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Performance Evaluation of Automatically Generated BIM from Laser Scanner Data for Sustainability Analyses

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Abstract

Existing buildings now represent the greatest opportunity to improve building energy efficiency. Building performance analysis is becoming increasingly important because decision makers can have a better visualization of their building's performance and quickly make the solution for improving building energy efficiency and reducing environmental impacts. Nowadays, building information models (BIMs) have been widely created during the design phase of new buildings, and it can be easily imported to third party software to conduct various analyses. However, a BIM is not always available for all existing buildings. Even if a BIM is available during the design and construction phases, it is very challenging to keep updating it while a building is aged. A manual process to create or update a BIM is very time consuming and labor intensive. A laser scanning technology has been a popular tool to create as-is BIM. However it still needs labor-intensive manual processes to create a BIM out of point clouds. This paper introduces automatic as-is simplified BIM creation from point clouds for energy simulations. A framework of decision support system that can assist decision makers on retrofits for existing buildings is introduced as well. A case study on a residential house was tested in this study to validate the proposed framework, and the technical feasibility of the developed system was positively demonstrated.

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Keywords: Laser scanning; Energy efficiency; As-is BIM; Decision support;

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1. Introduction

Buildings account for about 42% of the primary energy usage – and 71% of the electricity usage – in the United States [1, 2], yet they receive much less public attention than fuel economy and new technologies for automobiles or alternative sources and distribution systems for power generation. President Obama launched the Better Building Challenge which asks leading organizations to commit to reducing the energy use of their buildings by 20% by 2020. In the United States, the majority of the energy usage is consumed by building sector [1-3], in which the existing residential buildings (more than 120 million buildings or more than 95% of the total number of buildings [U.S. DOC 2012] in the U.S.) comprise the single largest contributor to U.S. energy consumption and greenhouse gas emissions (more than 50%). Exacerbating these problems is the fact that the average age of residential buildings is over 50 years, with about 85% built before 2000 [1]. The U.S. Department of Energy's Build America Program [4] set a goal of reducing the average energy use in housing by 40% to 70%. Consequently, existing buildings represent the greatest opportunity to improve building energy efficiency and reduce environmental impacts.

For residential buildings, the thermal envelope components are typically designed as standard-satisfied. However, from the life-cycle viewpoint, the thermal performance during the installation, maintenance and operation phases will usually differ from during the design phase. The main reasons include the installation deviation, thermal bridge, and the insulation aging, etc. A home energy audit can help home owners determine where their houses is losing energy and money, and how much problem can be corrected to make their home more energy efficient. Traditional energy audit, also called on-site energy audit, is usually conducted by a trained energy engineer physically walking through the building to determine energy consuming characteristics and opportunities. A detailed traditional energy audit often involve advanced on-site measurements and computer-based simulation tools to calculate a more accurate energy cost for one year, and create a report of the anticipated energy performance of the building. Over the last few years, virtual energy audit has been increasingly used to find out whether or not a building is operating efficiently. Unlike traditional energy audit, virtual energy audit requires no contact with the building itself or its owner. It collects meter data, weather information, information about similar buildings, and other publicly available information and analysis them through algorithms.

Virtual energy audit can help energy service professionals quickly find the best targets, while it is not as detailed as a traditional energy audit. On the other hand, to conduct an ASHRAE Level II detailed energy audit, plenty of data need to be collected on site by auditors. Data of some existing residential buildings can be provided by owners or designers, but may be incorrect due to building's constant renovation, and insulation aging, and home owner's lack of technical knowledge. Among all the required data, collecting as-is building geometry and as-is thermal resistance value of the envelope components is a labor-intensive, costly, and slow process. In addition, different modelers inevitably create different simulation models even when they are modeling the same building using the same modeling tool because modeling of thermal views of buildings and the corresponding definition of data needed in the simulation is often arbitrary in practice [5].

The main objective of this paper is to investigate a non-invasive 3D thermal modeling methodology of automatically creating as-built BIM model of existing residential buildings for building energy simulation. Following sections will firstly review the existing approaches, then discuss the proposed method and preliminary experiment results, and finally present conclusion and future work.

2. Related Studies

To recognize objects and extract useful object information from point clouds, object recognition techniques have frequently been applied in recent studies in the AEC/FM domain. Tang et al. introduced a method of extracting geometric information items of bridges from point cloud data, collected from a laser scanner, for bridge management [6, 7]. Site laser scans have also been processed for 3D status visualization and construction progress monitoring [18-20]. In [8, 9], a new approach for automatic 3D CAD recognition and registration of steel structures was validated by processing the point cloud data of the steel structures. Advanced techniques and improvements in devices have resulted in textured point cloud data becoming available. Son and Kim [10] proposed a method for efficient, automated 3D structural component recognition and modeling from point cloud data with RGB color acquired from a stereo vision system. Point cloud data with RGB color can also be obtained by processing hundreds of photographs [11] for construction performance monitoring and 4D as-is model creation.

Another set of approaches presented to assist building facility management and performance analysis include the proposal by Pu and Vosselman [12]. They proposed a knowledge based method for reconstructing building models from laser scanner data. In their method, they extract the features and the outline of the building and make the geometric model of the building based on several assumptions because only facades on the street side are scanned. Xiong et al. [13] proposed a context-based modeling algorithm for creating semantic 3D as-is building models of the interior of buildings. Their context-based modeling algorithm was able to identify and model the main visible structural components of an indoor environment, but could not recognize components with irregular shapes that are frequently seen from the exterior of the building envelope. In current literature, the generated as-is model can extract object-based geometry models from the point cloud data, however, the thermal information is missing in these models, and the thermal value of each components of the building envelope are essential for building performance analysis. As a result, rapid and efficient creation of a building envelope model possessing both geometric and thermal data is a challenging emerging topic.

3. System Framework

3.1. System Architecture

The overall framework of the proposed framework is shown in Fig. 1. First, a hybrid 3D LIDAR system developed in this study simultaneously collects point clouds and temperature data from the envelope of existing buildings. Temperature data are automatically fused with corresponding points during the data collection process. After registering all individual thermal point clouds, a building envelope recognition algorithm will be applied to automatically create an as-is BIM. The as-is BIM can be imported into energy analysis software through being saved as an industry standard file format. Finally, the energy simulation results can provide the retrofit decision makers more information to assist them on their decision making process.

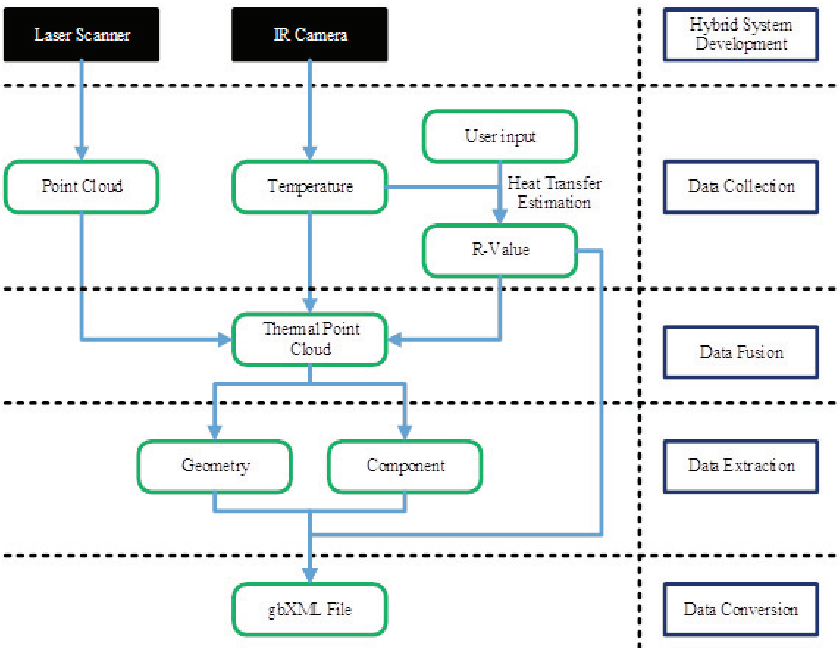

Fig. 1. Framework of the proposed framework.

3.2. System Hardware

In this paper, an innovative robotic hybrid system was developed, integrating two 2D laser scanner and an IR camera (320 x 240 pixels), as shown in Fig. 2. The 2D laser scanners can measure the distance between an object and itself through emitting and receiving the laser lights. After it was mounted on a pan and tilt unit (PTU), the 3D LIDAR system was able to scan 3D features. This 3D LIDAR allowed us to have more flexibility in hardware control and software programming than a commercial LIDAR scanner. Based on the current mounting configuration, multiple degree-of-freedom (DOF) kinematics was solved to obtain x-y-z coordinates from the LIDAR, and corresponding temperature data were obtained from the IR camera.

A graphical user interface (GUI) was developed using Visual C++. The GUI controls the LIDAR scanner and the IR camera, and visualizes the captured 3D model.

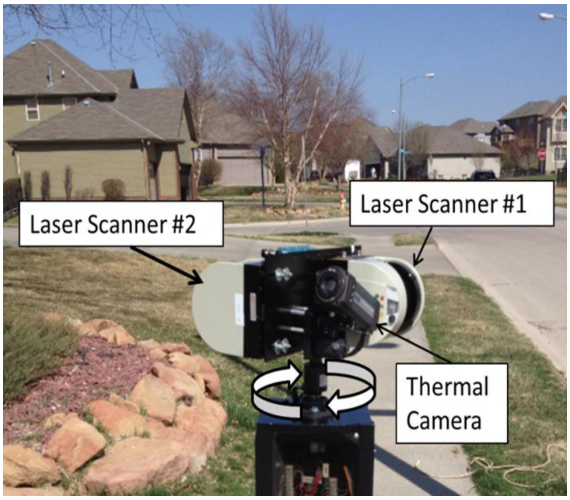

Fig. 2. System Hardware

4. System Processing Procedure

In this section, the systemprocessing procedure is illustrated by a case study on a residential house.

4.1. Data Collection

Building geometry and temperature data of the building envelope need to be collected from the building. As the result of the 3D scanning process, a set of points in a 3D coordinate system is created. These points are defined by X, Y, and Z coordinates which are representative of the external surface of an object. The developed LIDAR system can provide up to 200K points per second from a scene with 8mm accuracy at a 15m distance [14]. One snapshot of the IR camera produces a matrix (320 x 240) where each element contains a temperature value of the corresponding pixel of the IR image which is created. As shown in Fig. 3, point clouds of a residential house were visualized in the developed GUI.

Fig. 3. Point clouds of residential house.

4.2. Data Fusion

The data fusion process is similar to texture mapping, a method for adding images as texture to the surfaces of the 3D models. The main difference in the proposed data fusion process is that the temperature data from each IR image pixel – instead of RGB pixel values – are directly extracted and assigned to points as non-graphic values [15, 16]. Thus, each point is considered as an object containing different types of data, such as x-y-z coordinates, intensity, temperature, RGB, etc.

Through the data fusion process, all the collected temperature data were mapped to the corresponding points. The point cloud was colored according to temperature value where red represents the higher temperature and blue stands for lower temperature. In the developed GUI, a simple mouse click on a point shows all information containing in it. For example, in Fig. 4, the X, Y, and Z coordination of the selected point is (-17485.301, 5695.268, 21654.367), and the temperature of this point is 24.084℃. The color coded thermal information along with the text data would be useful indicators to identify heat loss or gain areas in the building envelop, which can be further considered for improvement in the retrofit process.

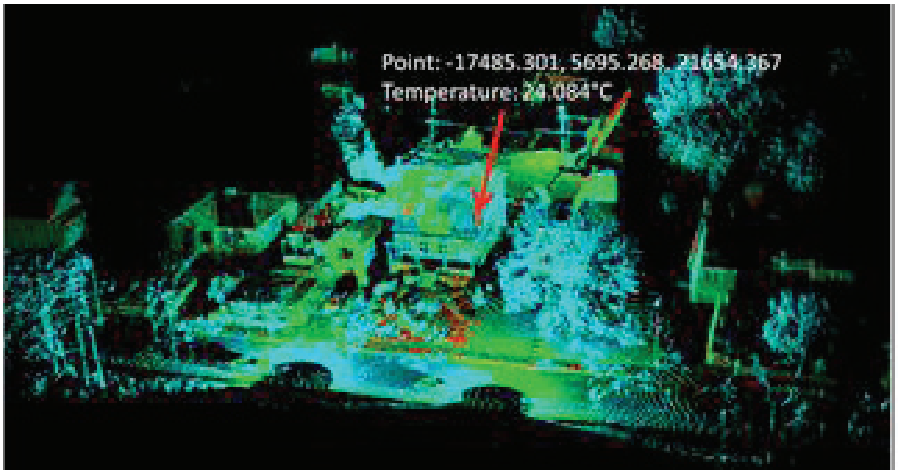

Fig. 4. Point clouds with temperature fused.

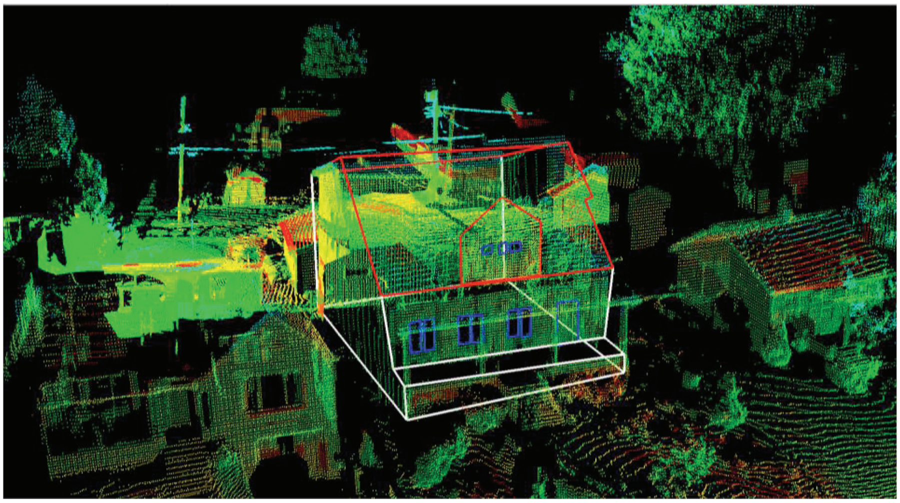

Fig. 5. As-is BIM created from thermal point cloud.

4.3. Data Fusion

4.3.1. As-is BIM Creation

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 the proposed system, an automated building envelope recognition algorithm was developed to recognize all key building envelope components from the 3D point clouds [17]. In Fig. 5, 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.

4.3.2. Format Conversion

The created as-is BIM was originally saved as a text file (*.txt) which includes all the recognized geometry information. To be useful for energy simulation, the file has to be converted to another file format that can be imported. In the proposed system, the Green Building XML (gbXML) open schema was chosen to help facilitate the transfer of building properties stored in as-is BIM to engineering analysis tools. Today, gbXML is supported by most of the 3D BIM modeling tools.

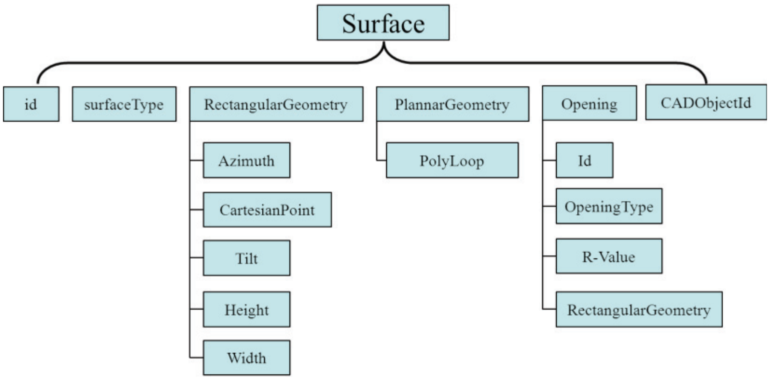

Fig. 6. Structure of element "Surface".

Fig. 6 is a structure chart of element "Surface" in gbXML schema (Version 5.0.1). This element was used to interpret the created as-is BIM. Each surface requires a unique ID, surface type, and geometry. Surface type includes interior wall, exterior wall, roof, ceiling, and etc. In this paper, exterior wall and roof were assigned to corresponding surface. RectangularGeometry specifies the location of the surface, and PlannarGeometry lists all vertexes of the surface to define a loop. Attribute "Opening" will be needed if there is any opening in the surface.

4.3.3. Building Performance Analysis

Once a gbXML file is created, it can be opened in energy analysis tool as shown in Fig. 7. Three thermal zones were visualized in the software with different color. With this created as-is BIM, many analysis can be conducted. Fig. 8 shows hourly and annual shade analysis based on the weather data in Omaha, NE. Through sun path simulation, decision makers can have better decisions on redesign of the passive features which may include the roof overhang, window size and location, or the orientation of the building. This will allow the winter's warming rays, but exclude the summer sun's direct radiation.

Fig. 9 and 10 show an hourly temperature graph and an annual temperature distribution graph for all visible zones respectively. Combining these simulated results with the visualized thermal data of building envelop will allow decision makers to better identify the problem areas such as heat loss/gain, and choose better products and retrofit designs to improve the current state of energy performance of their buildings.

5. Conclusions

This paper introduces a framework of decision support system on energy retrofit for existing buildings. To rapidly and accurately measure the 3D geometry with thermal data of a building envelope, a hybrid 3D LIDAR scanner was developed. An IR camera was integrated into the 3D LIDAR system to measure the temperature of the building surface. Multiple degrees of freedom (DOF) kinematics were solved to integrate the two units to obtain x-y-z coordinates and corresponding temperature data for each point. A GUI was developed to control the hardware units (LIDAR, stepper motor, and IR camera) for data collection and to edit and visualize 3D thermal point clouds. As-is BIM can be automatically created through recognizing all the components of the building envelope. After converting file format into gbXML, the as-is BIM can be imported into energy analysis software to conduct building performance analysis.

The technical feasibility of the developed system has been successfully demonstrated through a case study with a residential house. In our on-going research, we will continue to improve the current hybrid prototype and develop more complete forms of information, such as recognizing more semantic object classes from point clouds in addition to windows (e.g., doors, walls, and roof), and determining energy usage status from an economic standpoint. These are expected to help decision makers to improve their buildings by providing more reliable, visual information about their building's energy performance, thus benefiting the economy, society, and the environment.

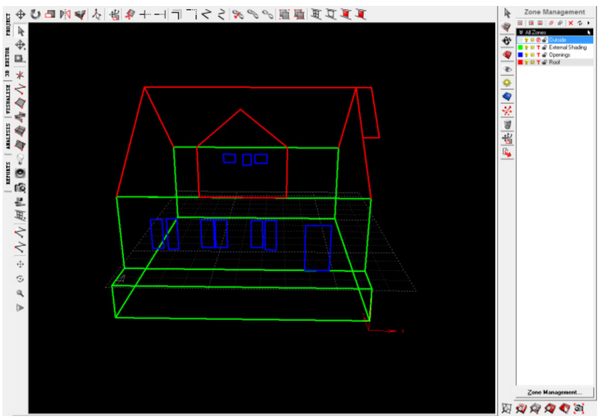

Fig. 7. As-is BIM imported into energy analysis software.

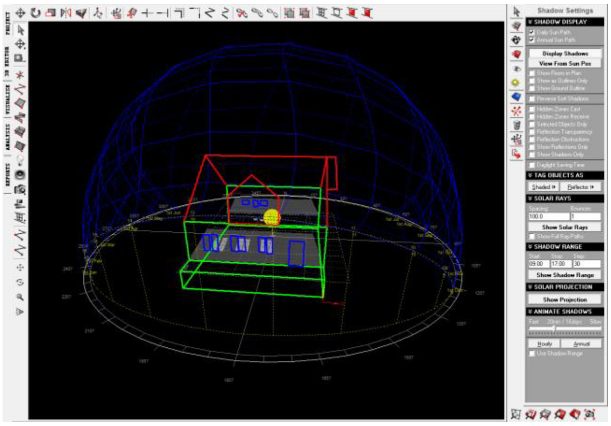

Fig. 8. Hourly and annual shade analysis.

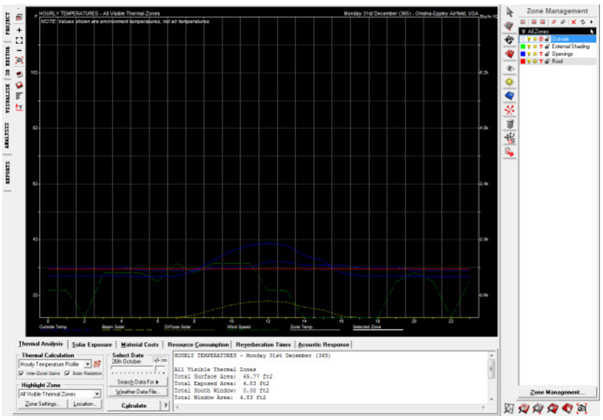

Fig. 9. Hourly temperature graph.

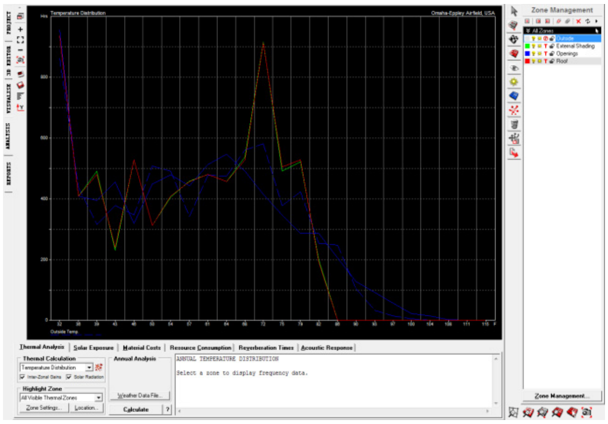

Fig. 10. Annual temperature distribution graph.

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