Automatic 3D Thermal Zones Creation for Building Energy Simulation of Existing Residential Buildings

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ABSTRACT

Existing buildings now represent the greatest opportunity to improve building energy performance. Building energy simulation is becoming increasingly important because the simulation results can assist the decision makers to quickly make the solution for improving building energy efficiency and reducing environmental impacts. However, most of the time there is no available as-is 3D building models for the existing buildings to conduct energy simulation. Nowadays, it is a common practice to obtain point clouds of existing buildings through using 3D laser scanning technologies for as-is building modeling. Current methods using point clouds need manual processes to prepare thermal zones based on point clouds data which is very time consuming and labor intensive. This paper introduces an automated thermal zone creation method to create both a building zone and room zones. A building thermal envelope was extracted from 3D point clouds. Then, 2D building floor plans were used as references to accurately determine the location and size of each thermal zone. A preliminary experiment has been conducted on a residential house to validate the proposed method, and the created building components and thermal zones were successfully imported into a building energy simulation program and ready for various energy analyses.

INTRODUCTION

Improving Energy efficiency has been a popular subject for the whole world since the energy crisis in the late 1970's (Maldague 2001). Buildings account for 16 percent of world energy consumption (EIA 2009), with a higher share in developed economies (nearly 42 percent of total energy use in the United States) (DOE 2010). Each year, roughly four percent of the building is newly constructed or renovated, thus the existing building stock will have the majority of opportunities to improve energy efficiency over the next several decades. Thus, existing buildings represent the greatest opportunity to improve building energy efficiency and reduce environmental impacts. The public and private building stocks are increasingly mandated to meet green standards by the federal government and jurisdictions across the country. The fact that people gradually consider saving energy and lowering greenhouse gas emissions as civil virtues boosts the private demand for green buildings (VENABLE LLP 2010).

Shareholders, employees and customers increasingly expect their corporations, employers, landlords, retailers and hotels to share their sustainability values. The U.S. Green Building Council's Leadership in Energy and Environmental Design Rating System (LEED™) requires energy modeling to assess the energy use of a building and to quantify the savings attributable to the proposed design. In many cases, architects and building owners are inexperienced with energy modeling and simulation and uncertain how to harness this powerful tool to inform the design and decision-making process. Properly used, energy modeling can help optimize the building design and allow the design team to prioritize investment in the strategies that will have the greatest effect on the building's energy use. Thermal zones with either graphic or non-graphic data are needed for people conducting energy modeling in the energy simulation software. Many energy simulation software tools have building geometry drawing functions or can import building information models (BIMs). However, the models are usually manually created within the simulation tools or BIM tools. This manual process could be time-consuming and costly. Further, it is a much more complex process to model as-built geometries of existing buildings. In this paper, a thermal zone creation method is introduced which automatically generates thermal zones for existing buildings using 3D point clouds data obtained from a laser scanner and 2D floor plan images of the buildings.

BACKGROUND

Thermal zone

A thermal zone, defined as a homogenous enclosed volume of air, will be a single room in most cases, assuming that the air within it is able to mix freely. The thermal zone can be applied for computer software simulation that begins with specified materials and systems for a building, calculates the annual energy cost, and creates a report of the anticipated energy performance of the building. The analysis will reveal how energy efficient the building can be, while there is still time to enhance it (Marsh 2006).

Manual thermal zone creation

Currently, many energy simulation software packages are available to be used on the market. Many of them need graphic building geometries to operate which may include walls, doors, windows, floors, ceilings, and roofs (Bazjanac 2009). Each element could be represented as an object, capable of representing its relationship with the walls in which it is placed. The building geometry could be easily obtained from a building information model (BIM) as an object-oriented parametric model. BIM has been widely applied in the design phase by the construction companies. It can be viewed in multiple views, as well as having other information related to the individual element. More importantly, abstract objects in BIMs, such as space and zone, can be defined by the relationships between physical building elements (Howell 2004). Although BIM contains rich

information about the building, not all of them are essential for most engineering analysis tools. Taking energy analysis tools as an example, only thermal view of the building is needed which is a simplistic representation of the building containing all the information about each room such as volume, geometry, and adjacency. With the help of the Green Building XML (gbXML) schema, Industry Foundation Classes (IFC), and IFCXML, BIM software can easily communicate with other energy analysis software programs. However, BIM is not available for most of the current old buildings. Even though some existing buildings may have BIM, it may not be up-to-date since the buildings keep being renovated. The preparation for a new BIM is usually labor-intensive, costly and time consuming. In addition, it is inevitable that different modelers could create different models even they are modeling the same building with the same software (Bazjanac 2009). Nowadays, the valuable laser scanning technology provides people the ability to acquire building spatial data in three dimensions with high fidelity and short processing time. The output of the laser scanning is as-is point clouds which are composed of millions of individual points in which each point has its 3D relative coordinate information. This can highly ease the measurement process of the geometry, however the as-is BIM has to be still manually created from the 3D point cloud data.

AUTOMATIC THERMAL ZONE CREATION

Thermal zones have two categories: building zone and room zone. Building zone includes exterior walls, exterior windows, exterior doors, and roofs. Each single room is defined as a room zone in this study. Rough energy performance analysis can be obtained through conducting simulation with the only building zone, however, more accurate results can be expected if simulating with the both categories of thermal zones.

Building zone

The building envelope is an important part of building when it comes to energy efficiency. It is a physical separator in which energy exchange with the environment can take place. The components of the building envelope include roof, walls, doors and windows. The dimensions and the positions of all these components are essential data in conducting energy analysis. In our previous study, an automatic building envelope recognition algorithm was developed to recognize all key building envelope components from the 3D point clouds. The developed recognition algorithm was tested on the point cloud of the residential house and achieved very positive preliminary results in which different building envelope components were recognized as individual objects and rendered in different colors as shown in Figure 1.
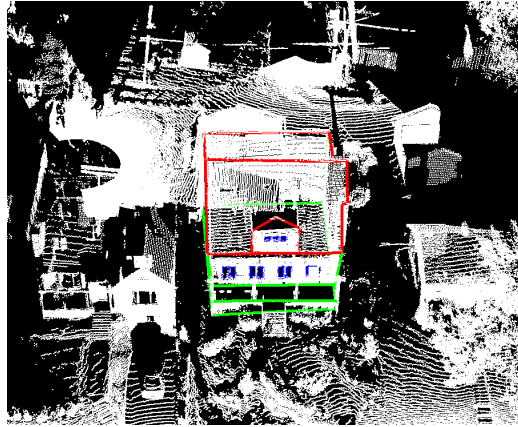
Figure 1. Residential house created from 3D point clouds

Room zones

Research have been done on creating indoor geometric models from point clouds collected by laser scanner or made from photogrammetry. However, both methods take a long time on data collection, which is a disturbance to people living in the building. In this paper, room zones are automatically created by processing 2D floor plans of the building. It is assumed that the building has available 2D floor plans so that more specific simulation results can be obtained, although a building zone alone can be used for broad energy simulation. Region growing algorithm (Gonzalez and Woods 2002), a region-based image segmentation method, was applied in this paper for the automatic room zone creation. Since it involves the selection of initial seed points, the region growing algorithm is also categorized as a pixel-based image segmentation method which examines neighboring pixels of initial seed points and determines whether the pixel neighbors should be added to the region. In the same way the process is

```
for each pixel
   if color == white
      if all eight neighbor points' color == white
         create a random color;
         pixel color = random color;
      else if neighbor point's color != black
         pixel color = neighbor point's color;
      end
   end
end
```

Figure 2. Room zone creation algorithm

iterated on as a general data clustering. Figure 2 shows the pseudo code of this algorithm. In this study, it is assumed that the background of the floor plan image is white, and the color of the lines is black. As illustrated in Figure 2, the

algorithm traverses all the pixels in the image. For each pixel, if its color and all its eight neighbor points' color are all white, then a random color is assigned to this pixel. If this pixel's color is not white, the algorithm doesn't do anything and moves to the next pixel. If this pixel's color is white, while at least one of its eight neighbor points' color is neither white nor black, then its color is assigned as its neighbor point's color. Through iterating all the pixels of the floor plan image, different room zones can be recognized in 2D floor plan image.

Zones integration and format conversion

In the previous sections, a building zone and room zones are separately created. A building zone is created based on as-built point clouds so that all the dimensions of the building zone can be directly employed. As for the room zones, they are created based on 2D floor plan images so that the size is not the actual size. Thus, one more step needs to be done to scale the room zones to the actual size so that they can integrate with the building zone in 1:1 scale. In this paper, a first floor plan image was mainly used to calculate the scale value. The elevation of the first floor was assumed to be equal to the elevation of the front door. Then the scale value can be calculated through automatically matching the front windows in between first floor plan image and building zone. Once the scale value is calculated, it will be applied to the other floor plan images. The ceiling height of each story is assumed as 8 feet, so the second floor will be 8 feet above the first floor and the basement floor will be 8 feet below the first floor.
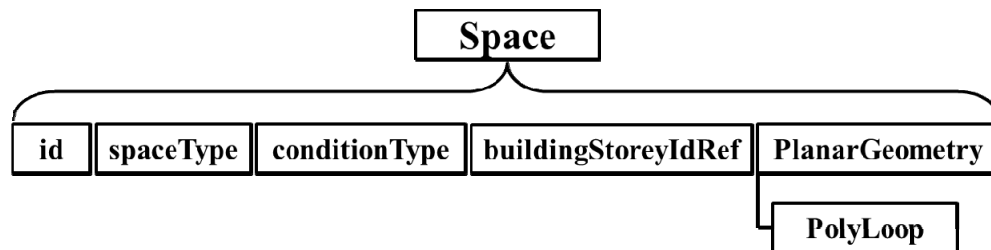
Space

id	spaceType	conditionType	buildingStoreyIdRef	PlanarGeometry

PolyLoop

Figure 3. Structure of element "Space" in gbXML schema

Now, all the dimensions and locations of building zone and room zones have been decided. The last step is to save all the data in one format which can be imported into the energy simulation tools. The created thermal zones were originally saved as a text file (*. txt) which includes all the zone information. To be useful for energy simulation, the file has to be converted to another file format that can be imported. In the proposed method, the Green Building XML (gbXML) open schema was chosen to help facilitate the transfer of the thermal zone to engineering analysis tools.

Figure 3 is a structure of element "Space" in gbXML schema (Version 5.0.1). Each space element requires a unique ID, space type, and geometry. "spaceType" represents how a space is used, such as restrooms, bedroom, living room, and etc. "conditionType" represents the heating and cooling conditions of

the corresponding zone. "buildingStoreyIdRef" shows the ID of the floor where this zone is on. "PlannarGeometry" lists all vertexes of the surface to define a 3D space. Attribute "Opening" will be needed if there is any opening in the surface.

EXPERIMENT AND RESULTS

A preliminary test on a residential house (Figure 5 (a)) was conducted to verify the proposed thermal zone creation method. 3D point clouds and 2D floor plans were processed by the proposed algorithms. As shown in Figure 4, floor plans of the basement, first floor, and second floor respectively, and 2D room zones were successfully recognized from the corresponding floor plan images. Different room zones were rendered in different colors, and eight room zones were recognized in a basement plan image as well as eight in first floor plan image, and ten in the second floor plan image. In this paper, the room zones were filtered based on the numbers of the pixels to eliminate some wrong recognition, for example, door area, and balcony. A threshold value was set up as 100 pixels, and any zone less than 100 pixels was eliminated.

Once a building zone and room zones were prepared, the integration was to be conducted to calculate the scale ratio between the building zone and the room zones. The scale factor obtained in this experiment was 15, which means the actual size room zones should be fifteen times as big as the ones recognized in 2D floor plan images. At last, all the thermal zones were saved following the gbXML schema. As shown in Figure 5, the thermal zones were successfully imported into a commercial energy simulation software and ready for energy performance analysis.

CONCLUSIONS

This paper introduced a method of automatic thermal zone creation for building energy simulation of existing buildings. To rapidly and accurately obtain the 3D thermal zone geometry, 3D as-is point clouds and 2D floor plans were employed to create a building zone and room zones. After converting thermal zone data format into gbXML, it was imported into energy analysis software to conduct building performance analysis. The technical feasibility of the proposed method was successfully demonstrated through a preliminary experiment with a residential house.

In our future study, we will continue to improve the accuracy of the thermal zone. Quantitative comparison between automatically created thermal zones and manually created thermal zones from as-built BIM will also be conducted in the future work.

Basement

First floor

Second floor
Figure 4. Original floor plan image (left) Room zone segmented floor plan image (right)

(a)   (b)

(c)   (d)

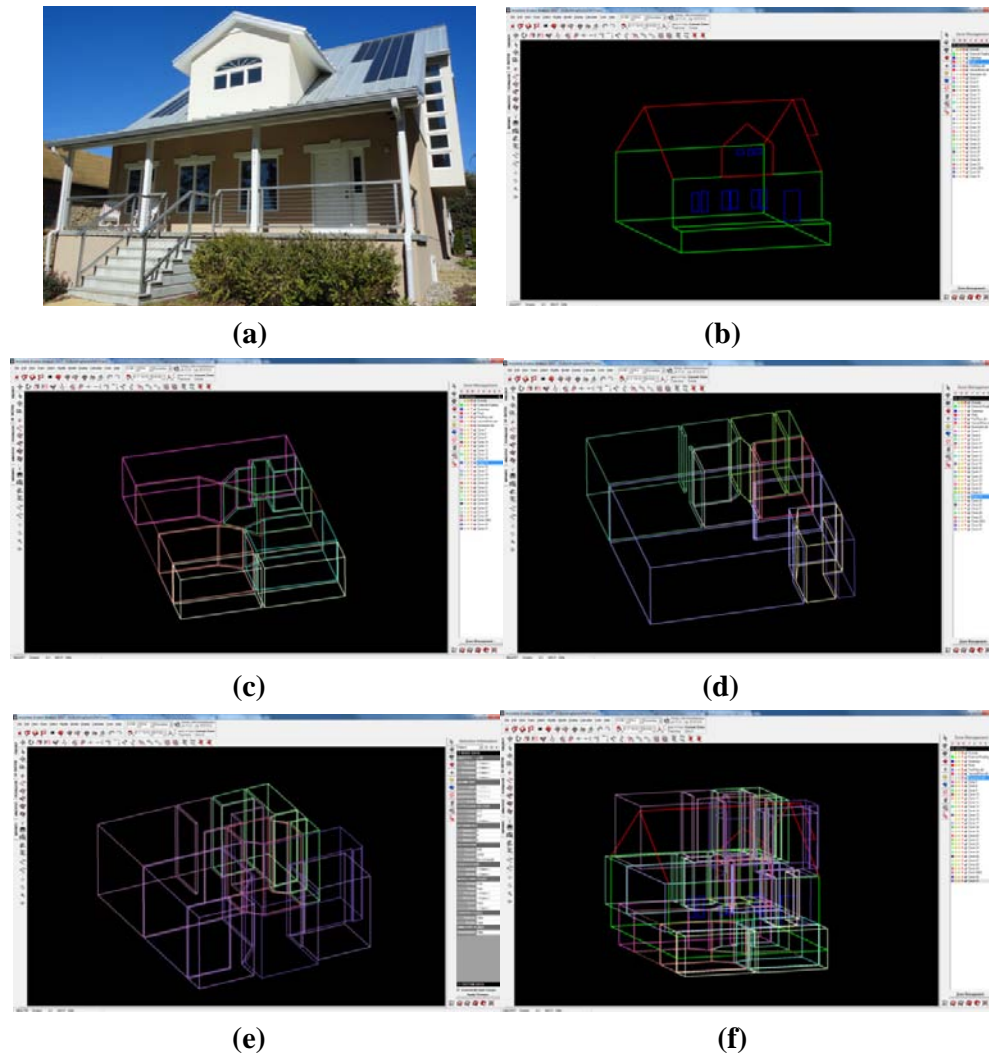(e)   (f)

Figure 5. (a) Existing residential house (b) Created building zone (c) Room zones in the basement (d) Room zones in first floor (e) Room zones in second floor (f) Building and thermal zones integration in an energy simulation program

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