GIS-BIM Based Virtual Facility Energy Assessment (VFEA) – Framework Development and Use Case of California State University, Fresno

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ABSTRACT

Assembly Bill 758 (AB758) of California Energy Commission (CEC) incentivizes radical improvement of energy performance in existing buildings. Execution of AB758 relies heavily on building performance data and energy assessment. Traditionally, building performance data are not available for public consumption, while energy assessment is complex and time-consuming to conduct. Thus, a Virtual Facility Energy Assessment (VFEA) strategic planning tool is proposed built upon the robust integration of Geographic Information Systems (GIS) and Building Information Modeling (BIM) with a cloud infrastructure. For owners with large portfolios of facilities, such as the California State University (CSU) system, VFEA can leverage location-based building information, dynamic simulation capacity of BIM and wireless sensor network (WSN) for real-time building energy performance detection, visualization, analysis and optimization across campuses. It provides stakeholders a dynamic and holistic virtual assessment for energy performance of buildings that are geographically dispersed. VFEA offers conceptual yet informative suggestions in the decision-making process directed to meet the AB758 requirements. This paper conducted the feasibility analysis, established the system framework of VFEA, and discussed the use case of CSU, Fresno campus for VFEA implementation.

INTRODUCTION

Improving energy performance of existing buildings plays a crucial role in achieving energy efficiency targets and carbon emissions reduction goals. Large-scale improvements to the existing building stock will need broad involvement of a wide array of stakeholders via innovative and strategic solutions (Brook et al 2012). In the State of California, Assembly Bill 758 (AB758) is such a framework that encourages collaboration between California Energy Commission (CEC) and a wide array of stakeholders to develop a comprehensive program to achieve greater energy efficiency in existing buildings. Execution of AB758 will be heavily relying on data availability such as building performance data to inform program design and evaluation efforts, and enable contractors, investors, entrepreneurs and other essential market players in their business decisions. California has been investing in energy efficiency for more than three decades, but building performance data is not managed in a consolidated location and generally is not available for public consumption (Brook et al 2012). Decision makers, especially owners and managers with large portfolio of building facilities, will be handicapped when attempting to implement efficiency upgrade projects across the state.

Energy assessment is another critical component of the AB758 program. An energy assessment determines the anticipated energy performance and specific opportunities for improvement in a building. Traditional methodology of energy assessment for existing non-residential buildings tends to be time and labor-intensive. It typically lacks the robustness to provide real-time feedback on building energy performance and energy consumption. Therefore, stakeholders lose the direct insights into the operational status of their facility. They will not be able to conduct meaningful as-if scenario analysis to identify optimal strategies when there are opportunities for building renovation and remodeling. To overcome these barriers, stakeholders will need innovative, data-driven and performance-based solutions for strategic planning and decision-making. An emerging trend is the integration of Geographic Information Systems (GIS) and Building Information Modeling (BIM).

BIM is an emerging trend in the Architecture, Engineering and Construction (AEC) industry that can be used to improve the performance and productivity of buildings' life cycle throughout the design, construction, operation and maintenance process. There is growing evidence that links BIM benefits to Facilities Management (FM) (Love et al 2013). However, BIM that addresses details of individual buildings without the contextual geospatial information support will be inadequate and struggling to meet FM needs of a geographically dispersed, large portfolio of building facilities, for instance, state-owned campus buildings. GIS is a technology that when integrated with BIM and the myriad facility management technologies, can offer scalable solutions to FM far beyond the building perimeter. By integrating BIM and geospatial information via standards based methods, decision makers can significantly improve their ability to visualize, analyze, model and forecast the building performance, user behavior and material assets in the context of the broader facility and urban enterprise (Zhang et al 2009). Traditionally, GIS is strong for mapping and geospatial analytic power. It has great flexibility of integration with Computerized Maintenance Management System (CMMS), Computer Aided Facility Management (CAFM), Integrated Workplace Management System (IWMS) and Electronic Document Management System (EDMS) geared towards large number of users. BIM on the other hand provides highly structured and detailed information in 3D or multidimensional format that is lack in GIS (Przybyla 2010). Together, the integrated GIS-BIM platform offers owners and facility managers with the total scalability (Figure 1) desired to meet a variety of business needs, including energy management, facility management, space management and public safety.

This research attempts to utilize an integrated GIS-BIM infrastructure to create a cloud-based Virtual Facility Energy Assessment (VFEA) tool for strategic planning purposes. VFEA enables stakeholders of the CSU system to quickly assess real-time building energy performance, identify efficiency improvement opportunities and proceed with sound business decisions on the basis of dynamic and scalable information visualization at district, city, campus or building level (Figure 2).

Figure 1. Information scalability of the integrated GIS-BIM platform.

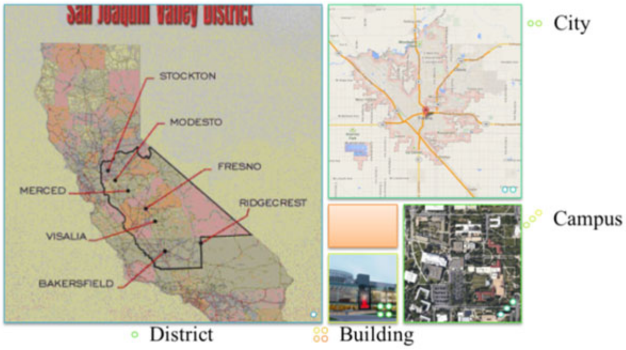

Figure 2. Scalability of business decision-making with VFEA.

RELATED WORK – FEASIBILITY ANALYSIS

Giving the increased interest in GIS-BIM integration (de Laat and van Berlo 2011), there are very few studies conceived to investigate the potential utilization of BIM in the geospatial context to improve energy efficiency of a massive volume of buildings. Kim et al (2012) documented an effort by the Korean government named U-Eco City, which was a web-based platform and aimed at the monitoring and visualization of aggregated and real time states of various energy usages represented by location-based sensor data accrued from city to building scale. This paper provided valuable elaboration on how to construct the urban data structure model and sensor data integration with geospatial applications such as Google Earth and Google Maps plug-ins for real-time energy information visualization. It also demonstrated best practices in large data treatment and optimization geared towards diverse representation strategies with diverse visualization at different levels of detail (LOD), and possible robust statistical analysis enabled accordingly. However, the 3D geological environment and 3D building models in this study were not constructed directly using BIM, due to the perceived limitations of closed nature of data querying characteristics in the model and the difficulty to sustain BIM data for ubiquitous access across the World Wide Web (WWW). Alternatively, 3D building models were generated by a customized modeler from GIS data to allow manual editing and easy integration of sensor data gathered from building operations.

Sebastian et al (2013) discussed another example of semantic BIM and GIS modeling for energy efficient buildings integrated in a healthcare district, which was part of a large-scale research project titled STREAMER under the European Union (EU) Seventh Framework Program (FP7). This project focused on developing a new design methodology to achieve energy-efficient buildings (EeB) at neighborhood level. To achieve this goal, this paper addressed three key areas of optimization to tackle the complex interactions between technology, building systems and stakeholders:

- Functional and technical optimization of spatial layout and building envelope related to operation and services in the surrounding neighborhood;
- Cost-effective optimization of the interdependent building components and energy systems, e.g. MEP and HVAC systems;
- Interaction optimization between building and neighborhood energy systems, e.g. smart grid or district heating/cooling and energy generation.

A major contribution of this paper was the proposition of a semantics design methodology called *Semantics BIM+GIS*, which is the new generation of Semantics Building and Geo Information Modeling. It utilized a Semantic Web based solution to reconcile semantic data from domain information models, e.g. BIM, Building Assembly Model (BAM), Building Energy Model (BEM) and Building Operation and Optimization Model (BOOM). In this methodology, interconnected product, process and knowledge modelling for energy-efficient buildings and neighborhoods is fully supported by interoperable BIM and GIS in a Semantic Web environment.

A third research by Lee et al (2013), although not directly relevant to building energy efficiency, conducted a critical review of information integration strategies that were at the heart of an intelligent urban FM system. It shed light to the framework development of the proposed VFEA. Exemplary information integration use cases discussed here include:

- Facility information integration: refers to the reconciliation of the heterogeneous information types and formats contributed by various participants along the design, construction and management of the building facility and the contextual geospatial conditions.
- Sensor information integration: refers to integrated management of various sensors, e.g. temperature, pressure, power, and noise sensors and corresponding controllers.
- Link of facility-sensor information: this refers to the integration of both static information (facility information) and dynamic information (sensor information) through Urban Object Identification (UOID) to realize real-time monitoring of facility, systems and events.
- Functional integration: refers to the consolidation of common FM system functions, including facility information management; facility operation and maintenance; facility event management; and facility information visualization.

Compared with previous geospatial FM systems, the proposed Intelligent Urban Facilities Management System (IUFMS) had two major innovations: 1) aboveground and underground facilities were modularized but integrated to communicate with the UOID module for dynamic real-time representation of 3D facility and geospatial information; and 2) use of ontology-based context modeling for a Contextual-Awareness module to infer event occurrence and urgency, and create indicative 3D information visualization so prompt and appropriate responses could be made before significant loss incurred.

To prepare the integrated data infrastructure for the proposed VFEA framework using BIM and GIS, a dilemma, as identified by Rich and Davis (2010), was that the vast majority of existing building stock was built before the advent of BIM technology. As a result, how to capture existing conditions into BIM so it can be used by facility managers and other stakeholders in operation and maintenance has to be addressed. Recent advancement in 3D laser-scan technology and research in automatic reconstruction of as-built BIM from laser-scanned point clouds (Tang et al 2010, Volk et al 2014) suggest that cost-effective solutions to this concern are promising. At the frontier of the software industry, Project Dasher (Autodesk 2013) is an Autodesk research project that extends the value of BIM to the life-cycle of the building by integrating as-built BIM data via laser scanning and building instrumentation (e.g. sensor and meter data) to provide building owners with more insight into how existing buildings perform in real time.

Another relevant argument is regarding whether or not a highly developed BIM, e.g. LOD 400-500 as defined by BIMForum (2013), is really needed. Or, the building models constructed in the semantic 3D city models represented using City Geography Markup Language (CityGML) LOD 1-4 as defined by OGC (2012) will be sufficient. Literature review suggests that there have been efforts and success to represent BIM using Industry Foundation Classes (IFCs) within the CityGML models or to integrate both models. More importantly, the intended uses of 3D building models in IFCs and CityGML respectively are quite different (Nagel et al 2009). For example, OGC Web Services Phase 4 (OWS-4) test-bed initiative looked at how CAD/GIS/BIM (CGB) information can be integrated at web services level (Lapierre and Cote 2007). Isikdag and Zlatanova (2008) focused on the derivation of CityGML from IFC models and proposed a formal framework for a semantic mapping between both models, which allowed for an automatic transformation. The main findings of their study were that IFC models contained all necessary information to generate CityGML models in different LODs, and that it was possible to define rules for geometric transformation and semantic matching. Hijatzi et al. (2011) created a web-based tool to integrate IFC/BIM data into a 3D GIS environment, which provided navigation and visualization functionalities, as well as some analysis operations (routing, network analyses).

VFEA FRAMEWORK AND USE CASE

VFEA is proposed to serve the facility energy management needs of the California State University (CSU) system, which is the largest university system in the U.S., composed of 23 campuses and 8 off-campus centers. According to the CSU Space and Facilities Database (SFDB), CSU owns a total of 2145 buildings with space of 88.0 million gross square feet (MGSF), and consumes 170 million kilowatt-hours(KWh) of power annually. As a proof of concept, CSU, Fresno is selected as a use case, which owns 178 buildings with a total space area of 3.5 MGSF, and consumes about 7.5 million KWh of power annually. To accommodate an energy system with this magnitude, the framework of VFEA, which is illustrated in Figure 3, is premised on consolidating several critical information exchange and interaction interfaces with the following characteristics and intended functionality:

- Cloud-based platform and user interface
- Real-time based sensor data collection and aggregation
- Bidirectional GIS-BIM information exchange with open standards
- Intuitive information visualization and statistical analysis
- Scalable building/spatial data loading and visualization

The following paragraphs will briefly discuss the rationale behind the framework. At the time of this paper, the VFEA framework is being discussed by stakeholders of CSU, Fresno. The framework architecture is tentatively designed and a prototype using the Henry Madden Library (HML) is being formulated.

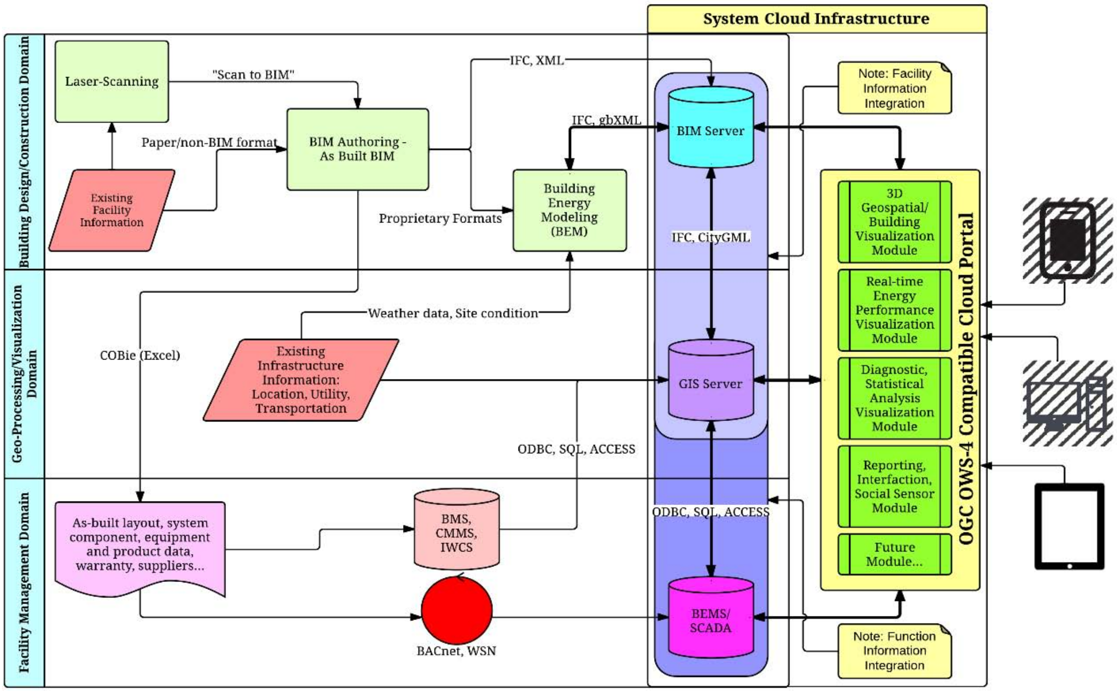

Figure 3. Framework of the proposed VFEA: system architecture and information integration strategy.

Cloud-based GIS-BIM-EMS information portal. Current development of BIM Server and GIS Server technology make it possible to leverage the power of cloud computing for mega data storage, querying and processing in a scalable, demand- responsive and secure manner (Lapierre and Cote 2007, de Laat and van Berlo 2011). As shown in Figure 3, the overall scope of information authoring, exchanging and management have been categorized into three interdependent domains: *Building Design/Construction (BDC), Geo-Processing/Visualization (GPV) and Facility Management (FM).* In the BDC domain, existing building conditions could be either scanned to BIM, or generated using BIM authoring tools with as-built building documents. The reconstructed as-built BIM will be deployed in the cloud through BIM Server technology, usually in the format of IFC or XML. Meanwhile, building energy modeling (BEM) can be performed to simulate optimized energy performance of facilities in ideal situations, results of which could be used in comparison with sensor information to identify and test energy efficiency improvement opportunities and strategies. In the GPV domain, existing geospatial information including sites, utility (power, water, gas, etc.) systems and transportation systems can be represented in GIS server using CityGML based 3D city model. Facility information integration then is accomplished through the communication between BIM Server and GIS Server.

In the FM domain, function information collection relies on the Building Energy Manage System (BEMS) with Supervisory Control and Data Acquisition (SCADA) integration that gathers HVAC systems and other energy systems real-time operation data through BACnet (Building Automation and Control Networks) and Wireless Sensor Network (WSN). Notice that with information extracted from the as-built BIM via the Construction Operations Building Information Exchange (COBie) format, facility managers can more efficiently manage the overall space layout, equipment and product data as well as other critical system information for sensor deployment and energy performance data gathering. Through standard protocols, the GIS Server is able to communicate with BEMS/SCADA at the database level. The function information integration is then accomplished.

Information Visualization and User Interface. Briefly speaking, the BIM Server, GIS Server and BEMS/SCADA platforms and applications all have built-in human machine interface (HMI) and support comprehensive information visualization and analysis. Nevertheless, one of the major contributions of the proposed VFEA framework is to synthesize all these interfaces and information visualization/analysis into a common OGC OWS-4 compatible cloud portal. Through a flexible user interface (UI) that supports conventional and mobile access, stakeholders at CSU, Fresno can visualize, conduct analysis and make decisions based on the instant and aggregated real-time energy performance of any campus buildings. At this stage, the focus is on energy efficiency and consumption only. Nevertheless, with further data infrastructure expansion, relevant functions including carbon emission calculation and cost-benefit analysis for energy system renovation options can be added to the framework, attributed to automated sustainability analysis and cost estimating capacities of BIM. This is also a major consideration behind using a high-LOD BIM as the data source of the 3D building facility representation instead of the 3D building model in GIS.

CONCLUSION AND FUTURE RESEARCH

VFEA is still at its inception stage and part of the key stakeholders need yet to be on board. The next steps will be: 1) Continuing tweaking and finalizing the system architecture and information integration strategies of VFEA. For each use case, there are multiple solutions and decisions have to be made to determine which ones work best holistically; 2) Scoping, formulating and conducting the prototype test using the HML building. HML is one of the most visited and utilized buildings on campus, and has a major addition added with completely different space layout and energy systems, which provides a perfect opportunity to validate energy efficiency improvement efforts.

It is a true emerging trend today to integrate GIS, BIM and BEMS for more intuitive and effective facility, asset management. As the regulatory requirements on energy efficiency in this country keep getting more stringent, smarter strategic planning tools like VFEA will be valuable to stakeholders at all levels. Accelerated advancement in ICT clears obstacles in the technology arena but in many circumstances, the human factors and decision-makers’ mindset have to transform as well.

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