A Case Study of Embedding Real Time Infrastructure Sensor Data to BIM

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ABSTRACT

One of the premises of Building Information Modeling (BIM) is becoming a repository for all building related data throughout its lifecycle. However, the use of current models developed in existing BIM based software rarely go beyond the construction phase. During a facility’s management, these models are treated as static information sources that contain the as-built data. Making BIM based models dynamic, to represent the real time building information, introduces various opportunities for facility managers to get the accurate information about the state of various systems. In this paper, we will introduce an approach used to connect the sensor data to the IFC-based BIM model. We will use a geothermal bridge deck deicing system, which involves embedded sensors as a case study. The real time monitoring of these sensor data is crucial for assessing the state of the bridge deck under different climate conditions. First, we will describe our model in Revit and the data we collected from temperature sensors. These sensor data will be subsequently fused into the IFC-based BIM model and processed for visualization through the development of new add-ins in Revit. Finally all the sensor data should be easily monitored in our BIM model for condition assessment.

INTRODUCTION

Building Information Modeling (BIM) refers to using an n-dimensional model during the planning, design, construction and operation of a facility. It has received increasing attention from the Architectural, Engineering and Construction (AEC) industry in recent years. BIM is used to facilitate a more integrated design and construction process that leads to reductions in cost and project duration (Eastman et al, 2008). However, one of the earliest drivers of various BIM initiatives was to utilize it during the whole facility lifecycle, from
cradle to grave. Due to the lack of specific data storage mechanisms and control issues for lifecycle information management, most BIMs are only used as “static” information sources that comprise limited design and construction data. Therefore, a big challenge for the utilization of BIM during a facility’s lifecycle stands to make it “dynamic”. A “dynamic” BIM contains real time building information such as data from various kinds of sensors, so the model can reflect the existing conditions.

Benefits of having a “dynamic” BIM with real time data for facility administrators include having the opportunity to react emergencies on time, proactive maintenance planning, better control and management of building data, and identifying use patterns and trends. Through the “dynamic” BIM, facility administrators will be able to visualize and monitor the current situation of facilities so they can detect a problem immediately. It will help them minimize the cost of restoring the facility, together with preventing inconvenient and unsafe conditions for the users. The accurate data stored in the BIM model is also crucial for documentation, which can be either a valid operating history or a good source for evaluating the performance of both facilities and facility administrators in the long run. Lastly, the combination of operational data with the design data that has already been stored in the model is a useful reference for designers and researchers in other projects.

BACKGROUND

The United States has an aging infrastructure network and is currently facing a crucial need for maintaining and upgrading that infrastructure. According to ASCE’s report, $2.2 trillion is needed to upgrade the current transportation infrastructure to a satisfactory level. (Beckner, 2010) The annual cost to maintain the highways and bridges is projected to be $78.8 billion from 2005 to 2024, which is 2.3% higher than the predicted “cost to maintain” in 2004. (FHWA, 2006). Similarly, the building industry is expected to address sustainability challenges while delivering better operated, more energy efficient buildings. All these give rise to the demand for the “content-aware facilities” that have higher efficiency in daily operation and maintenance.

In order to gain control over a facility’s data at all stages, construction projects managers and facility managers begin to include sensors into their operations. The types of sensors change from embedded systems to spatial sensing and imaging technology. The application of sensors in construction usually focuses on individual applications and varies from quality control (Bosche and Haas 2008, Zhenhua and Brilakis 2008), to safety (Teizer 2008, Chi et al. 2008), to active infrastructure management (Kiziltas et al. 2008, Dziadak et al. 2008, Moustafa et al. 2008) and to energy saving (Jain et al. 2012, Gulbinas et al. 2013). However, embedding sensors to BIM by modeling them in the design phase and then later using them for infrastructure monitoring has not been explored yet. Akanmu proposes a cyber-physical system, which utilizes sensors to link the virtual model with real world (Abiola Akanmu et al, 2013). Similarly, there is
research on combining BIM with sensors for occupant-centric capture of building performance data (Attar et al, 2011) and improving comfort level of building occupants through a non-intrusive occupancy monitoring system for demand driven HVAC operations (Yang et al, 2012).

**SCOPE AND OBJECTIVE OF RESEARCH**

The objective of this research is developing a proof of concept prototype for a “dynamic” BIM framework that is enriched with the real time information of the operation phase. We will test existing BIM based software to see how much real time sensor data can be inserted in the model. This way, the model will be able to support regular operation and monitoring processes, allowing the facility administrators to access and directly visualize all the data in the model.

There are many BIM based software programs in the market, such as Autodesk Revit for architecture, structure and MEP system, Bentley Structure Modeler for structure, Graphisoft EcoDesigner for sustainability design. We choose Autodesk Revit in this research since Revit provides a powerful application programming interface (API) and it is a widely used BIM software in the market. Revit also has IFC (Industrial Foundation Class) importing and exporting capabilities that we can utilize to improve the interoperability of our model.

**CASE STUDY – Ground Sourced Bridge Deck Deicing System**

The bridge deck deicing system is built as an experimental setting by the geotechnical engineering researchers at the civil and environmental engineering department of Virginia Tech. In the case study, we will first describe the model, then we will introduce the methods and nine identified use cases in daily operation.

**Model Description**

As shown in figures 1 and 2 below, the bridge deck is concrete and has embedded pipes that extend to the ground. There are 6 rows of sensors (4 sensors in each row) attached to the rebars in the whole bridge deck. The red elements shown in Figure 1 are all the sensors in the system, while Figure 1 shows the details of the model, Figure 2 shows the real system in the lab.
Methods

Since Revit doesn’t have functions to store data from real time sensor and show them, we achieve “dynamic” BIM through the Revit add-ins. The add-ins are developed using Revit’s .NET API (Application Programming Interface) to extend the core functionality. With add-ins, Revit is able to store and manage real time data. Though the developed add-ins still have some limitations, they offer many possibilities for BIM.

IFC Representation

In order to create a fully interoperable dynamic system the sensor information need to be embedded in the IFC output. In the dynamic BIM framework, the sensors are set as ifcSensor type when we are creating the sensor family in Revit for a neutral data format. The Industry Foundation Classes (IFC)
data model is a standard format to describe building and construction industry data. It is intended to facilitate the interoperability among different software platforms. Entities such as ifcSensor and ifcSensorType can be used to represent sensors. It also has a detailed domain and entity descriptions that can be used to represent components in buildings, such as Building Control domain, HVAC domain, Electrical domain etc. On the other hand majority of the IFC format focus on building models and properties of infrastructure elements such as bridges are not fully addressed. There is continuing work on developing IFC-Bridge to represent specific bridge related information, however the scope of this research is limited with sensors and we only look at sensor related data representation in IFC. Figure 5 below shows IFC output of the model and the stored sensor data.

![Figure 5. IFC output of sensor data](image)

**Details of Work**

We identified nine use cases to meet the requirements of the regular monitoring of the system for the visualization of sensor data. Then we implemented these use cases using the Revit .NET API.

For the description of this case study we will discuss the details of four use cases and how they are implemented:

*Use case 1: Automated Input of Sensor Data*

The first add-in is for automated input of all the sensor data. The original sensor data downloaded from sensor controller is a txt file shown in Figure 6. Through our add-in, we are able to automatically parse this txt file and then create the shared parameter for each sensor data. Shared parameters are the parameters...
that can be added to families or projects in Revit. It gives user the flexibility to add specific data that is not already predefined in the family file or the project template. Since we have created sensor as a new family, we used shared parameter for storing the data. After parsing all the data, they are automatically shown in the schedule that can be set specially for all the sensors of this project (shown in Figure 7). The schedule is a useful tool in Revit that can provide data lists for users.

![Figure 6. Sensor data file](image)

<table>
<thead>
<tr>
<th>Mark</th>
<th>Date</th>
<th>Sensor Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2012-08-15</td>
<td>23.034</td>
</tr>
<tr>
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<td>22.215</td>
</tr>
</tbody>
</table>

![Figure 7. Schedules for sensors and sensor data in Revit](image)

This add-in’s interface is simply designed and shown in Figures 8 & 9. First the user selects the date of the data, and then a dialog box will come out for selection of the txt sensor data file. After choosing the date and the corresponding
Use case 3: Show Data for Multiple Sensors at Specific Day

In this case, after clicking on “Show Data for Multiple Sensors at Specific Day” on the add-in menu, a window will come out where you can input the data and sensor number. After inputting the date and sensors’ mark in the form created and clicking ‘OK’ and ‘Show The Chart’, you will get the chart shown below. The line chart with two different colors and legend will appear showing trend of changing temperature at the sensor locations on the bridge deck.

Use case 6: Show Average Temperature for a Specific Sensor at a Specific Month

After starting the add-in, the user selects the specific sensor by clicking on it in the Revit model. Then a form shown in figure 11 will come out. Inputting the month in YYYY-MM format, the API will take out the data stored and automatically calculate the average temperature for each day then show it in a histogram. The legend will show the sensor mark of what is chosen in the first
Use case 8: Show Average Temperature for All Sensors at a Specific Day and 2D Temperature Field Graph of Bridge Deck

This add-in lets the user see the average temperature for all the sensors at a specific day. After inputting the date, if the user clicks on ‘Show the Chart’, the histogram is displayed in Figure 12. If the user clicks on ‘Show the 2D Graph’ a color coded temperature field according to the configuration of the sensors in the bridge deck and their recorded data will be generated automatically. Through the direct rendering shown in Figure 13, the users can get a direct view of all the temperatures in the bridge deck.
FIGURE 13. Temperature field of bridge deck at a specific day

CONCLUSION

The research describes a proof-of-concept prototype for embedding real time information to a BIM, thus making the model dynamic by using a modeled component in the operational phase. The author verify the dynamic BIM through a case study, in which the real time sensor data are successfully imported into the BIM model and can be clearly visualized by the BIM users. Extending BIM to operational stage provides convenience and efficiency for facility administrators. The information can also be saved in IFC as a neutral data format and can be transferred to other tools. By complementing the BIM model, we are able to gain better control of a facility in all the stages of its lifecycle.

The future work of this research involves using wireless sensors to get data directly into BIM and improving the user interface of add-ins. We will create a more professional interface, which includes mapping the information coming from the sensors to the 3D model to enhance the visibility and perception of current facility situation. It is a visualization challenge much more than graphs and charts. Finally, we will conduct user tests for our framework and improve the interfaces according to their feedbacks.

REFERENCES


