AS–BUILT RESIDENTIAL BUILDING INFORMATION COLLECTION AND MODELING METHODS FOR ENERGY ANALYSIS

Chao Wang*, Yuye Peng, Yong Cho, and Haorong Li

The Charles W. Durham School of Architectural Engineering and Construction,
** Corresponding author (cwang@huskers.unl.edu)*

ABSTRACT: Existing buildings represent the greatest opportunity to improve building energy efficiency and reduce environmental impacts. However, millions of decision makers of the buildings usually lack sufficient information or tools for measuring their building's energy performance. The goal of this project is to develop and evaluate rapid low-cost measurement and modeling approaches that will allow "virtual" representations for the energy and environmental performance of existing houses to be created for retrofit decision-support tools for the decision makers. To conduct an energy analysis or simulation, obtaining accurate geometric information of the house is critical. As an on-going research project, a digital image processing technique has been developed to extract digitized and vectorized house information with a high confidence and accuracy level (95%) from floor plan images available in a large local online database containing more than 150,000 houses. In addition, the elevation-view images of several houses have been tested to extract vertical view information. The algorithm can correctly recognize and extract basic geometric information of house envelops required for the energy analysis including windows, doors, walls, and a roof.

Keywords: *Image Processing, Energy, Residential Building, 3D Modeling, Object Recognition*

1. INTRODUCTION

The importance of analyzing energy performance for buildings is growing since energy efficiency is a significant issue for the whole world [1]. The decision makers of the buildings need to have the information of energy analysis to reduce environmental impacts and make full use of the energy. Therefore how to analyze energy performance of building has been widely discussed. For decades, energy simulation software tools have been utilized to assist in energy analysis [2]. Geometric models are essential for energy analysis as an input to energy simulation software. These days, many BIM models for new buildings are generated at the design stage [3]. Most of the specific information of building elements needed in energy simulation is described in the BIM models. By utilizing BIM as a data source for energy analysis, the data input will be more efficient and the existing data will be more reusable [4]. As shown in Fig. 1, a simplified geometric model including information of zones and openings of the house can be generated from most of the current BIM software packages.

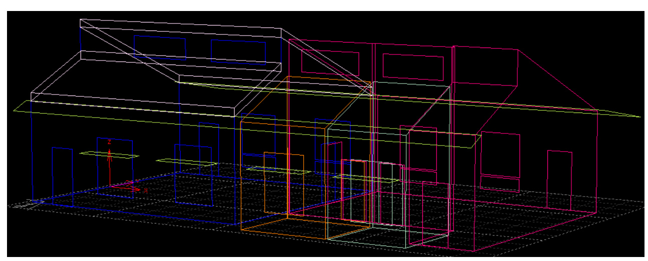


Fig. 1 3D geometry model for energy analysis generated from BIM software

Compared to commercial buildings, most existing or even new residential houses do not have BIM models. All geometries should be measured by a certain means to generate an as-built design, which may leads to high cost and long data collection time. Therefore, the main objective of this research is to develop a low cost and fast geometry measurement technology to extract important features for energy analysis. With the development of image processing, it becomes possible to obtain geometry information through normal RGB images. In this research, we collected different building information through multiple images of the house. The developed algorithms of floor plan frame extraction and vertical view information extraction are introduced in the following sections.

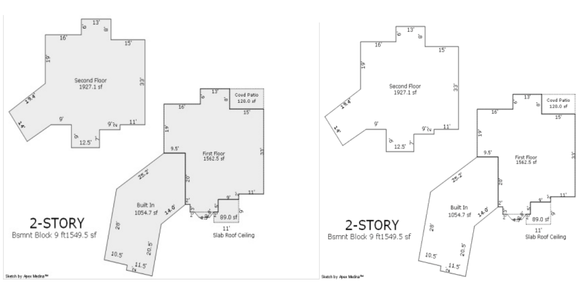
2. FLOOR PLAN FRAME EXTRACTION

A floor plan, from which geometry information can be obtained, is an important document for buildings and houses. All the floor plan images tested in this research can be easily accessed from public online databases where the floor plan images are made by being scanned from hard copies into JPG or PDF files. Sections 2.1 and 2.2 describe how the floor plan images are processed to extract useful geometric information.

2.1 Feature Extraction

For some scanned floor plan images, the floor area has a background color. It is necessary to delete the background color before processing the floor plan image.

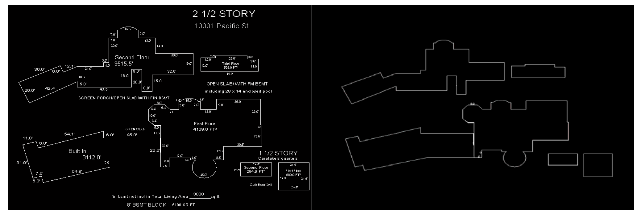
As a first step, the occurrences of each pixel value are recorded. If the count of the second most occurred pixel value exceeds 50000, this pixel value is assumed as the value of the background color. Those pixels with a background color pixel value are changed to the value of the most occurred pixel value to eliminate the background color. As shown in Fig. 2 (b), the background color is eliminated in the revised image.



(a) (b)

Fig. 2 (a) Original image; (b) revised image

Most of the floor plans generally contain texts and symbols in the images. Such noisey information also affects our floor plan recognition. In the developed algorithm, a small isolated pixel group will be eliminated if the amount of pixels in the group is less than 100. As shown in Fig. 3 (b), all the texts and symbols are deleted.



(a) (b)

Fig.3 (a) Original Image; (b) revised image

2.2 Feature Classification

With the new floor plan after feature extraction, floor plan's feature classification, recognition and vectorization will be realized. The understanding of floor plans is composed with mainly three kinds of pattern recognition including straight line recognition, slashed line recognition and curved recognition. All lines' necessary information is extracted after these pattern recognitions are processed. Then the recognized line information will be used for a 3D modeling process later. Rate of change (slope) is the major criteria for differentiating these lines.

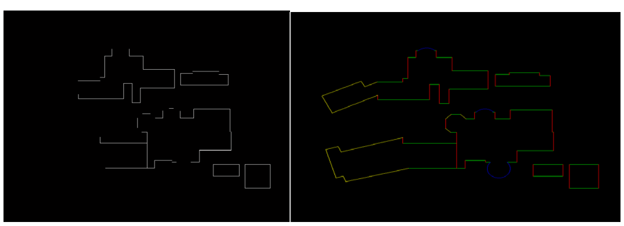
2.2.1 Straight Line Segmentation

Based on the knowledge that each pixel of a horizontal line exists on the same row, the image can be scanned horizontally, and only those line segments with no less than 4 pixels are kept. After all rows are scanned, the position of each line's end points is recorded. The vertical lines are recognized in the same method replacing rows with columns. In Fig. 4 (a), all the horizontal and vertical lines are recognized.

2.2.1 Slashed and Curved Line Segmentation

This phase is aimed at recognizing slashed lines and curves that contribute to the closure of floor plan frames. First, all the recognized horizontal and vertical lines are deleted from floor plan frames. The pixels left in the image are selected as slashed lines or curved lines if the end points of these line segments match with endpoints of horizontal and vertical line segments. The openings can be located by determining whether they have overlapping ending points or not. No overlap defines the openings.

All the edge points are linked together into lists of coordinate pairs, and the change of slopes on each pixel group is calculated. If the rate of slope change is very fast, and the difference between two adjacent slops is relatively small, it will be recognized as a curved line segment; otherwise it is a slashed line segments. Finally, all coordinate pairs are checked to close up any tiny openings if they exist. As shown in Fig. 4 (b), slashed lines and curved lines are correctly recognized and are rendered by different colors.



(a) (b)

Fig.4 (a) All recognized horizontal and vertical line segments; (b) Different kinds of the line segments marked by color

3. VERTICAL VIEW INFORMATION EXTRACTION

3.1 Window Detection

Window detection is an essential process for building thermal modeling in order to do the energy analysis. The position and size of the windows can be calculated with recognition of windows. Recognizing the windows from the RGB images is an issue to be solved.

To solve this problem, Hue, Saturation, and Value (HSV) color space was utilized in our algorithm. In HSV color space, different materials of different brightness in the image have different color, and this characteristic can be used to distinguish windows [5]. According to brightness in HSV images, main wall area tends to be blue, while windows and other areas tend to be red/green, as shown in Fig. 5 (b). Because of the reflection of the glass and other smooth interface, the saturation of windows is always very low. Therefore, for windows, HSV will have (high, low, low) value, and the color tends to be red. The main wall is brighter, so it has larger value in HSV (low, low, high) and tends to be blue. Under some circumstances, the color of the wall is green if it is not bright enough.

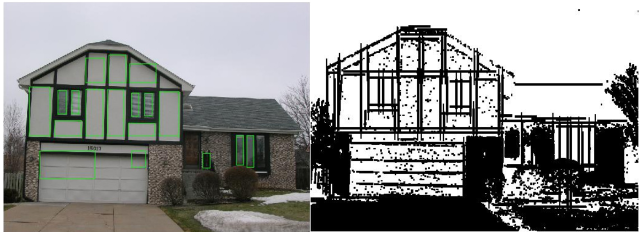
(a) (b)

Fig. 5 (a) RGB image; (b) HSV image

In the developed algorithm, the RGB images needed to be transformed to HSV color space first. Then based on empirical values of HSV for windows obtained through our tests, it is recognized as a window if the following is satisfied,

$$H>0.2,\ S<0.4,\ V<0.4$$

After filtering through HSV segmentation, some parts of image might be recognized as windows by mistake. To assist with HSV segmentation, RGB color segmentation was also added into the developed algorithm. The output of RGB color segmentation is a black and white image, as shown in Fig. 6 (b), in which real windows are always a purely white area, while fake windows tend to have many noise points inside because of the different color segmentation characters in different materials (wall surface and glass). As shown in Fig. 6 (a), eighteen areas are detected as windows. By utilizing RGB color segmentation, the wrongly detected windows can be successfully deleted if there is any dark point in the window panel area. It can be seen in Fig. 6 (c) that twelve wrongly detected windows among eighteen detected widows are deleted, and the rest are recognized as the real windows.



(a) (b)

(c)

Fig. 6 (a) Windows detection without RGB color segmentation; (b) RGB color segmentation; (c) windows detection with RGB color segmentation

It is inevitable that some objects in the image can have a bad impact on the window recognition. The most common problem is that the window area is separated by something in front of it or behind it. Vertical or horizontal blinds in big windows can split the window into small strips and cannot be detected correctly through the developed algorithm. After doing image segmentation, the blinds leaf is shown as lines in the white area. To find out whether the lines are strips caused by blinds or are actual window borders, the neighborhood around the lines is checked. If the line is among the white area, it is blinds. Otherwise it is the boundary of the window. In Fig. 7 (a), the left window is wrongly recognized because there are blinds behind the window. Several lines are created after color segmentation which results in an erroneous window detection as shown in Fig. 7 (c). After using the developed algorithm described above, the lines in the window area are eliminated. Then the window can be correctly recognized. As shown in Fig. 7 (d), six windows are correctly recognized.

According to the boundaries of the windows detected by the algorithm, the bounding boxes are added into the RGB image to be defined as window areas. In this research, about 90 images of different houses were tested; Fig. 8 shows four examples of windows detection, in which there are several different shapes of windows, such as rectangular, fan-shape, and elliptical. As shown in Fig. 8, most of the windows are successfully recognized from the images.

(a) (b)

(c) (d)

Fig. 7 (a) Wrong window detection; (b) color segmentation; (c) improved color segmentation; (d) improved results with correct window detection

(a) (b)

(c) (d)

Fig. 8 Different shapes of windows being recognized

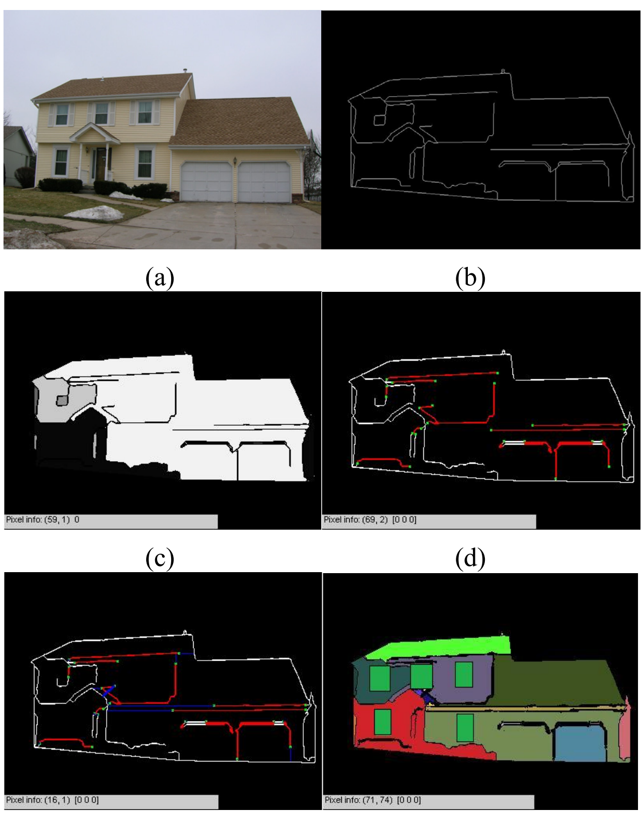
3.2 House Surface Layout Detection

In this section, the objective is to extract the vertical view information from the elevation-view images.

In Section 2.2, our edge detection algorithm is utilized to get the edge map of the image as well as delete the lines outside of the border of the house, as shown in Fig. 9 (b). Secondly, all closed areas are allocated with a different color, and all open lines merged in the same color are highlighted, as shown in Fig. 9 (c) and (d).

The highlighted lines are then extended in different ways. If the highlighted line is a horizontal or vertical line, it will be extended if the filter threshold can be satisfied. If it is a sliding highlighted line, the line will merge to the closest un-highlighted line. Due to the extension of the highlighted lines, more closed areas will be created. Then the algorithm loops back to the beginning to look for open lines and extend them.

Lastly, black gaps, useless lines, and color bands are removed to obtain a better result. Integrating the window information obtained from Section 3.1, the preliminary vertical house layout is obtained, as shown in Fig. 9 (h).



(a) (b) (c) (d) (e) (f)

(g) (h)

Fig. 9 (a) Original image; (b) edge map; (c) merged image colored in gray; (d) highlight lines and end points; (e) lines extension; (f) color result; (g) color result after cleaning black gap and useless lines; (h) color result after removing color band

4. METHODS FOR AS-BUILT BUILDING INFORMATION COLLECTION AND MODELING

Fig. 10 is a flow chart to show how the as-built building information can be collected and modeled through our proposed method. As shown in Fig. 10, floor plan image and elevation-view images can be downloaded from public online database. The floor plan frame is extracted from the original floor plan image after being processed by the algorithm proposed in section 2. Multiple elevation-view images are needed in this research, for example, as shown in Fig. 10, two images are front view and east side view of the house. For each side view of the image, it is processed by the algorithm proposed in section 3. All the information of house surface layout and openings is obtained after processing multiple images. To build a 3D geometry model through images, image registration algorithm should be utilized. As a similar technique, Mani Golparvar-Fard [6] has proposed a method showing the feasibility to create a 3D as-built model with multiple images.

Then the floor plan frame is scaled to fit with the 3D model. In addition, different zones can be created with help of the floor plan frame. The final objective is to make the 3D geometry model ready to be imported into the simulation software for energy analysis in IFC (Industry Foundation Classes) or gbxml (Green Building XML Schema) format.

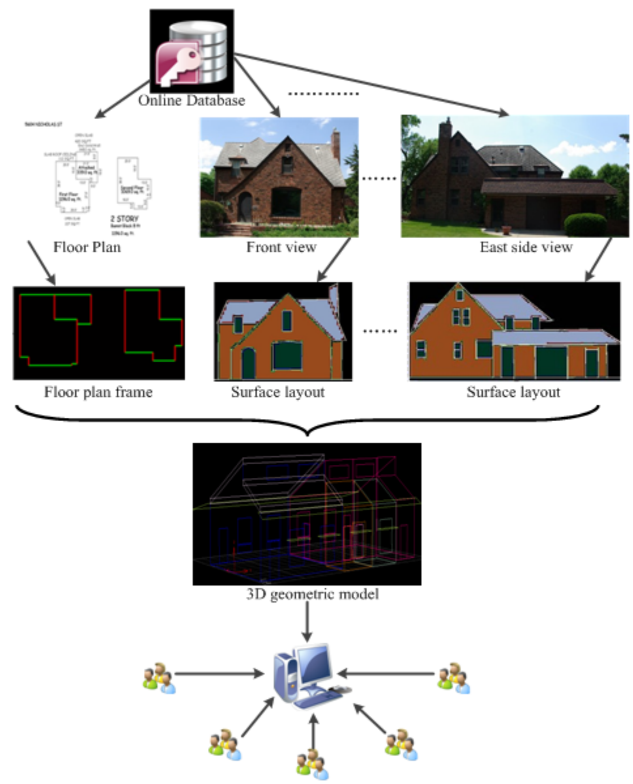


Fig. 10 Methods for as-built building information collection and modeling for energy analysis users

5. CONCLUSION AND FUTURE STUDY

In this paper, digital image processing techniques are utilized to extract house information from the images of houses. The developed floor plan frame recognition algorithm and vertical view information extraction algorithm are discussed. Through these two developed algorithms, the elevation view and vertical view information can both be obtained rapidly. About 90 house images were processed in our test with the developed algorithms with a 95% success rate. We show the feasibility to create "virtual" representations for the energy and environmental performance of existing buildings.

In future research, 3D registration algorithm will be developed to create 3D geometry model using multiple images. Zone creation algorithm will also be developed to separate different space of the house based on the floor plan frame. Finally the further developed algorithm will be able to create a 3D model ready for energy analysis. If successful, for the proposed method will significantly reduce data collection time and cost for the building energy analysis process. In the long run, this research expects to stimulate home owners to improve their buildings by providing reliable and visualized information of their building's energy performance, thus benefits to the economy, society, and environment.

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