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A SEMI-AUTOMATED APPROACH FOR DETECTING BUILDING SPACES WITH DETERIORATING PERFORMANCE USING IFC-BIM AND ENERGY SIMULATIONS

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Abstract: Facility managers constantly face energy performance issues, which result from the mismatch between a facility's actual energy performance and its predicted performance, i.e. design energy simulation results. While the gap between the predicted and actual energy performance may be result of several factors stem from any phase in a facility's life cycle, facility managers are the ones responsible for reducing it. Nevertheless, they lack the tools and methods for detecting spaces with deteriorated equipment or system malfunctions in timely manner, which only contributes to the energy performance gap in a given facility. Therefore, this paper proposes a semi-automated framework that enables detecting spaces with deteriorated energy performance within a facility using BIM and energy simulation results. The framework automatically aggregates data from two different Facility Management (FM) systems, namely Building Energy Management Systems (BEMS) and Computerized Maintenance Management Systems (CMMS), and use the aggregated data to run energy simulations in IFC-Building Information Modeling (BIM) environment. The next step is the comparison between the actual and the predicted energy performance that needs to be carried out manually by the facility manager. The proposed framework was validated using data obtained from an unoccupied educational building. The results indicated that the framework is capable of aggregating and visualizing space oriented information in IFC-BIM environment. Furthermore, the aggregated data was used to run energy simulations to obtain facility's actual energy performance, and was compared to the predicted energy performance. This study supplements the existing body of knowledge by providing a framework that enables facility managers to detect spaces with energy over consumption within their facilities. The proposed framework could help enhance current maintenance planning practices and help improve facilities energy performance.

1 Introduction

In buildings, 5% to 20% of Heating, Ventilation and Air Conditioning (HVAC) energy consumption goes to waste due to faults and lack of maintenance (Roth et al. 2005). On the one hand, facility managers emphasize the importance of finding more efficient ways of managing buildings' energy (Bush and Maestas 2002). On the other hand, they face many challenges to achieve their goals (Per Anker Jensen and Tu 2015). Such challenges include identifying problematic spaces in a facility, isolating different types of problems, prioritizing them based on their impact on the overall energy performance, and developing timely solutions (Zhu 2006).

Energy consumption in buildings can effectively be reduced using energy simulations (Kim et al. 2016), especially during the design phase. However, the results of such analysis are not typically used to manage the energy consumption during operations and maintenance phase. In addition, facility managers' ability to identify problematic areas and to isolate faults is limited because of the interconnected, multi-layered nature of Facility Management (FM) information systems and their dependency on design information. In addition, facility managers lack the tools that could help them aggregate and link the existing information in FM as well as other systems that are used to store FM data.

In this study, a semi-automated IFC-BIM based framework was developed using JavaScript programming language. It utilizes the abilities of IFC-BIM to combine data from multiple systems to identify problematic areas in a facility. Detailed tasks of the framework include: (1) aggregating building data from BEMS, CMMS and energy simulation results that are required for energy simulation, and compiling them for to be used in energy simulation programs, i.e. EnergyPlus; (2) developing an Application Program Interface (API) to collect and analyze the above-mentioned data and link them to their corresponding elements in BIM. The developed framework was validated using data obtained from an unoccupied educational building.

This paper is organized as follows: the next section provides a comprehensive review of the literature in this domain. The following section then details the research methodology. Implementation and validation of the framework are presented in the next section. The final section draws conclusions and discusses future research needs.

2 Background

Facility managers utilize various systems to manage and operate their buildings. BEMS is used to control and monitor HVAC and lighting equipment to optimize their energy performance, and to achieve thermal comfort for its users in a given facility. BEMS is a collection of microcomputer systems consist of Direct Digital Controllers (DDC) and their control devices, which operate under supervisory control equipment and software collectively. Their capabilities include data sharing with individual controllers for coordination and optimization, linking control processes, and performing operation tasks and reports (Doty and Turner 2012). In addition, BEMS sensors and controllers can report any dysfunction in building systems or equipment.

BEMS reports three types of data including weather and energy use data, alarm monitoring data, and controller condition data (Doty and Turner 2012). DDCs are numbered and organized based on their type, function and general location in a building, and presented in list format. However, detailed data regarding their precise location, equipment affected by them and their maintenance history information are stored in different systems, i.e. CMMS. In addition, building performance metrics including sensor readings and energy consumption data are presented in 2D histograms, tables, or similar formats, and it is cumbersome to extract and interpret such data.

2.1 BIM Implementation for Building Energy Management

BIM supports a multi-domain and multi-layer collaborative approach and engages multiple stakeholders in a project including architects, engineers, contractors as well as facility and energy managers (Eastman et al. 2011; Shalabi and Turkan 2016). The research on BIM for building energy management can be categorized into three groups. The first group includes studies that focused on developing BIM for energy modeling during design phase. Those studies included predicting energy generation of sustainable fixtures (Cho et al. 2010), using multi-objective genetic algorithms that depend on BIM-based energy simulation to optimize energy performance (Chen and Gao 2011), developing IFC-BIM energy simulation process that runs in DOE-2.2 (Kim et al. 2013). In addition, other studies included methods that use EnergyPlus and genetic algorithms to determine optimal design glazing option (Oh et al. 2011). The study presented in this paper utilized BIM and energy simulation and complements the before mentioned studies. However, it differs from them as it focuses on operation and maintenance phase instead of design phase.

The second group focused on data exchange between building systems and simulation tools. The studies in this group investigated IFC-BIM interoperability issues with building energy analysis tools (Bazjanac 2008). In addition, it included developing a graphical user interface to input necessary data about HVAC systems into IFC-BIM based energy simulation tools (O'Sullivan and Keane 2005). These studies developed methods for data exchange, which is outside the scope of this study.

The third group focused on the applicability of building simulation tools in different lifecycle stages of a facility. This paper complements the work in this group by developing tools that use energy simulation results and FM systems with BIM for maintenance and operation purposes. Such studies include developing an energy enhanced BIM (eeBIM) framework that aims to enable an efficient life-cycle energy performance estimation and decision-making (Katranuschkov et al. 2014). In addition, (Kim et al. 2016) developed a model for mapping IFC-BIM material information to building energy analysis. Another study developed an approach to optimize data collection from IFC-BIM to be used for corrective maintenance actions (Shalabi and Turkan 2016). However, none of the previous studies developed techniques for collecting and presenting energy simulation results in BIM during operation and maintenance phase.

2.2 BIM Implementation in FM

FM personnel aim to guarantee a thermally comfortable, and functional facility while remaining in a given operation budget. In order to reach their goal, FM personnel manage the HVAC systems and other building components using FM systems including BEMS and CMMS. Such systems interact directly and indirectly with several stakeholders including occupants and FM staff (Roper and Payant 2014). BEMS reports systems faults and energy consumption data caused by occupants to facility managers (Doty and Turner 2012). using space heaters in winter months which increases plug loads (Beltran et al. 2013) and blocking thermostats and sensors with furniture (Roper and Payant 2014) are among many well-known problems caused by occupants which give false readings to FM systems and result in inaccurate responses.

Many benefits are sought for using BIM in FM activities such as improving decision making processes by allowing for extracting and analyzing relevant data (Azhar 2011). In addition, BIM in FM applications can improve the process of locating facility elements, which result in increasing the efficiency of executing work orders (Kelly 2013). Also, BIM can support all activities throughout a building life-cycle especially when BIM is carried from design to operation (Fallon and Palmer 2007). However, BIM adoption is still in its infantry stages (Kelly 2013).

Previous studies developed methods to streamline existing processes and systems. Those studies include using 2D barcode BIM-based facility management system (Lin et al. 2012), 3D BIM based facility maintenance and management system (Chen et al. 2013), (Lin and Su 2013), and augmented reality based operations and maintenance support (Lee and Akin 2011). The work presented here differs from the previous studies by using Energy simulation and monitoring to detect systems dysfunctions.

Another group of studies developed BIM-based approaches to replace existing processes and systems. Those studies include using BIM to generate customized templates to capture maintenance work related changes (Akcamete 2011), BIM-based system that uses case-based reasoning for building maintenance (Motawa and Almarshad 2013), developing fault tree analysis for failure root cause detection (Lucas et al. 2012; Motamedi et al. 2014), and using BIM for HVAC troubleshooting (Yang and Ergan 2015). However, none of these studies used BIM to link different FM systems with energy simulation results to provide proactive solutions to improve building performance.

3 Methodology

In current practice, detecting building spaces with performance abnormalities and malfunctions during operations and maintenance phase is a cumbersome task for facility managers. This is mainly due to the increasing amount and the complex nature of data collected from various building systems. The purpose of the proposed framework in this paper is to utilize building data collected from BEMS and CMMS during operations phase to identify excess energy consumption and detect faults in building systems. Such faults are hidden by nature and not detected by BEMS sensors and algorithms. This study focuses on heating and cooling equipment and spaces monitored and controlled by BEMS.

The framework was implemented in JavaScript to automatically collect data from various facility management systems including BEMS and CMMS. It combines the collected data with the energy simulation results obtained for the building running under same operational conditions. The framework automatically compares both datasets and detects spaces showing abnormal behavior and possible expected faults. The results would be presented to facility managers in IFC-BIM format where they can visualize and have access to actual energy performance (based on readings from BEMS), maintenance and energy simulation (based on as-built data) information within the same environment.

The proposed framework (Fig.1) presents that four file types are mapped and their information recorded and linked to the corresponding equipment in IFC-BIM. The logic starts with “add_maintenance_records()” step, where it reads the IFC, BEMS, and CMMS files and then generates an Interim_IFC file including maintenance and operation data obtained from BEMS and CMMS files. The following step is to read the Interim_file and return the line number with zone number from each system. It is very common for FM systems to have different zone names or unique identifiers for each system. This makes it cumbersome for facility managers to link problems between different systems. The next two steps, namely linkGeneration() and linking(), aim to create a HashMap with identity data hierarchy. The goal of this step is to link and track different zone names between different FM systems and their actual physical place in the IFC-BIM. The last step, PrintExcel(), reads the simulation file and calculates the difference between the simulation performance and the actual performance. Once the differences are calculated, the results are plugged into the IFC file and a new IFC file is generated.

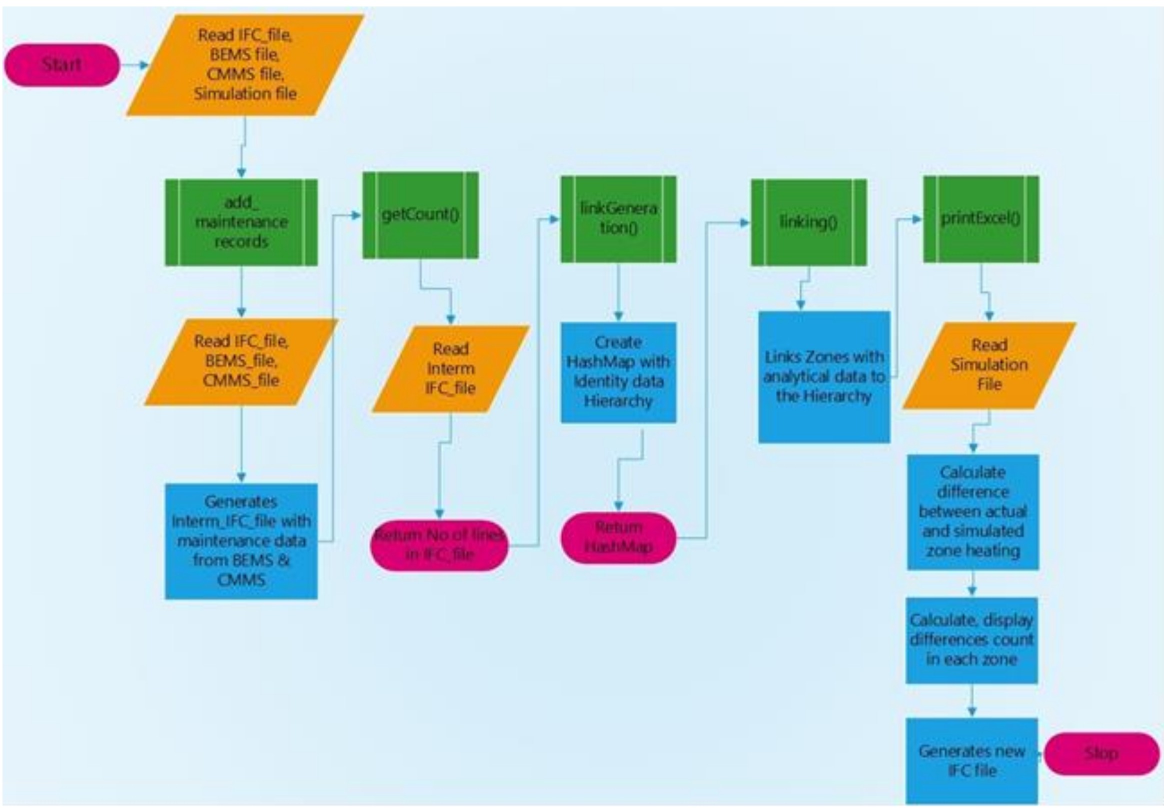

Figure 1: Proposed Framework Logic

For implementation, an Application Program Interface (API) was developed in JavaScript environment (Figs. 2 and 3). In the API, there are four main functions. The first one, Main.java, generates and presents the User Interface (UI) to the user. The second function, SampleController.java, enables users control the actions of the UI by selecting the files. This function is responsible for handling events generated by the user such as uploading and reading the BEMS file. The following function, Module1.java, is responsible for generating the interim_IFC file. Finally, IFCGeneration.java step reads the simulation and the interim.IFC files, processes the calculations, highlights the zones with flags, links them to the IFC file and generates a new IFC file.

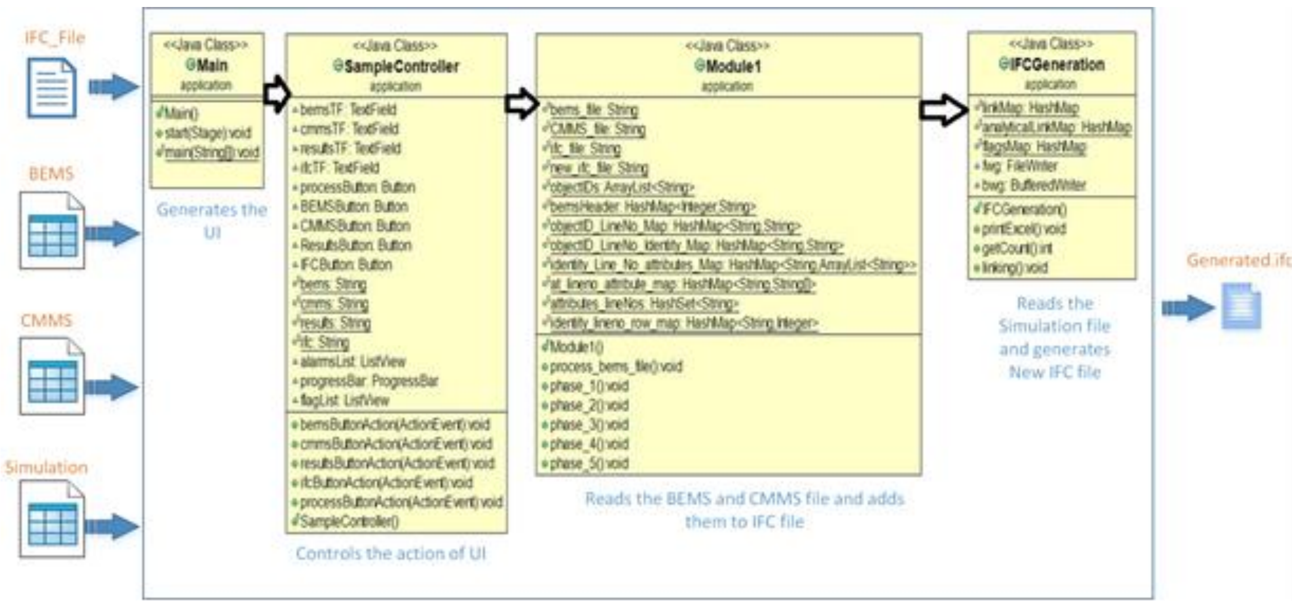

Figure 2: API Functions

```
Input: IFC_file, BEMS_file, CMMS_file, Simulation Excel File
Output: Final_IFC_file with simulation information from Simulation Excel File
Main function: IFC_Generation()
        Sub  function: add_maintenance_records()
                        Reads IFC_file, BEMS_file, CMMS_file
                        Generates Interm_IFC_file with maintenance data from BEMS & CMMS
        End sub function
        Sub  function: getCount()
                        Return the number of lines in Interm_IFC_file
        End sub function
        Sub  function: linkGeneration()
                        Return HashMap of Identity data Hierarchy
        End sub function
        Sub  function: linking()
                        Links the Zones with analytical data to the Hierarchy
        End sub function
        Sub  function: printExcel()
                        Reads the Simulation Excel file
                        Calculates the difference between actual and simulated zone heatings
                        Displays the Count of Differences in each Zone
                        Generate Final_Final_IFC file with Calculated data
        End sub function
End function
```

Figure 3: API Pseudo Code

It is important to note that the user is required to provide the BEMS, CMMS, and simulation file in Excel format in order for the algorithm read and extract the required information. Most commonly used BEMS and CMMS systems enable Excel format output.

4 Implementation and Experimental Results

The proposed framework was implemented on data collected from a two-story educational building. The building serves as a design studio space with open floor plan. The building has a central heating boiler that is connected to fourteen heating zones (Fig. 4). Each zone is connected to the heating system via one radiator that is responsible for heating that particular zone. Each zone is equipped with various sensors to measure humidity, dry bulb temperature, and CO2 for air change rate that is controlled by mechanical ventilation equipment. All fourteen spaces have the same thermal zone. It is important to note that in order to eliminate user's effect on sensor readings, data was collected during winter break when the building was unoccupied.

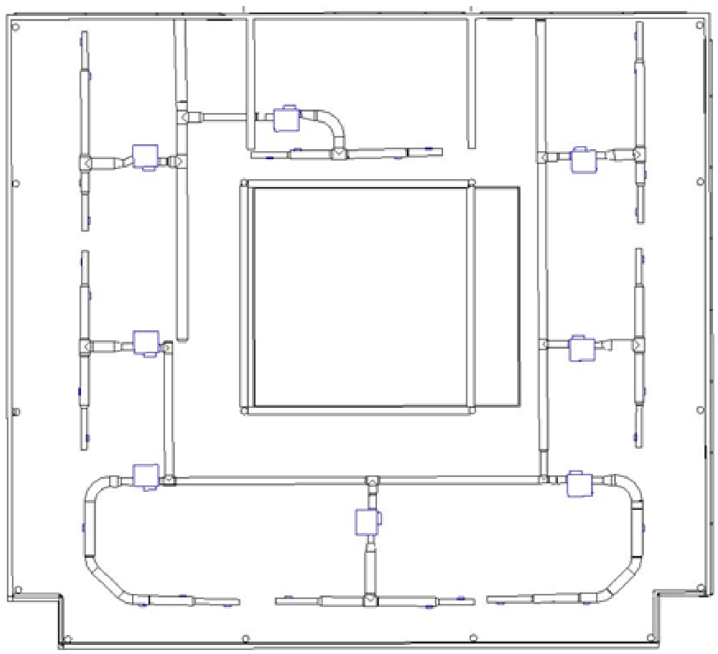

Figure 4: First Floor Heating Zone Layout

IFC-BIM of the building was developed using both 3D geometry and its corresponding attribute data. First, 3D geometry data was developed using a laser scan point cloud that was captured with a Trimble TX5 laser scanner. Autodesk Revit Scan-to-BIM, a semi-automated modeling tool, was used to model the structural and HVAC components from the laser scan point cloud. Then the materials and systems data, which was obtained from the handover documents and the building commissioning verification results, were added to the simulation software and to the IFC-BIM manually.

The developed framework was tested on the collected data, and it succeeded in identifying one zone with potential future maintenance issues, namely Zone 3. In addition, it succeeded in presenting the results in BIM environment (Fig.5) by highlighting the affected zone and raising a flag next to the time in which the readings differ. As can be seen in Fig.5, the differences between the values are listed adjacent to the time of the measurement, and for each difference, where the actual heating demand is more than the simulated one, a flag is raised. It should be noted that BIM vision 2.13, an open source software, was used to view the IFC-BIM.

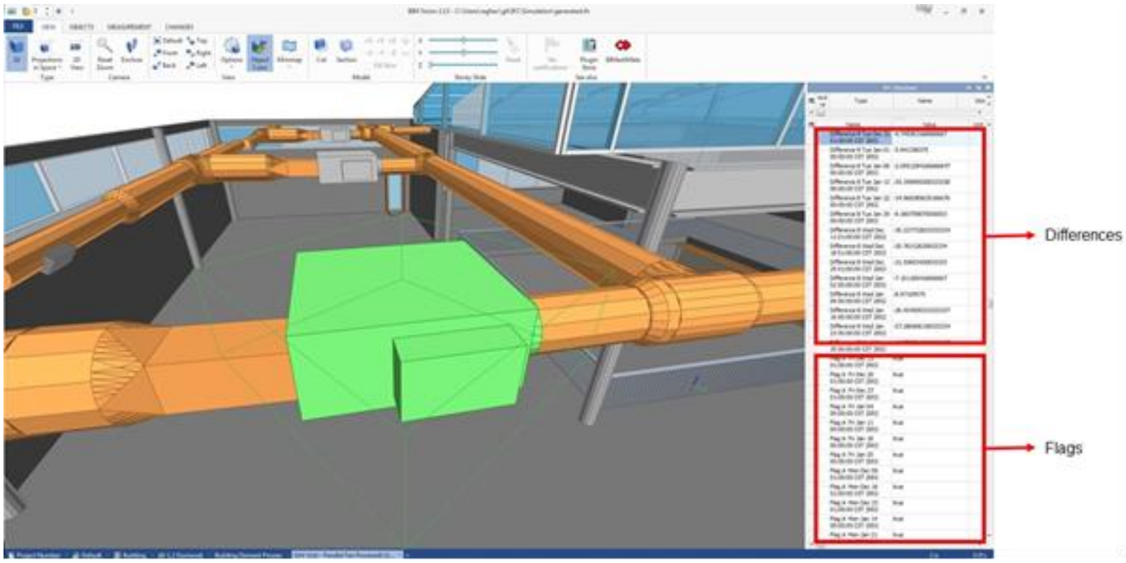

Figure 5: IFC-BIM Representation in BIM Vision 2.13

5 Conclusions

This paper presented a semi-automated framework that enables detecting spaces with deteriorated energy performance within a facility using BIM and energy simulation results. It automatically aggregates output data from BEMS and CMMS systems, and use the aggregated data to run energy simulations in IFC-BIM environment. In the next step, the energy simulation results obtained using the data from BEMS and CMMS, i.e. actual energy performance, was compared to the design energy simulation results, i.e. predicted energy performance. The framework presented in this paper requires the comparison between the actual and the predicted energy performance to be carried out manually by the facility manager. In future research, this step can be automated by adding an additional API that enables automated comparison between the design and actual energy simulation results.

The proposed framework was validated using the data obtained from an unoccupied educational building. The results showed that the framework aggregated BEMS and CMMS data automatically and enabled space oriented information visualization in IFC-BIM environment. The aggregated data was then used to run energy simulations to obtain facility's actual energy performance, and compared to the predicted energy performance. It succeeded in identifying one zone with potential future maintenance issues. Furthermore, it succeeded in presenting the results in IFC-BIM environment by highlighting the affected zone and raising a flag next to the time where the readings differ.

This study supplements the existing body of knowledge by providing a framework that enables facility managers to detect spaces with energy over consumption within their facilities. The proposed framework could enhance current maintenance planning practices and help improve facilities energy performance.

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