A framework to leverage BIM for knowledge management in AEC projects

Abhijeet Deshpande\textsuperscript{a}, Salman Azhar\textsuperscript{b}, Shreekanth Amireddy\textsuperscript{a}

\textsuperscript{a} Department of Civil Engineering, Auburn University, Auburn, AL-36849, USA
\textsuperscript{b} McWhorter School of Building Science, Auburn University, Auburn, AL-36849, USA

Abstract

Knowledge is generated in projects throughout the design and construction processes in Architecture/Engineering/Construction (AEC) projects. The management of this knowledge has been implemented by various firms in AEC the industry through the development of lessons learned databases, best practices, project closeout interviews, communities of practice and various other informal techniques. In the traditional project processes which don’t use building information modeling, the data generated through the project life cycle is typically stored in a fragmented manner in multiple formats. This makes it difficult to capture, catalog and disseminate the knowledge present in the data effectively. The objective of the research study described in this paper was to identify the ways in which Building Information Models can be used for effective Knowledge Management. Building Information Models are data-rich, object-based, intelligent and parametric digital representations of building structures. In this research, we hypothesize that the parametric models used in building information modeling can provide a centralized global context to the information stored therein and thus be an effective tool as a knowledge store; provide support other knowledge management processes. In this paper, we present a method to capture knowledge during the design and construction processes using the parametric, object oriented nature of the BIM models; extract the stored knowledge from the BIM models. Finally, we present a framework to enable the use of Building Information Models to support the organization wide Knowledge Management processes.

Keywords: Knowledge Management, Parametric Design, Virtual Design and Construction, Building Information Models

1. Introduction

AEC projects inherently involve the creation of unique designs to satisfy owner’s aesthetic and functional requirements and construction processes to convert those designs into tangible products. In most circumstances, the stakeholders involved in the project collaborate to achieve the required outcome and once the project is delivered, they disband and move on to the next project. The uniqueness of the design, construction processes and the inherently uncertain nature of construction requires creativity on the part of designers and constructors to ensure successful execution of the project. The ingenuity and experiential knowledge plays an important role in the decision making regarding construction means and methods, identification and implementation of solutions to problems (Ferrada and Serpell 2014). The construction phase of every project generates hands-on experience, problem solving capabilities, understanding of various means and methods and highly contextualized solutions. (Y-C Lin et al.2006). The knowledge generated throughout the lifecycle of a project is one of the most important assets of an AEC firm. Effective capture, storage, dissemination and reuse of this knowledge are critical for the successful execution of construction projects and thus vital for competitiveness and survival of the organization (Tserng and Yu-Cheng 2004).

Systematic management of knowledge can help in encouraging continuous improvement, sharing tacit knowledge, faster response to customers, disseminating best practices, reduction in rework (Carrillo and Chinowsky 2004). Additionally, the adoption of such practices may help transfer new knowledge to innovative practices, while helping to improve project performance by contributing to a greater understanding of innovation knowledge (Yang et al. 2011). Effective management of this knowledge is challenging for AEC firms on account of several reasons. The projects are often executed by transient teams that come together for a project. These teams are disbanded as soon as the project is complete. The knowledge gained collectively by the group of individuals participating in the design and construction processes is scattered across project teams (Fong 2005). Sometimes, the lessons learned during the project are not properly captured, stored or communicated to the potential user of this knowledge (Dane and Koskela 2009). This results in the repetition of avoidable mistakes.
which often have deleterious consequences to the project performance. Many construction organizations face
loss of knowledge when employees leave to pursue other opportunities on account of retirement. Extracting and
documenting knowledge post-hoc can be very challenging because the information on which this knowledge is
based is extremely fragmented. For example, the information may be stored in design documents which may be
in proprietary formats. The lessons learned in knowledge generated during the design review process may be
stored in a portable document file format. Additional knowledge may be scattered across the organization in
value engineering proposals, change orders, requests for information by the construction contractors, text
documents resulting from the post project reviews, organizational best practices etc. Building Information
Models provide a platform to potentially integrate the dispersed construction information with the data rich three
dimensional representation of facilities (Goedert and Meadati 2008).

1.1 A case for the use of BIM models for Knowledge Management

Virtual Design and Construction (VDC) / Building Information Modeling are revolutionizing the delivery of
AEC projects. In the last decade, Building Information Models have been successfully used to enhance project
performance by improving communication of the design between various stakeholders, by enabling the
identification of clashes ahead of time, by enabling the simulation of the construction sequence, and improving
the communication between various craft subcontractors and the general contractor. Building information
models are inherently parametric, data rich, object based representations of the facility being designed and
constructed. Alternately, building information models can be conceptualized as centralized, interconnected data
stores which can contain design and some construction information about architectural, structural, MEP and
HVAC systems. This centralized and integrated nature of the design information can potentially provide a very
context rich platform for the capture, storage and dissemination of the knowledge generated during the design
and construction processes. One of the requirements of an effective knowledge management system is its ability
in communicating and preserving knowledge effectively across various stages of a construction project (Dave
and Koskela 2009). BIM models can be effective in this regard because they span and evolve through the entire
design cycle from programming through the construction phase. Additionally, it is important to capture
knowledge as soon as the knowledge is created or identified so as to ensure that there is no loss of the generated
knowledge due to time loss or other constraints (Tan et al. 2012). BIM models can be thought of as stores of
knowledge (Meadati and Irizzari 2010). In this paper, we present a mechanism for “live” capture and storage of
the lessons learned during a project using building information models. This paper is structured as follows:
firstly provide a brief overview of the techniques and processes currently used by the AEC industry for
knowledge management. Secondly, we review published research on the subject. Thirdly, we describe a
mechanism to use BIM to capture and store, extract lessons learned. Finally, we discuss a framework for
integrating BIM into existing KM processes and scope for further research.

2. Review of the State of the Practice

AEC organizations around the world are recognizing the competitive advantage in managing their repository
of Knowledge. Some of the techniques commonly used include Post Project Reviews, Communities of Practice
(Tan et al. 2012), documentation and dissemination of best practices, lessons learned (Carrillo and Chinowsky
2004) expert directories and various tools based on intranets or extranets. Post Project Reviews is one of the
most commonly used tool for capturing the knowledge generated during the construction process. These review
sessions are typically conducted at the end of the project to discuss the lessons learned, problems addressed
during the course of the project (Egbu et al. 2003). This practice suffers from two key shortcomings.
Oftentimes, the knowledge generated in the project is forgotten by the end of the project if not documented
regularly. The participation of all key personnel is essential for the success of post project reviews. In practice,
project teams are disbanded before the formal completion of the project and key personnel move on to the next
project. Without a significant commitment in terms of organizational time and resources, the reviews may not be
an effective tool. Even when the reviews are done with proper care, the dissemination and real time access are a
challenge. These documents may not serve any purpose if they are placed in archives that are not easily and
universally accessible (Dave and Koskela 2009). Communities of Practice, also known as knowledge

...
being used to support various KM processes. Groupware systems typically support communication, coordination of activities and knowledge sharing among groups of people from multiple organizations and geographically dispersed locations. Its functionality can help manage and track information, documents, users and the applications they use. These systems offer the potential to maintain the project memory (Rezgui & Miles, 2011). However, groupware systems are not efficient for the exchange of more complex knowledge (Robertson et al., 2001).

3. KM Research in Construction

Knowledge Management has received a significant attention from the US construction industry and the construction research community world-wide over the last decade. Carrillo et al. (2003) developed a framework (IMPaKT) to enable AEC organizations to understand the business impact of their KM strategies. Tserng and Yu- Anumba et al. (2005) developed a tool (CLEVER_KM) to provide a structured approach to KM problem definition and strategy formulation for an AEC organization. Cheng (2004) presented an activity based Knowledge Management system for capturing the knowledge generated in the construction phase. Lin et al. (2005) proposed the use of knowledge maps for capture and reuse of knowledge in construction projects. Lee et al. (2005) developed a framework (Knowledge Document Management) for a web based portal which enables the user to search and read construction documents in different formats. Tan et al. (2007) developed a web based KM system (Capri.net) which allows for “live” capture of knowledge which can be subsequently used in the same project as well as future projects. Researchers have studied the issues associated with the definition for appropriate Ontologies and Taxonomies for the organization and useful retrieval of knowledge (Regzui 2006; El-Gohary and El-Diraby 2010,2011; Wang et al. 2011; El-Diraby 2013). A significant amount of research has also focused on the “people”, state-of the practice, and implementation aspects of knowledge management (CII 2013, Ferrada and Serpell 2011, Zhang et al. 2013, Javernick-Will 2012). Solibleman et al. (2003) discussed web based systems developed by the U.S. Army Construction Engineering Research Laboratory to collect personal experiences and lessons learned on projects, success stories and best practices and incorporate these data into corporate knowledge. Caldas et al.(2009) identified effective management practices and technologies for implementing lessons learned programs in construction organizations.

It is important to note that the social systems, such as communities of practice, Lessons Learned programs, Post Project Reviews etc. for knowledge sharing and the Information Technology tools for KM are complementary to each other. The information generated in a construction project resides in various formats across organizational boundaries. Despite their limitations, Dave and Koskela (2009) warn against underestimating the impact of Information Technology (IT) tools for management of Knowledge in AEC organizations. A majority of the problems associated with the use of IT technologies seems to be around how it is implemented and managed rather than the capabilities of IT tools. If used in conjunction with KM strategies, IT tools have the capability of positively influencing project performance in terms of schedule and cost success and quality and safety performance (Yang et al. 2012). In this paper, we propose that BIM models can be used to capture knowledge as it is generated throughout the design and construction processes.

4. Capture of Knowledge

The parametric, object oriented design is one of the defining characteristics of Building Information Models. The model consists of objects which are defined by various parameters. Each object is not defined by the geometry alone, but rather by parameters. These parameters and the parametric relationships between objects define the behavior of the object inside the model. Software vendors typically provide a basic set of objects which are universally required during the structural, architectural and mechanical systems designs of a building. In the AutoDesk REVIT® software, these objects are known as System Objects. Objects are classified in various families based on their function in the structure. For example in AutoDesk REVIT®, a typical concrete beam belongs to the “Concrete-Rectangular Beam” Family. Each concrete beam is defined by two parameters that define the dimensions of the beam (breadth and depth) and a number of descriptive parameters under the Identity Data category (Uniformat II Assembly Code, Description, Model No., Manufacturer Information etc.). Within each Family, multiple “Types” representing combinations of width and depth may be created. For example, 18” X 24” and 24” X 32” are two different Object “Types” within this Family. When the object is placed within a model, an “Instance” of the object is created.

In addition to the default parameters defined in the software, the user can also create a user defined “Shared Parameter” and associate it with a specific set of objects in the BIM model. For example, a “Shared Parameter”
called “Lessons_Learned_Concrete” was created and associated with Structural beam systems family. When an instance of a structural beam system is created in the model, the shared parameter is displayed as a property of the system (Figure 1).

![Figure 1. Shared Parameter for a Structural Beam System](image)

The Shared Parameters can be defined either as “Instance Parameters” or “Type Parameters”. If the shared parameter is created as an Instance Parameter, the information entered therein by the user will only be available at that particular instance of beam system in the model. On the other hand, if it is defined as a type parameter, it will be available to every instance of that type which exists in the model. Each of the strategies has its own advantages and pitfalls. The first strategy (defining as an “Instance Parameter”) can allow for vetting the information before it is published throughout the model, while the second strategy allows for instantaneous distribution within the model. An AEC firm can develop shared parameters strategically and deploy them to allow the users to enter the information as soon as the user learns something new/unique during the design or construction processes.

5. Extracting Stored Knowledge

The Shared Parameters discussed in the previous step can be deployed as early as the schematic design phase. The lessons learned and the new ideas generated can be extracted using two strategies. The organization can extract all the knowledge generated at the end of the project, vet it and share it across the organization. This strategy would potentially create a significant lag between knowledge generation and its dissemination. In the second strategy, the organization can set milestones during the design and construction processes when the knowledge generated and stored in the model can be extracted. This would allow for a shorter lag in dissemination of knowledge and spur continuous improvement.

As discussed previously, a BIM model can be conceptualized as a centralized object database. The knowledge stored in the database can be extracted in two ways. An application specific program can be written using the appropriate Application Programming Interface (API). This could potentially prove to be an effort that requires significant resources for the initial development and upkeep to stay current with the changing API. The second, easier, approach would involve the use of the Industry Foundation Classes (IFC) for data extraction. The IFC specification is an international platform neutral standard specification (ISO 16739) which is used to describe, exchange and share information between various software applications used in the AEC industry. AutoDesk REVIT® software allows the export of the BIM model as an IFC file, which is a structured ASCII plain text file.

The Shared Parameters and the information added by the users can easily be extracted from this file. The background information on the project can be extracted using the information associated with the relevant IfcPropertySingleValue and the associated IfcLabel. For example, the following line shows the information from the following line from the IFC file can be used to extract the project name (Birmingham Labs).

```plaintext
#1202= IFCPROPERTYSINGLEVALUE('Project Name',$,IFCLABEL('Birmingham Labs'),$);
```

Similarly information regarding the location, type, owner name, project stage, name of the designer can easily be extracted. This information can be valuable in the future when a user wants to know more information about the context in which knowledge was generated.
Once the relevant project related information is extracted then the user / program can extract the lessons learned / innovative ideas generated in the project. This information will be located in the IfcPropertySingleValue 'Lessons_Learned_Concrete', the corresponding IfcLabel will provide the actual text of the lesson learned / innovative idea. Additionally, one can also extract the “Mark” of the element. This will identify the location of that particular element in the model. If another person wants to get the complete context under which this information was entered, they can open the BIM model and look for that particular element. Once all the lessons learned are extracted, they are then classified. This classification can be performed using a classification system that is appropriate for the organization. The classified information should then subsequently be vetted by subject area experts for its accuracy and appropriateness. Once vetted, the new knowledge can be published to personnel working in the same specialty and stored in a centralized database for future reference and use.

6. Building Information Models and Knowledge Management

The following figure (Figure 2) describes a conceptual framework for using the method described in this paper for enhancing Knowledge Management Systems in an AEC organization.

In the first step, appropriate Shared Parameters are created and deployed, preferably at the beginning of the project. As new lessons are learned, knowledge is generated through design reviews, errors and omissions, request for information from contractors and unique situations encountered at the site, these can be entered in the BIM model. At various stages of the design process and during the construction phase, the BIM model is exported in IFC format. The relevant knowledge can then be extracted. This information is then classified and vetted by experts in the subject area. After this, the knowledge generated can be published to other BIM projects in the organization using project standards. At the same time, the Knowledge can be archived for future use in a database. This database can contain information about project team, lessons learned and a link to the location of the IFC file. The IFC file can be easily viewed by free software such as the Solibri Model Checker. As many experts have pointed out, information technology is only one of the tools for effective knowledge management in an organization. BIM models should be used in conjunction with other KM methods such as Communities of Practice to get its full benefit.

7. Concluding Remarks

Building Information Modeling is increasingly being used by AEC organizations to improve project performance. The centralized and integrated nature of the design information in BIM models can provide a very context rich platform for the capture, storage and dissemination of the knowledge generated during the design and construction processes. A methodology for leveraging the inherently object oriented, parametric nature of BIM models for capturing lessons learned, innovative ideas, and knowledge generated during design and construction processes is presented in this paper. A framework for integrating this methodology in the existing KM practices is also presented. We are currently continuing this research. The remaining work includes the identification of appropriate ontologies and taxonomies for this method and the design of database for storage of the knowledge. We are also in the process of identifying an AEC firm to implement some of these ideas in a live project environment. Lastly, this could be one of the tools in a toolbox for management of knowledge generated in AEC projects.
Acknowledgements

The authors would like to acknowledge the financial support provided by the Auburn University Intramural Grant Program for this research study.

References


