is to finish this extraction task for high volume data in a comparative short time period automatically than manually.

These two challenges could only be overcome by utilizing proper methods. For example, introducing parallel computing technology could meet the computational demand of the high data volume of simulation data; while the complex spatial relationship model could only be constructed by improving existing models across several related disciplines.

2. LTERATURE REVIEW

Different researchers have taken various approaches to prepare raw navigation data for evacuation simulation. Lee and Zlatanova has proposed a solution to introduce the spatial topological relationships into the working procedure of extracting communication network from existed CAD files, which records the building structure(Lee and Zlatanova 2008). Li and He took a further step to prepare accessible data ready, and they combine the routing context information with the graph-extracted communication network(LI and HE 2008).

This approach is followed by several researchers. Nagel has successfully produce some semantic information of building structure from un-interpreted data files, and this finding could also be easily transformed to extract communication data for emergency evacuation simulation(Nagel, Stadler et al. 2009). Furthermore, Boguslawski has introduced a boundary object called ‘cell’ to improve the extraction efficiency(Boguslawski, Gold et al. 2011).

Besides the CAD extraction research, there is another approach discussing the 3D discretization of the accessible position for building environment. Bandi and Thalmann proposed a method of discretize the accessible plane for human navigation with 2D cells. Yuan and Schneider argue that a LEGO representation

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and organization for evacuation simulation would be more sounding (Yuan and Schneider 2010). This research trend is also very helpful about the idea of introducing consistent basic unit to represent the whole building area.

All these contributions by researchers have enlightened us to develop an improved method to prepare navigation data for evacuation simulation. In our opinion, the combination of a 3D normalized spatial relationship model and a parallel computational framework can answer the question of providing accessible data for emergency evacuation simulation in large buildings. Therefore, this paper will concentrate on the introduction of these algorithms to the working procedure in emergency communication data extraction.

To finish this task, this paper contains four parts including the introduction part. In the second part, we come to analyse the key features of inner-building space and formulate a normalized spatial relationship model to extract communication information; in the third part, we use a test area to prove our model is workable; in the final part, we discuss the advantage and disadvantage of our solution.

3. EVACUATION COMMUNICATION DATA EXTRACTION FROM LARGE BUILDING

As mentioned in the first part, the striving needs of emergency evacuation require large volume of simulation data. Evacuation simulation needs two basic types of data: people behaviour data and basic environment data(Vanclooster, De Maeyer et al. 2010). The people behaviour data could be generated from social research or psychological research, and this is not the focus of our research. Nevertheless, the related factors of the building environment data draw our attention.

For the purpose of evacuation simulations is moving a group of people from the dangerous area to the safe area, the spatial distribution feature of evacuation building is the most important element among its environment factors. Furthermore, the inner-space feature of buildings is also crucial, since the artificial structure mainly places its function area in the inner part of building. Therefore, we should consider both the spatial distribution and the inner-space feature of large buildings. Thus the next part of the paper is about the accessible position description of the inner space feature for large buildings and a designed extraction solution for the communication data of inner-building space.

3.1 Inner-Space Feature of Large Building

Due to the fact that buildings are artificial objects, the inner-space of large buildings is defined before the structure is physically constructed. This space is classified into many functional parts, such as electrical supply part, heating-pipe part or other parts, and all these parts must be accessible for people(Martín, García et al. 2011). If the functional part is not accessible, then the part cannot be maintained by workers. Nevertheless, the ‘accessible’ meaning for skilled building workers is quite different from normal pedestrians. This is caused by the different mobility ability of these two groups of people, for example a well-trained electrical worker could use climbing tools like ropes to climb up a tall wall easily, and a normal person cannot do this. For the emergency evacuation simulation the mobility ability of people is restricted into the minimum level, in other words the accessible area means the area easily moved in and out on foot by normal people.

To restrict the accessible area for normal people, the limitation for moving from one place to another place must be defined. Otherwise, some un-acceptable moving condition would appear, such as through one step people could jump directly from one floor to the neighbour floors. The mobility limitation for people in inner-building space has three types.

The first type of limitation is the step length limitation. Every moving step from one position to the neighbour position must not be over the average step length of normal people, otherwise the moving request is rejected. The second type of limitation is the step height limitation. Like the step length limitation, the height difference between two neighbouring positions should not be over normal people level. The third type of moving restriction is the slope limitation. This type of limitation is introduced to eliminate the case that two neighbouring position are on the edge of a large slope. All these three types of limitation will be carried out in the communication data extraction for evacuation simulation.

The three types of movement limitation lead to the construction of a special relationship model for the inner-space of large buildings. The feature of spatial distribution for inner-building space requires us to introduce several popular types of spatial objects and their important relationships. In the next section, we will focus on the explanation of these introduced spatial objects and the related spatial relationships model.

3.1.1 Typical Spatial Object

From many aspects, the considering scope of candidates for basic spatial object are comparative narrow. In detail, the artificial feature of buildings determines that the inner-building objects of the structure are in regular shape. This determines the introduction of regular shape object (figure 2), and leads to the choice of cuboid as the basic spatial object. We have evaluated many types of polyhedron. At last we choose the cuboid, because other types of polyhedrons have many disadvantages in the evacuation simulations.

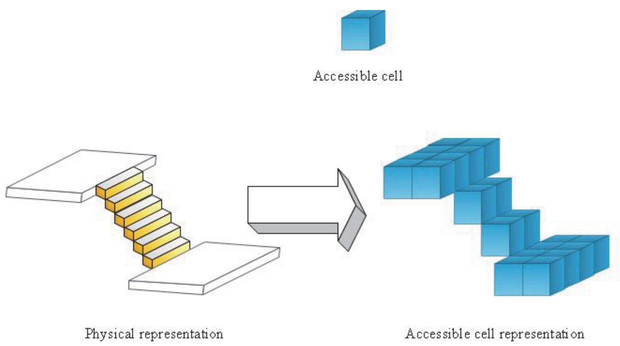

Figure 2. Diagram showing transformation from existing building structure data to pedestrian accessible cell form

For example, if we use an octahedron with six rectangle faces and two honeycomb faces as the basic unit, then each unit normally has six neighbouring units, and this makes an obstacle to simulate people choosing path in evacuation. This is because people have been accustomed to eight direction choices for moving to the neighbouring units. If they have six direction choices, they will be confused.

After the setting of basic units, we can only use larger cuboid as an index to represent a specific collection of basic units. And by using the cuboid index, we could filter the unnecessary space for a specific extraction operation out.

Besides the introduction of basic unit and spatial index object, we should also introduce triangles to represent the boundary of the existing 3D objects for large buildings. The reason is that the evacuation position extraction currently set the data source to several common formats of 3D files using the triangle to compose the building structure. Thus only after fully analysing information kept by triangles could we finish the task of evacuation communication data extraction.

3.1.2 Normalized Spatial Relationship for Inner-Building Space

The triangles and cuboids play different roles in our normalized spatial relationship model. The triangles in the existing data are used to form up the skeleton of the building structure, and this function is transferred to the boundary forming objects in our model. These boundary objects could distinguish the inner-space with outer-space of the building. The inner-space of the building would possibly be involved in the evacuation simulation, for they may be the communication position in the next step. Nevertheless most of the outer-space will be filtered out for being little value in evacuation simulation. Furthermore we should also create a standard to differentiate the involved inner-space from non-involved inner-space for a specific evacuation research. We believe this standard could only be defined by analysing the communication information from two aspects.

The two aspects are whether current considering position is in the possible inner-building communication space and whether this position is accessible physically by normal people. The first question could be answered by following this logic. The triangles of the building representation successfully define the inner-space and outer-space of the research building. We could properly determine the accessibility of current position by fully analysing the relationship between current position and all the triangles belonged to the same building.

The second question could be solved by the establishment of accessible position evaluation standards proposed in the former section. This means we must check the moving length, height and slope restriction to finally figure out whether the considering position could be moved into from its neighbour positions.

3.1.3 Manual Settings for Accessible Position Extraction

The accessible position extraction theory is the core of our solution. And this theory mainly covers two aspects explained in the former section and several key topics about other important details in the communication position extraction process. First, we must clarify that the basic communication unit in our research is the cuboid object with a fixed width, length and height, which is normally a long 3D box with a square bottom. The fixed size of 3D box helps us format the whole area into a 3D array. This array could be well organized the accessible information of the building part (figure 3). Furthermore, the equal size of length and width is intended to regularize every horizontal moving step length committed by simulated people.

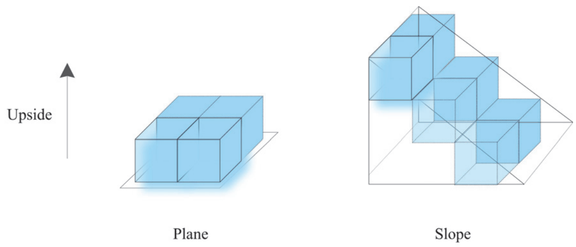

Figure 3. Evacuation area represented by regular accessible 3D boxes

Second, the considering target (pedestrian) of the evacuation simulation restrict the moving style to walking. This indicates no long distance and cross-layer jumping is allowed. Thus one building layer is divided into several layers formed by basic units to prevent cross-layer moving.

Beyond the topic of basic unit and basic moving styles, there still are many subjects not covered in this approach. They will be supplemented in the future papers.

3.2 Key Algorithms for Evacuation Data Extraction

The key algorithms for evacuation data extraction are inner-space determination algorithm for buildings, accessible position analysis algorithm for buildings. The former algorithm is to evaluate whether the current position is in the inner-space of the specific building; while the latter algorithm evaluate whether the inner-building position is an accessible position. The two algorithms are combined to produce the result of accessible communication position for specific large buildings.

3.2.1 Inner-space Determination

Researchers want to know one position is whether topologically inside a building. This analysing operation is comparatively complex. In this operation, we should not only decide whether the position is in the convex boundary of the building, but also evaluate whether the position is in the bounding area of the triangles belonged to the building. This task could be simplified by treating the position as a square unit. Therefore, we could use the centre of mass evaluation method when we need to determine whether this box object is inside the polyhedron representing the building. In short words this means we only need to consider the mass centre of the box object is in the polyhedron or not. As is shown in figure 4, we could see the belongingness for the small box unit is determined by the mass centre position to the large polyhedron.

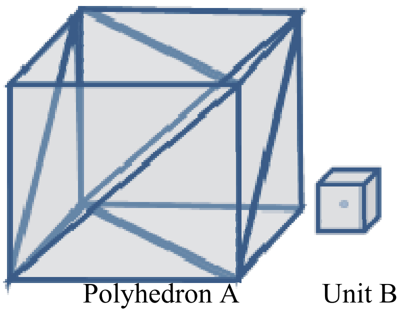

Figure 4. Typical spatial relationships with communication unit and the building

3.2.1.1 Polyhedron Decomposition

According to our knowledge, the relationship between a point and a polyhedron must be decomposed to relationships between point and triangles. This accelerates the operation that evaluate whether a point belongs to the area surrounded by a collection of triangles. The detail implementation of this decomposition is demonstrated in figure 5 (The polyhedron A in figure 4 is decomposed). After this process, we use a method named as "point in triangle normal space evaluation" to solve the point-inner-space evaluation problem.

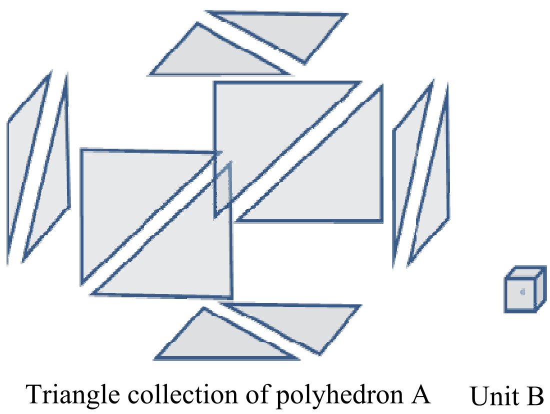

Figure 5. Polyhedron-inner side evaluation decomposition process

3.2.1.2 Point Triangle Relationship Analysis

As is shown in figure 6, this method uses a reference point P_r on triangle plane belonged to the polyhedron, the normal vector N_p pointing to the polyhedron inside and the vector V_c from the reference point P_r to the considering point P_c. If the vector product of N_p and V_c is positive, then the point P_c is on the normal direction side of the triangle consisting the polyhedron; otherwise the point P_c on the anti-normal direction side. After summing up all the computational result between the point and all the triangles of the polyhedron, we can tell whether the point P_c is topologically inside the polyhedron.

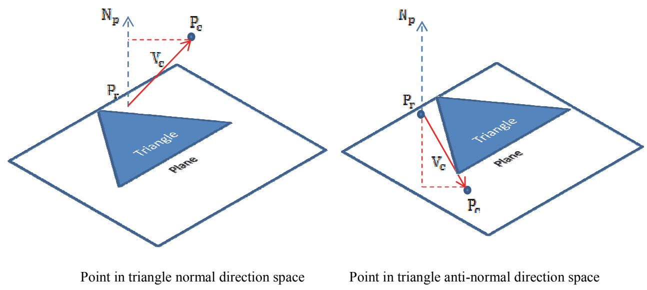

Figure 6. Polyhedron-inner side evaluation for point by using the triangle plane

3.2.2 Evaluation of Accessible Feature

After the evaluation of the relationship between the basic unit and the polyhedron, there are two possible results. First possible result is that the basic unit does not belong to the inner space of the polyhedron, thus there is no need to analyse whether the unit is accessible. Second result is that the unit belongs to the inner space, and this means we need to evaluate the accessibility of the unit.

Figure 7 shows that the accessibility evaluation progress could be classified into two parts. The first part is named as the evaluation between the unit and bottom triangles of the polyhedron. Since the accessibility of a position requires this position must be placed on the building floor, the intersection between the unit and bottom triangles of the polyhedron need to be checked. The second part is mainly about the slope evaluation between the plane of unit-intersecting triangle and the horizontal plane. This operation insures that the accessible position must be placed on the slope that has an acceptable angle of inclination, and eliminate any vertical movement beyond the moving ability of normal people.

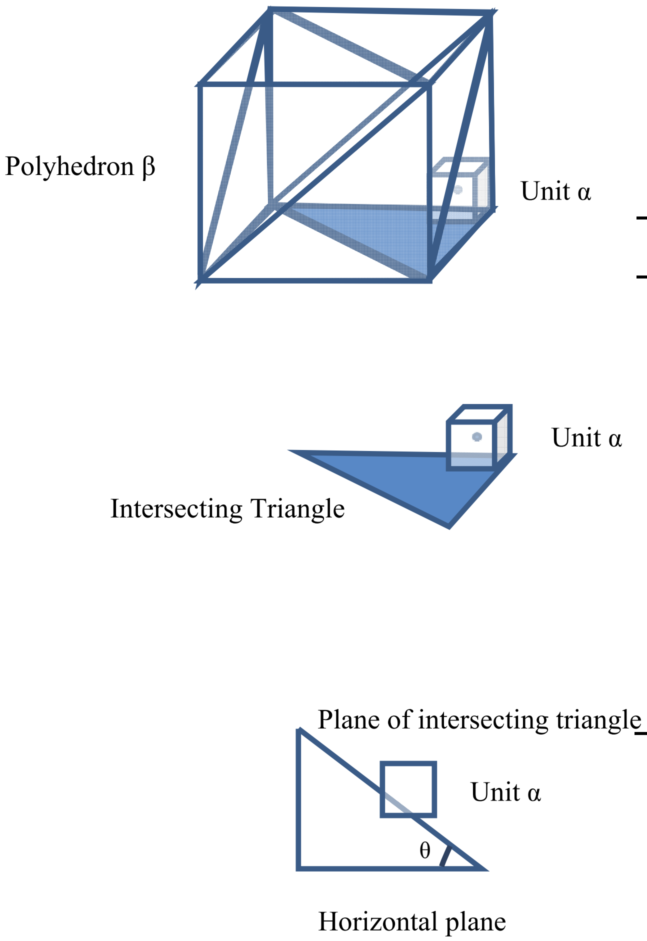

Figure 7. Accessibility evaluation of the unit belonged to the inner space of the building polyhedron

4. EXPERIMENT

The experiment area is the LaGuardia Airport in the City of New York. This area contains large groups of connected buildings, and as a public area it needs a proper evacuation plan under emergency situations. To provide the communication data for this simulation, we decide to generate the evacuation data from an existing Sketch-up file, and the skeleton of this file is shown in figure 8.

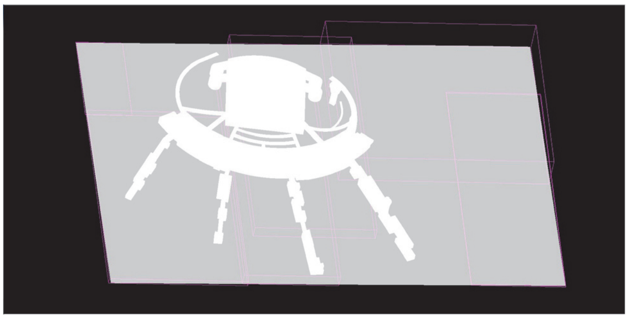

Figure 8. Polyhedron-inner side evaluation for point by using the triangle plane

After applying our extraction solution to the experiment area, we successfully generate a collection of accessible positions for the airport. To provide a general data view, the accessible position extraction result is shown in table 1. This table shows the building group is divided into 9 parts to finish the extraction task. The division of the whole area is expected to help accelerate the extraction analysis process. These building parts vary significantly both from size and direction. The largest part contains more than 16,000,000 units compared to the 7480 units in the smallest part. Furthermore, we provide the accessible data of part 3 in figure 9.

Building Part ID	Start and End Position	Communication Unit Number
1	38424-13015-3890,39241-15174-5700	7480
2	74617-912-469,83068-17688-537	57120
3	0-11091-557,17084-55753-801	611496
4	57648-17587-345,82880-56696-1506	2372490
5	41143-9565-422,58635-56346-2766	3931200
6	33414-450-500,55538-45225-2766	4763136
7	49955-607-394,77921-41954-2766	5557440
8	16442-15691-0,45491-56114-4642	11280696
9	546-0-375,38703-31697-6590	16111528

Table 1. The Extraction Result of the Experiment Area

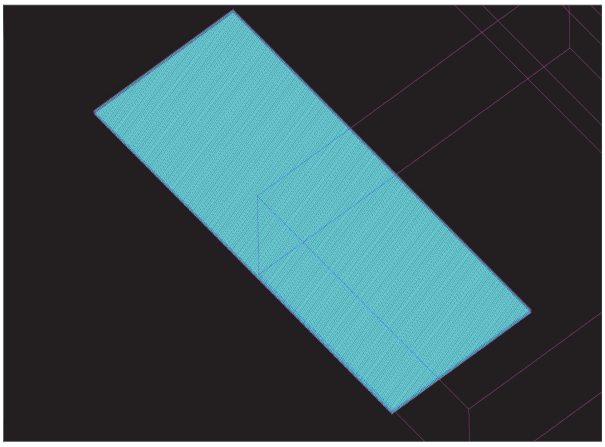

Figure 9. Extracted accessible positions in one region

There is one more thing that should draw attentions. The time cost of the proposed method is depressive, and it uses about 90 days to finish the extraction task. This long time period makes our solution not appropriate for some fast emergency response applications, and certainly we need to overcome this problem in the future work. We plan to use high frequency multi-core CPUs with multi-thread capability to finish this task. Since our current test platform only has a CPU with 2 cores and 4 threads capability, we could use two CPUs both with 8 cores and 16 threads to reduce the execution time to less than 10 days theoretically.

5. CONCLUSION

We have systematically formulated a semi-automatic solution of inner-building communication data extraction for emergency evacuation simulation. And this solution takes proper usage of spatial relationships and geometric features of artificial buildings. The experiment shows the solution is workable for large building group communication data extraction from existing 3D data files, i.e. in Sketch-up format.

Nevertheless, our solution could be greatly improved from two directions. First, although we have divided a complex building into several minor parts to relieve the computational burden for computers, the spatial dividing product of the buildings is not very good. Therefore, a better dividing evaluation system for complex buildings should be developed. Second, the proposed solution uses multithread method to finish the extraction task, but the parallel-computing concept is not implemented in the extraction operation in each building part. This results in a waste of multi-core CPU computing resources. In the next step, we should implement the multithread mechanism in the lower level extraction process such as building part level.

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