Parametric Building Information Models For Knowledge Management

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The 2012 BIM SmartMarket report published by McGraw-Hill states that construction contractors are increasingly adopting Building Information Models in managing their operations. Building Information Models are being used in the construction industry for clash detection, cost estimating construction sequencing, preparation of construction documents etc., to increase the efficiency and reduce the overall budget of construction. Building information models are essentially databases of parametric objects. This paper proposes Building Information Modeling (BIM) as a tool for capturing, storing and sharing knowledge in the construction industry. The parametric nature of objects contained in a typical building information model can be leveraged to capture and store knowledge gained in that particular project. The gained knowledge then can be vetted and shared across projects by sharing the parameters about the object. Finally, this paper also describes how Building Information Models can be used in conjunction with the extant knowledge management tools to potentially improve their effectiveness.

Key Words: Knowledge Management, Building Information Modeling, knowledge, lessons learned, construction.

Introduction

Knowledge Management (KM) can be defined as a systematic and organized attempt to use knowledge within an organization to transform its ability to store and use knowledge to improve performance (Rezgui, Hopfe, & Vorakulpipat, 2010). The competitive advantage of an organization is dependent on the knowledge of its employees and its capability to harness the knowledge for meeting its business objectives, for continuous improvement and for not repeating errors and mistakes from past projects (Tan et al., 2009). According to Dave and Koskela (2009), knowledge is a significant organization resource which provides competitive advantage to construction organizations when used effectively. The storage of knowledge/lessons learned from the previous project is a crucial factor in retaining a construction organization's knowledge.

Each construction project is unique in its design, execution processes, and budgetary limitations, environmental and organizational conditions. The project team consists of various stakeholders who contribute their area of expertise for the successful completion of a project. The flow of information among the various stakeholders needs to be smooth for the timely completion of the project. Although each construction project is unique, there are processes/special conditions which require designers and construction professionals to reference knowledge gained from similar projects to solve the problem on hand. Often such experience is brought to the project by experienced project managers who are familiar with such experiences/situations from past projects. It is also important for an organization to retain such knowledge after the retirement of the experienced personnel from the organization. It helps in problem solving and troubleshooting, thereby increasing the efficiency of the output. The reuse of existing organizational knowledge gained via past experience can greatly reduce the time spent on problem solving and increase the quality of work. (Dave and Koskela 2009)

Due to the fragmented nature of the construction industry, critical mistakes are sometimes repeated and hence knowledge management processes are very important to capture project based knowledge to enhance organizational performance across projects. It is important to capture and share the knowledge generated on construction projects between the project team members for continuous improvement, to avoid repetition of previous mistakes and to prevent finding same solutions to the same problems over and over again. The construction industry is very competitive in nature with low profit margins, which makes knowledge management appear attractive (Carrillo & Chinowsky, 2006). Despite the growing awareness of KM to the industry, limitations such as loss of knowledge due to time lapse in capturing the knowledge, high staff turnover and reassignment of people still remain a problem. It is therefore crucial to capture and present the knowledge in a format that will facilitate its reuse during and after the project (Tan et al., 2006).

While information and communication technologies (ICT) offer numerous solutions to implement knowledge management, the construction industry has traditionally been relatively slow in adopting these technologies when compared to other industries like automobile and manufacturing to improve efficiency of its processes. However, the construction industry has made significant efforts to embrace ICT solutions during the last decade. (Dave & Koskela, 2009) This paper suggests BIM as a potential ICT tool to overcome some of the limitations of knowledge management in construction. This paper discusses the existing knowledge management models along with their limitations, then describes the role of BIM in construction industry and proposes a methodology to store the lessons learned during the project design and construction in the BIM model.

Literature Review: Existing Knowledge Management Models

Knowledge Management practice in an organization depends significantly on the use of various KM tools (either IT-based or non-IT based). Some of the important KM techniques and technologies used by the construction include (Tan et al., 2009):

Post Project Reviews (PPRs)

The most common approach to capture the learning from the projects in the construction industry is the post-project reviews (PPRs) (Orange et al. in Tan et al., 2009). PPRs are the review sessions conducted at the end of the project to discuss the lessons learned, problems addressed during the course of the project. PPRs are important to capture the knowledge about the causes of mistakes in design and construction process, how these mistakes were addressed by the project team and the best practices identified in a project (Egbu et al., 2003). The inherently project based nature of construction means that project teams are split up after the completion of a project. PPR is considered to be the last chance an organization has to capture the learning from the project so that it can be transferred to other projects.

PPRs give the project personnel an opportunity to learn valuable lessons from the experienced project manager who conducts PPR. However, Tan et al., (2009) state that there are indications that the current practice does not provide an effective framework for the capture and reuse of learning. For this technique to be used effectively, adequate time should be allocated for those who were involved in a project to participate (Egbu et al., 2003). But insufficient time for post project evaluation is a common problem as the relevant personnel are many times transferred to other projects where their skills are needed. Additionally, there is a problem of loss of important insights or knowledge due to the time lapse in capturing the learning. Hence, a successful technique would be to add important insights as soon as they are discovered and also not at the end of the project but during the course of the project. With the proposed method such knowledge can be added to the knowledge database during the course of the project and then added to the BIM model for future references.

Communities of Practice (CoPs)

CoPs generally consist of design and construction professionals who share a passion about a discipline specific subject, and who interact with each other to deepen their knowledge and expertise in this area. CoPs are also called communities of interest, knowledge communities, learning communities, knowledge networks and thematic groups. CoPs usually consist of members who possess different skill sets, development histories and experiences but work together to achieve commonly shared goals (Tan et al., 2009). Therefore CoPs provide a platform for their members to pool their experience, expertise, and ideas, and to find solutions. Also, new knowledge can be created in CoPs through an incremental improvement of an idea during a brainstorming session. It is also possible to produce organization wide best practice guides from the results of CoPs members' interactions and discussions. Web based forums can be used to foster geographically dispersed CoPs.

Lessons Learned Programs

Succession planning and management by the organizations is concerned with the identification of the gaps which are likely to occur due to the anticipated future changes or known factors such as retirement and reassignment (Tan et al., 2009). According to a recent study conducted by the Construction Industry Institute (2013), construction industry is likely to lose a significant amount of knowledge base due to the experienced baby boomer generation employees leaving the workforce due to retirement. These employees possess a knowledge inventory accrued through the lessons learned from their long career of successes and failures in the construction field. Often this knowledge base is the foundation of decisions that reduce the repetition of critical mistakes, foster innovation, enhance overall efficiency and enable new growth strategies. Traditional practices aim to replace the individuals who are about to retire but often make cursory efforts to retain their knowledge prior to their departure. The study also reveals that there is a shortage of qualified individuals who will be able to fill the resulting employment gap. This affects the organization's capacity to compete successfully. Another approach which the organizations follow is promoting mid-level employees to fill the seats of the experienced employees. However, this approach fails to replace the experiential knowledge possessed by the departing professionals.

Knowledge bases

"Knowledge bases are repositories that store knowledge about a topic in a concise and organized manner" (Egbu et al., 2003). They can be information that can be found in a book, code, websites, human knowledge, lessons learned or best practices followed.

Data and Text Mining

Data and text mining refers to a technology to extract knowledge from text documents. The process of data/text mining enables extracting interesting and meaningful patterns and association of data (words or phrases) to be identified from one or more large databases (Egbu et al., 2003). In the text mining the patterns are extracted from natural language text while in data mining the patterns are extracted from datasets (Tan et al., 2009). The main purpose of data and text mining is to support knowledge discovery process in large document collections (Tan et al., 2009). However, this technology is not widely used as it is difficult to access data via an enterprise-wide corporate portal (Egbu et al., 2003).

Groupware Systems

Groupware is a software product that supports communication, coordination of activities and knowledge sharing among groups of people from multiple organizations and geographically dispersed locations (Tan et al., 2009; Egbu et al., 2003). Its functionality can help manage and track information, documents, users and the applications they use (Rezgui & Miles, 2011). "It offers the potential to maintain the so-called 'project-memory' and record all lessons learnt in a way that promises re-use" (Rezgui & Miles, 2011, p.55). However, groupware is less efficient for the exchange of more complex knowledge (Tan et al., 2009; Robertson et al., 2001). Also, there is a strong reluctance in the construction sector to fully use groupware solutions (Rezgui & Miles, 2011).

Intranets and Project Extranets

An intranet is a computer network system that uses internet to share information within an organization while extranet is a network with limited access to outsiders for the exchange of information and knowledge. The advantage of these systems include a consistent and structured approach to sharing and updating documents within and among organizations resulting in the overall improvement in the quality of documents (up-to-date and timely fashion) (Rezgui & Miles, 2011). The intranet is not a solution in itself but they facilitate communication across different web-based applications (Tan et al., 2009). The main issue with project extranets is the security of information stored, cost of implementation and legal issues to the ownership of data (Ruikar et al in Tan et al., 2009).

The techniques and technologies presented above have been used in the construction industry for a while in a fragmented manner but none of them have received wide spread acceptance. Therefore an approach which is not entirely new but has a potential to be the solution to the problem must be designed. BIM has received wide-spread acceptance from the industry and is slowly becoming a standard operating practice in the design and execution of construction projects. This paper proposes a way to leverage this technology to store and share knowledge gained during the construction process.

Building Information Modeling

Building Information Modeling can be defined as “a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder” (NBIMS, 2010). Building Information Modeling is revolutionizing the way capital projects are conceived, designed and constructed. Design of any building is inherently an iterative process where various designers continuously revise and refine the design as increasingly specific design information becomes available. The BIM models centralize all the components of the building including the architectural, structural, HVAC and MEP components in a centralized three dimensional model. BIM is changing the workflows in design and construction from isolated discipline specific silos to a more collaborative design processes. Thus, from a process perspective BIM can be viewed as a virtual process that encompasses all the aspects, disciplines and systems of a facility within a single virtual model. The process component of BIM enables close collaboration and encourages integration of the roles of all the stakeholders on a project. The technology helps stakeholders accurately visualize what is to be built in a simulated environment to identify any potential design, construction and operational issues (Azhar et al., 2012).

The Building Information Models created through the design process can then be used by construction contractors to efficiently plan construction operations. The building model can be used for 3D rendering, proposals can be better understood through visualization, it can be used for shop drawings, code reviews, cost estimating, construction sequencing. Since the models are created to scale in 3D space, all the major systems can be visually checked for conflict, interference and collision detection. BIM provides dynamic decision-making information throughout a project lifecycle and the information encapsulated in the model synchronizes with various construction practices ranging from design, execution, operation, maintenance, renovation etc. ((Lu & Li, 2011).

These models are sometimes referred to as n-Dimensional models because construction contractors can add temporal (schedule related) data and cost related data to the model. Goedert and Meadati (2008) identified the potential of using BIM models are repositories for contextualized storage of construction documents and presented a menthod for using shared parameters to store web links to construction documents stored externally on the web. We believe that the model can be further enriched by adding knowledge component to it, helping capture and store any relevant lessons learned or any important information necessary for efficient execution of the project. Researchers caution that that with such a rich data, describing every detail of a project component, “BIM would be too unwieldy and the overwhelming amount of data would be impossible to maintain” (Bazjanac, in Suermann, 2009). Bazjanac argues that a successful BIM should include “pointers” to external databases which are being maintained up to date (Suermann, 2009). Extending on these concepts, our paper tries to accomplish the same by including all the lessons learned in the BIM model attached to the appropriate components but also recognizes the need for an organization to maintain an external database which includes all the lessons learned and is updated regularly with new knowledge.

Parametric Design

Building Information Models are inherently object based parametric models. Each component of the structure designed in a building information model is an object. For example, in a BIM model, each isolated foundation is an object. In parametric design, each object is not defined by fixed geometry and properties, rather each object is represented by parameters that control the behavior of the object. These parameters control geometric as well as non-geometric properties of the object. In addition, each object is defined by parametric rules that define the behavior of the objects in the model. For example, a simple rule defines that windows can only exist within walls. This rule controls the behavior of the window object within the model. The window object and wall object are related by this parametric rule. The parametric rules also allow the objects to automatically update on the basis of changed context.

Software vendors typically provide a predefined set of object classes that implement the basic behaviors required from building objects. In case of AutoDesk REVIT® platform, these objects are known as *System Families*. For example, in the Structural modeling component of REVIT®, *Concrete-Rectangular-Column* is a *Family* under structural columns. Each family can have multiple *Types* that exhibit the same behavior. This behavior is defined by two parameters, breadth and height. Thus, by changing the values of the parameters, multiple *Types* of objects can be generated. For example, under the *Concrete-Rectangular-Column* family, one can create objects representing columns of various sizes such as 18” X 24”, 12” x 18” etc (as shown in *figure 1*). Thus, even though each *Type* represents certain specific parameters, every object under that type exhibits exactly the same behavior. When a user places an 18” X 24” concrete column in their structural model, they are creating an instance of that particular *Type*. Many instances of the same Type can exist in the same model. While each *System Family* possesses a predefined set of parameters, the software allows each user to define custom parameters. Once these parameters are created, grouped under a specific category and applied to a certain category of objects (say Columns), each column created in this fashion will have a user defined parameter associated with it.

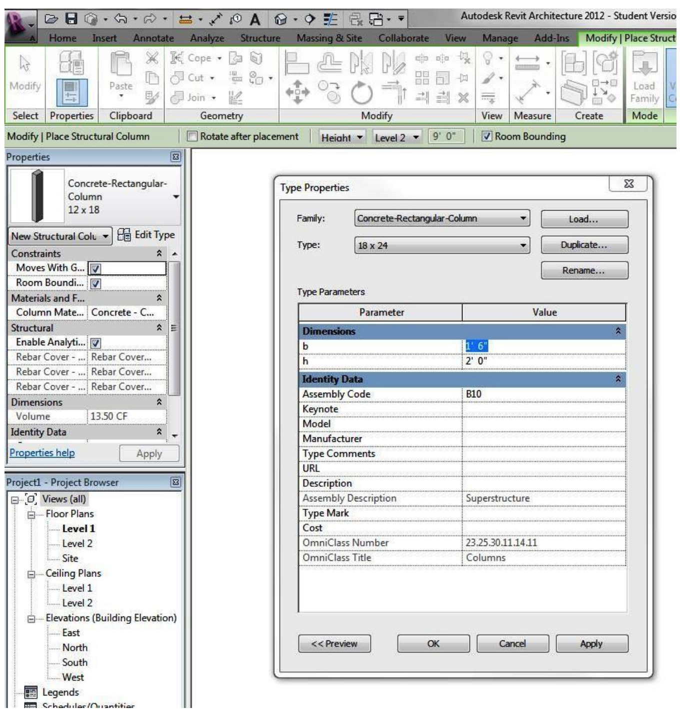

Figure 1: Creating an 18” X 24” concrete column *type* under *Concrete-Rectangular-Column* family in the REVIT

Capturing Lessons Learned Using Parameters

This flexibility in parametric modeling can be leveraged to capture lessons learned in the BIM model itself. This process is explained using AutoDesk REVIT® platform as an example. REVIT® allows the user to create parameters called *Shared Parameters*, which can be shared across projects. These shared parameters are interpreted by the software in the exact same way in every project that they are used. Additionally, shared parameters can be grouped together based on the user preference. Meadati and Irizzarry (2010) developed a methodology that uses shared parameters to store additional information in stored parameters so that the models can be used as a knowledge repository for residential construction process teaching and learning applications.
The following steps can be used to capture lessons learned or the knowledge generated in a project:

1. Create a *Shared Parameter Group*. (say Lessons Learned)
2. Under this *Group*, create a new *Shared Parameter* (say Structural Column lessons)

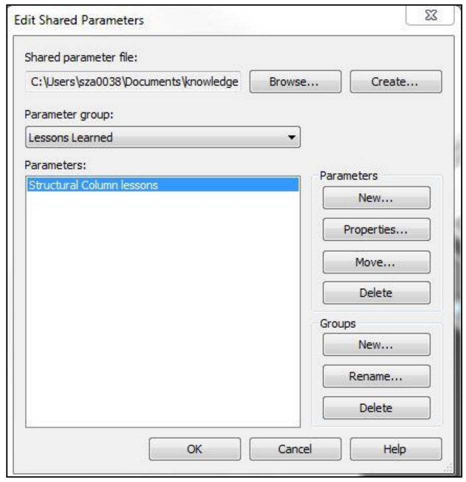

Figure 2: Creating a new shared parameter in Revit Architecture

3. Add the newly created *Shared Parameter* to the list of already existing project parameters.
4. Once the newly created *Shared Parameter* is added to the project within REVIT®, the user can start using the parameter to add any lessons learned to it.
5. The user can add the *Shared Parameter* either as a type or instance property. If the user creates a *Shared Parameter* as a *Type Parameter* and adds information to it, it is attached to all the similar *Type* objects in the project. For example, if the user creates a ‘Structural Column lessons’ *Shared Parameter* as a *Type Parameter* and assigns structural columns to it, the information added to this parameter can be seen on all the structural column *Type* it is attached to. If the user adds it as an Instance Property, it is available only for that particular instance of the project.

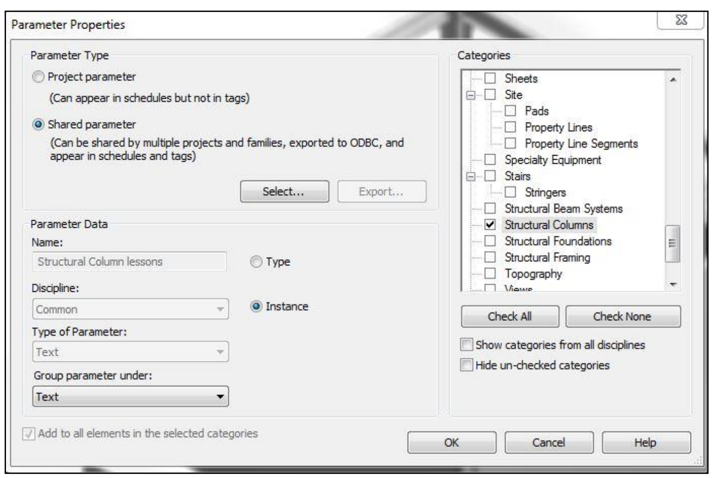

Figure 3: Adding the new shared parameter into the project as an instance property

With some pre-planning, various well-structured *Shared Parameters* can be created by a design or construction firm at the beginning of the project. These *Shared Parameters* can then be used by various users of the BIM model to enter the lessons learned during the design or construction of that particular component. This is a very powerful idea because it provides a data-rich multi-dimensional context to the stored knowledge. When another user accesses this lesson learned, that user can get a verbal description of what went wrong and how the error was fixed or innovative idea was used in the context of a three dimensional model. This is the unique strength of this approach of capturing lessons learned or new ideas using a Building Information Model.

After adding the lessons learned/ knowledge to the model, the organization can extract all the knowledge that has been added using shared parameters and validate it. Once validated, this knowledge can then be stored in a database for reuse in future projects or add them to any customized objects of the organization. This can be easily achieved by exporting the REVIT® model into an ifc format (text), then using ifc file analyzer or any other appropriate software extract the knowledge that has been attached to the shared parameters. The lessons learned can then be copied and the knowledge database of the organization updated. This knowledge database can contain pictures, animations and links to the actual REVIT file where the lesson was learned. This can be a very powerful tool for transferring knowledge because it provides a very data rich context to the knowledge generated. This methodology can also be used in a reverse fashion. Say, a company already has a knowledge database and wants to provide the required knowledge to the necessary personnel during the execution of a project. The company can appoint a person to add the required knowledge to the appropriate components within the BIM model so that the project personnel will refer to the information during the execution of that particular component.

Uses of the Proposed Methodology

By providing right information to the right person at the right time, an organization can save time and money in a construction project. It eliminates the potential mistakes that can otherwise be created. With the proposed methodology, the project personnel can refer the knowledge (lesson learned) attached to the BIM model during the design or construction phase to avoid mistakes from the past or reuse innovative ideas developed in other projects. Organizations can create customized object(s) based on the type of the project viz. commercial, residential, hospital, office etc., and add all the knowledge pertaining to each type to that particular customized model. Any new knowledge created or new lessons learned can easily be attached to the customized models for later use. These customized knowledge models can be used during the design stage of a project to help produce better designs. Knowledge gained from or required for a particular project is attached to its BIM model. The organizations can refer to the particular model to view what all knowledge was created during a particular project and can specifically train its employees using the 3D models.

From the literature review it is found that the most common approach to capture learning from the projects is post project reviews. With the help of the proposed methodology post project reviews can be even more effective because of enhanced visualization. Many organizations are now switching to cloud based BIM technology (AutoDesk® Glue®) where models can be accessed almost instantaneously over the internet. The design and construction teams working in different regions of the world can collaborate with each other. Using BIM models to share the lessons learned, communicate interesting and innovative ideas using cloud based technologies can potentially have a positive impact on the competitiveness of the companies. These models can also provide a very powerful visual context to the discussions between professionals in communities of practice.

Discussion

The 2012 BIM SmartMarket report states that Building Information Modeling is being adopted by the design and construction firms at an increasingly fast pace. As the learning curves for these technologies are becoming flatter and the usage of BIM in AEC industry is increasing, the powerful, data rich, multi-disciplinary, object based parametric design models can be leveraged to capture, store and effectively disseminate knowledge generated in the design and construction processes. These models can also be used to improve the effectiveness of the existing KM practices such as Post Project Reviews, Employee Training and Lessons Learned Programs. The work presented in this paper represents our initial conceptual ideas on the use of building information models for knowledge management. In order to develop an organization wide BIM based knowledge management system, much work remains to be done. We are currently working on identifying appropriate ontologies and taxonomy to classify and store knowledge.

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