Live capture of energy related Knowledge into BIM systems

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ABSTRACT

Energy Management in buildings is about operating and maintaining many complex energy systems used by buildings’ occupants. The generation and collection of energy-related building information is commonly fragmented, created over the building’s lifecycle by different teams with different objectives, and stored in different systems. The development of BIM systems has helped in storing this various information. However, the knowledge utilised in maintaining energy systems has also to be captured to develop a building portfolio that is comprehensive enough to benefit buildings’ owners, occupants, and energy managers. Capturing knowledge in digital format is always a challenge when developing such systems. Therefore, this research proposes an innovative means for capturing energy-related knowledge when monitoring and maintaining building performance by the integration of Spoken Dialogue Systems (SDS) with BIM models. SDS presents a natural language interface where the expert’s utterances are understood and answered back in speech format. The advancements in Spoken Dialogue technology will be employed to enable capturing and retrieving experts/occupants’ knowledge with the system interviewing the expert concerning the problem at hand. This interface will also allow easier searching for solutions to new problems with a more comprehensive retrieval of information.

Keywords: BIM, Knowledge systems, Spoken Dialogue Systems

INTRODUCTION

To operate and maintain the various complex energy systems used by buildings’ occupants, different types of information that is generated over the various phases of building’s lifecycle should be available. As the generation and collection of building information is commonly fragmented, created over the building’s lifecycle by different teams with different objectives, stored in different systems, the integration of this information is a complex process. In this respect, various studies have been conducted to develop ontological framework for the different types of energy-related information that can be used during the design, construction, and operation phases of buildings lifecycle to monitor building performance. With the recent development in Building Information Modelling (BIM), the research in this area has moved towards BIM-based frameworks which make use of the intelligent capabilities of BIM models, such as: the ontology proposed by Lee et al (2008) and by Venugopal et al (2012). Motawa and Carter (2013) developed an ontology for energy management in buildings to be integrated with building models via the advanced BIM platforms to spatially orientate necessary information. The study recommended that a knowledge system for monitoring and maintaining building performance would advance the proposed ontology and transform the typical information model of buildings (as it is currently developed) into an innovative knowledge model. Knowledge systems usually capture the experiences of professionals and store pervious operational and maintenance cases with all lessons learned and solutions adopted. The stored knowledge is later used by Energy managers to guide on solutions for new problems. With the most recent development in the integration of BIM systems with knowledge systems, the concept of “Building Knowledge
Modelling” has been established. In this respect, Motawa and Almarshad (2013) developed a knowledge-based BIM system which integrates case-based reasoning into BIM systems to capture and retrieve the information and knowledge of building maintenance.

Based on this previous efforts, this research proposes an innovative means for capturing the knowledge created by Energy Managers when monitoring and maintaining building performance in order to achieve Energy Efficient Buildings. The research will integrate Spoken Dialogue Systems (SDS) with the knowledge-based BIM system developed by Motawa and Almarshad (2013). The following section will briefly review the use of BIM and knowledge systems for building performance and management. SDS will be also reviewed with its potential benefits for this research. The architecture of the proposed system will be later illustrated followed by a case study to show how the proposed system works.

BIM AND KNOWLEDGE SYSTEMS FOR BUILDING MANAGEMENT

BIM as a process and technology can provide greater consistency of construction information when dealing with energy performance and ‘carbon’ accounting in buildings. Designers can use BIM applications to analyze how much energy the building will use, what are the anticipated CO₂ emissions and if the building will pass performance criteria (such as: LEED or BREEAM). For the post-occupancy stage which can be classified under Facility Management (FM), buildings need further analysis for critical decisions to ensure that the energy criteria of the design are really met in practice, which can be also facilitated by using BIM technology. In FM literature, there are several BIM-focused studies aimed at improving FM practices for the functions of locating components, facilitating access of real-time data, checking maintainability, automatic creation of digital assets, quality control and assurance, energy management, and space management (Becerik-Gerber et al. 2012). Among these applications there are: BIM based package for the FM Exemplar project of Sydney Opera House (Akhurst and Gillespie 2006), AROMA-FF which is developed to utilise data including BIM databases to obtain information and geometric representation of facilities and equipment (Lee and Akin 2011), and the web-based Facilities Maintenance Management prototype decision support system (Hao et al. 2010). Whereas BIM related systems mainly focus on utilising technical information and allowing the access to multiple databases, they generally do not consider the knowledge gained during the stage of maintenance and operation of buildings.

On the other hand, several Knowledge Management (KM) systems have been revolving around managing knowledge in FM. The concept of KM has been utilised to improve performance, reduce cost, increase efficiency and quality. Ali et al. (2002 and 2004) introduced a prototype KM system to improve the management of Reactive Maintenance projects. Other examples include: the web-based system “Consulting Knowledge System” by Lepkova and Bigelis (2007), and “Building Maintenance Community of Practice” by Fong and Wong (2009). The chief objective of such applications is the improvement of knowledge sharing and communication between stakeholders. As new levels of efficiency in sharing information and knowledge have been emerged, the integration of BIM systems with knowledge management tools to capture and retain the operational knowledge has been proposed. This is to enable further development of BIM systems from the focus on technical and geometric data to incorporate non-technical and non-geometric knowledge associated with building practices.

In addition and for knowledge systems, there is always the problem of capturing knowledge in digital format for future use. The traditional way is done by asking
professionals after they finish an operation to describe their experience of dealing with the problems and enter this description into a designed knowledge system. This task is always tedious and considered as additional work load, if at all completed. Therefore, this research aims to investigate the use of Spoken Dialogue Systems (SDS) for knowledge capture in the proposed BIM-based knowledge systems.

SPOKEN DIALOGUE SYSTEMS (SDS)

SDS are human-computer interfaces that converse with a human user using natural language speech in input and output modalities to complete a task or solve a problem. These systems provide the user with a very natural means of interaction with a computer. SDS technologies include: speech recognition, parsing and understanding, dialogue management, utterance generation and speech synthesis modules. Over the past years, several task specific dialogue systems have been developed. There are systems that provide flight schedule information (Seneff and Polifroni (2000); Levin et al. (2000); Rudnicky et al. (2000)), town information (Johnston et al. (2002); Lemon et al. (2006)), bus information (Raux et al. (2003, 2005)), and weather reports (Zue et al. (2000)). Dialogue systems are also used as in-car applications for music track selection (Hassel and Hagen (2005); Becker et al. (2006)), news and route advice (Rogers et al. (2000)), tourism and navigation (Janarthanam et al (2013)). Dialogue interfaces are also finding their way into multi-modal systems that include other modalities like gestures and GUIs (Lemon et al. (2001); Lopez-Cozar et al. (2005)). Dialogue interfaces have also been widely used in intelligent tutoring systems that interact with students to help them learn and solve problems (Graesser et al. (1999); Litman and Silliman (2004); Jordan et al. (2006); Callaway et al. (2007)). Recently, the focus has shifted to more complex domains like Self-Help, where the system engages the user in technical tasks like troubleshooting (Acomb et al. (2007); Boye (2007); Williams and Young (2007)). For instance, the system could help the user troubleshoot the broadband connection by requesting information and providing instructions. If developed with KM systems, SDSs can act as interactive expert agents that seek answers from the users for questions specific to the problem and help searching for solutions from the previously stored knowledge cases, which is the purpose of this research.

A standard architecture of a dialogue system is shown in Figure 1. The user’s utterance (in the form of acoustic speech signals) are converted to a stream of words by the automatic speech recogniser module. The semantic parser is a Natural Language Understanding (NLU) module converts the stream of words into semantic frames called “Dialogue Actions” which give meaning representations of the user’s utterances. The user dialogue actions are analysed by the Dialogue Manager (DM) and an appropriate response is formulated in consultation with the current state of the dialogue and the backend application. The system speech action produced by the DM is translated into utterance form by the Natural Language Generator (NLG) module and then is converted into acoustic signals by the speech synthesizer (or Text-To-Speech (TTS)) module.

However, designing a dialogue system is more than putting together these modules. Although these modules are necessary, what makes a dialogue system natural and effective is its ability to coordinate these modules in a natural conversation with its dialogue partner. This task is the responsibility of the DM which manages the conversation using a plan, called the dialogue policy (or dialogue strategy) that maps any dialogue state to a dialogue action. The dialogue state maintains the system’s knowledge, beliefs and observations of its environment (i.e. its current user), dialogue history, and goals. An enriched state may also contain the modality of interaction, and the user’s profile containing his level of expertise, and cooperativeness. Speech actions that the DM can select include for example, greeting the
user, requesting more information, presenting the results of the task, confirming existing information, and closing the dialogue. Dialogue policies can be manually coded for different tasks and situations. When there is a large number of factors affecting the dialogue (i.e. larger state space), manual coding can be difficult. One of the solutions to this problem is to learn the policies from human-human or human-machine dialogue data. For this research, SDS will be used to capture Energy Managers knowledge when dealing with Energy related problems in buildings and integrate this captured knowledge into the BIM model of the building. The following section will illustrate the architecture of the proposed system.

![Figure 1. Spoken Dialogue System – Architecture](image)

**SYSTEM ARCHITECTURE**

The proposed system, shown in Figure 2, integrates three modules: the BIM module to capture/retrieve the information of the building, the Case-Based Reasoning (CBR) knowledge module to retrieve the knowledge gained when dealing with energy problems in buildings, and the SDS module to verbally capture the energy-related knowledge.

![Figure 2. Main modules of the proposed system](image)

The virtual projects developed by the BIM-based environment (Autodesk Revit is the BIM environment used for this research) comprise elements such as wall, door, footing, etc. Further parameters have been added to the BIM model for building elements that comprises knowledge case details and categorisation which are mainly adopted from the taxonomy developed for this research, as shown in Table 1. Capturing knowledge/information cases
involves filling the fields of parameters with case details. These details are converted from the dialog captured by the SDS, which will be processed by the CBR knowledge module.

The taxonomy adopted for the knowledge cases in the proposed system is mainly based on findings from literature. Further research is sought to upgrade this taxonomy by conducting further case studies on managing energy in buildings. In order to distinguish between cases in the CBR module, certain attributes were assigned to the parameters of the taxonomy of the knowledge cases in order to query solutions of similar cases from the stored cases in the system. Dissimilarities between such attributes will lead to matching differences between the knowledge cases. Nearest-neighbour technique is implemented to retrieve the most similar case to a query by identifying and ranking the cases. Details on the algorithm adopted for the CBR module are beyond the scope of this paper. In order to use CBR in problem solving, a weighting score should be assigned to each attribute of a knowledge case. Assigning these scores are based on the influence of an attribute on the retrieving process. For this research, equal scores were assigned to all attributes. With the further research proposed to update the identified knowledge taxonomy, updated scores would be assigned to each attribute according to the judgement of building managers.

In the developed prototype of the SDS module, there are dialogue manager and a speech synthesiser module. The prototype does not include semantic parsing and utterance generation modules for experimental purposes at this stage of the study. The dialogue manager module uses a script in which the questions are prepared and coded in eXtensible Markup Language (XML). This script consists of a series of questions concerning the maintenance issue that will be put to the expert. The expert can answer these questions using speech input. Each question is displayed on the screen as well as spoken to the expert using a speech synthesis module. The answers are converted into text strings by the speech recognition module. These recognised text strings are then stored in the knowledge base as a XML script linked to the appropriate component of the BIM model. The knowledge base expands by capturing various maintenance cases which enable the CBR module to acquire the closest case when searching the knowledge base for new problems.

### Table 1. Parameters of the knowledge case in the BIM module

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Description</td>
<td>Problem description.</td>
</tr>
<tr>
<td>2. Classification</td>
<td>The technical classification of the problem.</td>
</tr>
<tr>
<td>3. Domain</td>
<td>The issue that the knowledge is related to.</td>
</tr>
<tr>
<td>4. Location</td>
<td>The location where the problem occurred.</td>
</tr>
<tr>
<td>5. Element</td>
<td>The element affected by the case.</td>
</tr>
<tr>
<td>6. Root causes</td>
<td>Description of the root causes of the problem</td>
</tr>
<tr>
<td>7. Reaction/Solution</td>
<td>The reaction/solution to the case.</td>
</tr>
<tr>
<td>8. Side-effect</td>
<td>Description of any additional or follow-up operations</td>
</tr>
<tr>
<td>9. BIM info</td>
<td>The BIM related information to the problem.</td>
</tr>
<tr>
<td>10. Other info</td>
<td>Other related information to the problem</td>
</tr>
</tbody>
</table>

The system uses an IFC protocol to integrate building models with the knowledge system. When uploading a BIM model for a particular building, the developed IFC protocol
extracts the building details from the BIM environment including the classified knowledge for energy-related cases which are then organised and stored in the knowledge base to be later searched for solutions.

**CASE STUDY**

The proposed system has been applied to maintain a complex of commercial buildings. One example is shown in Figure 3. When the expert (Facility/Energy managers) identifies the building element in the BIM model that has an energy problem and needs maintenance or repair, all details of the element and the added parameters will be shown. In addition, the details of the case are acquired by the system using the dialogue interface, as shown in Figure 4. In contrast to existing approaches where experts are asked to type in their experiences in dealing with the issue into a text box, the system acquires expert knowledge as an interviewer and presents the expert with a series of questions concerning the different dimensions of the problem at hand. Instead of typing the answers to the questions which are at the same time the required input in the parameter fields, the expert can switch to the voice mode of the system and answer the questions one by one. The answers to the questions will be then converted by the SDS module and stored into the knowledge base. Once all questions are answered, the user can search the knowledge base to retrieve the closest previous case to the new one and investigate the adopted solution. This is done using the developed CBR module. An example of the search results is shown in Figure 5.

![Figure 3. The BIM model of the case study building (output from Revit)](image)

The proposed system has the ability to seek relationships between cases of several elements using the intelligent features of BIM objects. By tracing history of work and identifying related problems, this feature can provide professionals with a comprehensive understanding of issues related to their maintenance works. The proposed system identifies the spatial relationships between elements that are provided by the IFC schema. The system then clusters elements along with the associated cases into groups. Whenever a case has been
searched and demonstrated, related cases of the same spatial group are presented. Figure 6 illustrates an example of the system output for this particular maintenance case and details of related cases.

**Figure 4. The dialogue interface to capture the knowledge case**

![Image of dialogue interface]

**Figure 5. The results of search the knowledge base using the CBR module**

![Image of search results]

**CONCLUSIONS**

The research in the area of BIM is dramatically growing and the next generation of BIM technology is seeking to establish the so called “Building Knowledge Modelling”. In this respect, an intelligent knowledge-based BIM system has been developed and presented in this paper to capture and retrieve energy-related information and knowledge of buildings. The
The proposed system is distinguished from previous responses to capture construction knowledge as it will establish new ways to integrate various modals for information/knowledge capture and retrieval in an integrated system. As a great step forward was achieved by incorporating knowledge systems into BIM environment, this proposed system will mark the start of another dimension to this development by bringing the Spoken Dialogue Systems (SDS) technology to establish a new research programme. The advancements in Dialogue technology to handle data from various input and output modalities to generate a conversational interface was employed in the proposed system which seeks to have a conversation with a user. This will enable energy experts/managers to freely store their knowledge on energy problems/solutions in buildings. It allows easier searching for solutions to new problems with a more comprehensive retrieval of information. The system acts as an interactive expert agent that seeks answers from the user for questions specific to the problem and help searching for solutions from the previously stored knowledge cases. The main conclusion from the study is that the practices of monitoring and maintaining building performance including energy use can be improved by integrating SDS with the knowledge-based BIM systems.

![Image of system output]

**Figure 6. System output for a particular maintenance case and related cases**

**REFERENCES**


