AUTOMATIC AS-IS BIM EXTRACTION FOR SUSTAINABLE SIMULATION OF BUILT ENVIRONMENTS

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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.

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

1. INTRODUCTION

Improving Energy efficiency has been a popular subject for the whole world since the energy crisis in the late 1970's [1]. Buildings account for 16 percent of world energy consumption [2], with a higher share in developed economies (nearly 42 percent of total energy use in the United States) [3]. While roughly two percent of commercial floors pace are newly constructed each year, and a comparable amount renovated, the majority of opportunities to improve efficiency over the next several decades will be in existing building stock. Thus existing buildings represent the greatest opportunity to improve building energy efficiency and reduce environmental impacts. However, a large number of decision makers lack sufficient information or tools for measuring their building's energy performance, and they are faced with a dizzying array of expensive products and services for energy efficiency retrofit (e.g., as-built 3D modeling services, modeling software, energy simulation software, energy audit services, etc.) with long, uncertain payback periods. The energy retrofit processes could be improved greatly if more reliable information was made available.

The design, construction, and operations of a successful energy retrofit begin with the owner's initial dedication to the project. Building owners and companies must utilize a clear decision process to analyze and justify energy conservation investments. The decision process contains important steps for gathering and analyzing information.

The disconnection between existing high performance building products and the willingness of decision makers to choose those products is likely due to the complexity of both the marketplace and building systems, as well as the lack of adequate feedback loops between decision makers and the outcomes associated with the different stages of the building lifecycle. To fill these remaining gaps, this paper introduces a framework and decision support system to assist decision makers on existing building energy retrofits.

The following sections will first present a background of this study, and then a framework of retrofit decision support system will be illustrated. Following that, the system processing procedure will be presented with a case study on one residential house.

2. DECISION SUPPORT SYSTEMS

For existing buildings, several decision support systems have been designed by researchers. Rosenfeld and Shohet [4] designed a decision support model for semi-automated selection of renovation alternatives. A preliminary survey was revealed to evaluate the condition of the existing buildings, and then different recommendations were made based on the evaluation result. Recently, a new decision support system was proposed to find the most optimized solution in terms of the trade-off between improved quality and investing cost for existing buildings renovation [5]. The solution of this system was determined by a hybrid approach combining A* and genetic algorithms. Although different decision support systems were designed, no one can provide decision makers the information about which part of the building should be renovate based on the results of energy analysis.

BIM has been widely applied in architecture, engineering, and construction (AEC) industry, and it can be analyzed in energy analysis software to conduct building energy simulation. However, BIM is not available for most of the current existing buildings. Even though some existing buildings may have BIM, it could not represent the current building conditions since the buildings keep being renovated. The preparation for new BIM is usually labor-intensive, costly and slow. In addition, it is inevitable that different modelers could create different models even though modeling the same building using the same software [6]. Nowadays, this problem can be easily solved using the valuable laser scanning technology due to its ability to acquire building spatial data in three dimensions with high fidelity and low processing time. The output of the laser scanning is an as-is point cloud which is composed of millions of individual points in which each point has its 3D relative coordinate information. Studies have been made on how to create as-is BIM based on point cloud. However it still needs labor-intensive manual processes to create a BIM out of point clouds.

3. SYSTEM FRAMEWORK

3.1 System Architecture

The overall framework of the retrofit decision support system is shown in Figure 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.

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 Figure 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.

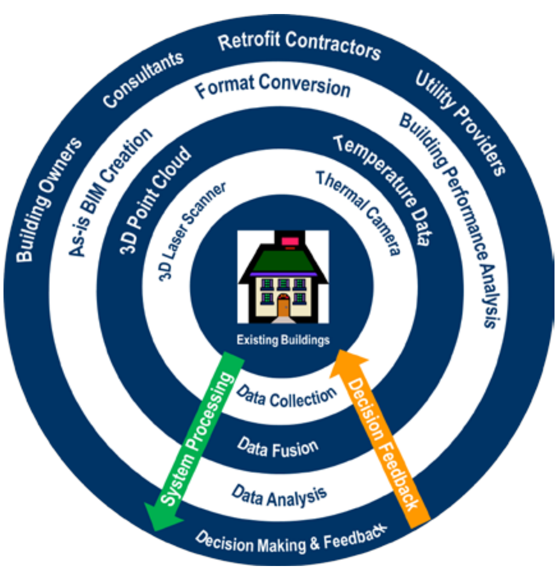

Figure 1. Framework of the retrofit decision support system

Figure 2. System Hardware

4. SYSTEM PROCESSING PROCEDURE

In this section, the system processing 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 [7]. 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 Figure 3, point clouds of a residential house were visualized in the developed GUI.

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 [8, 9]. 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 Figure 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.

4.3 Data Analysis

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 [10]. In Figure 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 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.

Figure 3. Point clouds of residential house

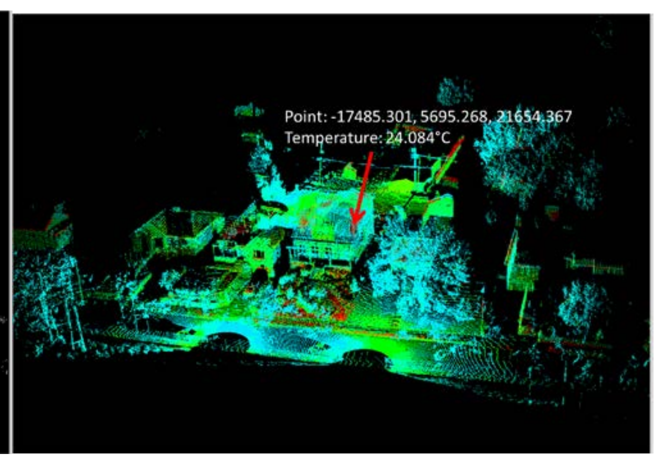

Figure 4. Point clouds with temperature fused

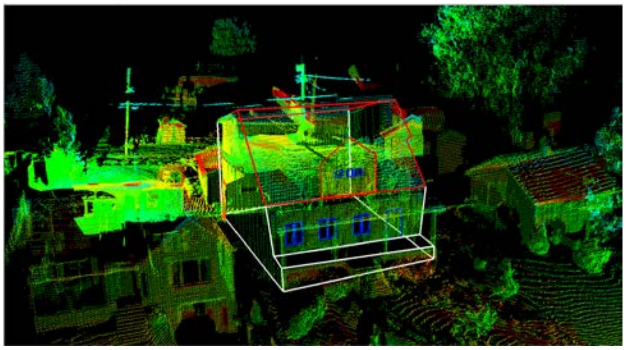

Figure 5. As-is BIM created from thermal point cloud

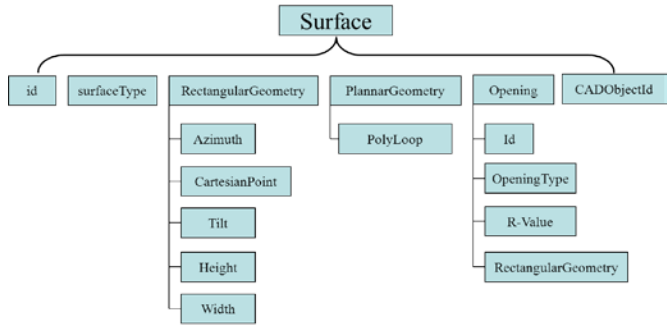

Figure 6. Structure of element "Surface"

Figure 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 Figure 7. Three thermal zones were visualized in the software with different color. With this created as-is BIM, many analysis can be conducted. Figure 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.

Figures 9 and 10 show an hourly temperature graph and an annually 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.

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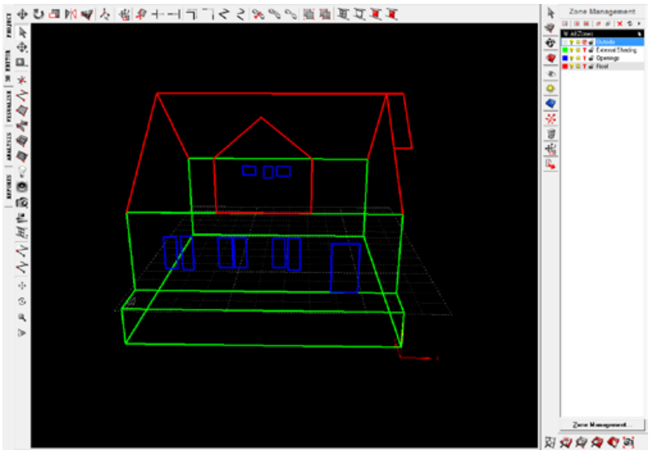

Figure 7. As-is BIM imported into energy analysis software

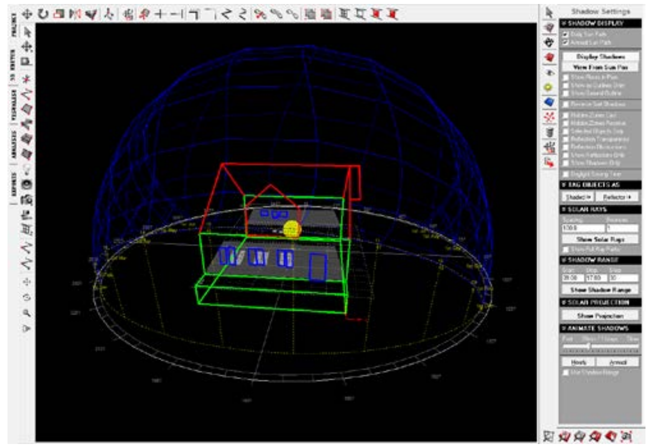

Figure 8. Hourly and annual shade analysis

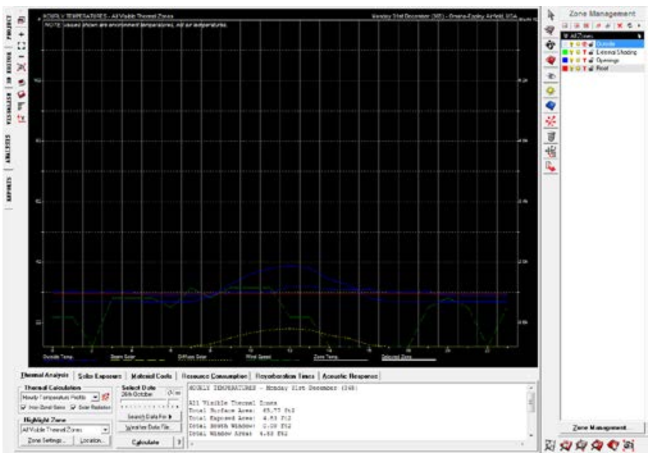

Figure 9. Hourly temperature graph

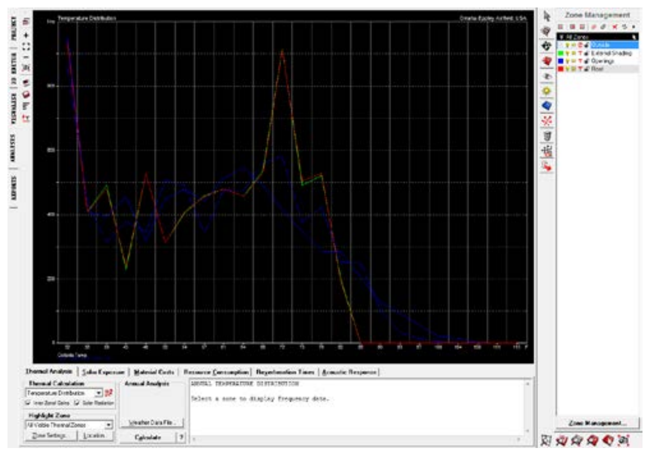

Figure 10. Annually temperature distribution graph

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