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A framework for a BIM-based knowledge management system

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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; present a framework for classification and dissemination of the knowledge. Finally, we present a framework to enable the use of Building Information Models to support the organization wide Knowledge Management processes.

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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 [1]. The construction phase of every project generates hands-on experience, problem solving capabilities, understanding of various means and methods and highly contextualized solutions [2]. The knowledge generated throughout the lifecycle of a project is one of the most important assets of an AEC firm. Effective capture, storage, dissemination. Design on and reuse of this knowledge are critical for the successful execution of construction projects and thus vital for competitiveness and survival of the organization [3].

Systematic management of knowledge can help in encouraging continuous improvement, sharing tacit knowledge, faster response to customers, disseminating best practices, reduction in rework [4]. 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 [5]. 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 [6]. Sometimes, the lessons learned during the project are not properly captured, stored or communicated to the potential user of this knowledge [7]. 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 [8].

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 [7]. 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 [9]. BIM models can be thought of as stores of knowledge [10]. 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 [9], documentation and dissemination of best practices, lessons learned [4] 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 [11]. 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 [7]. Communities of Practice, also known as knowledge communities, and knowledge networks, typically consist of experienced design and construction professionals who share expertise and passion about a discipline specific subject. They usually provide a platform for their members to pool their experience, expertise, and ideas, and to find solutions [12]. Web based communities of practice can pool expertise of inter and intra organizational experts from around the world. The capture and storage of lessons learned in every project is another commonly used knowledge management tool. On the Information Technology side, Groupware, Intranets and Extranets are some of the technologies that are 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 [13]. However, groupware systems are not efficient for the exchange of more complex knowledge [14].

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. [15] developed a framework (IMPaKT) to enable AEC organizations to understand the business impact of their KM strategies. Cheng et al. [16] developed a tool (CLEVER_KM) to provide a structured approach to KM problem definition and strategy formulation for an AEC organization. Tsreng[3] presented an activity based Knowledge Management system for capturing the knowledge generated in the construction phase. Lin et al. [17] proposed the use of knowledge maps for capture and reuse of knowledge in construction projects and 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. [18] 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 [19, 20, 21, 22, and 23]. A significant amount of research has also focused on the "people", state-of the practice, and implementation aspects of knowledge management [1, 23, 25, and 26]. Solibleman et al. [27] 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. [28] 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 [7] 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 [29]. 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 18" 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.

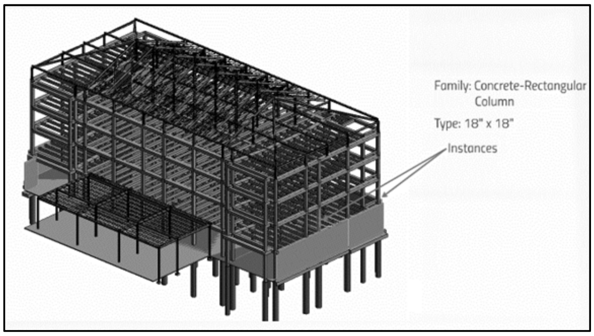

Fig 1. Illustration of Object Hierarchy

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. These shared parameters can subsequently be shared with other BIM models. For example, a *"Shared Parameter"* called "Lessons Learned: Concrete" was created and associated with Structural Columns family (Figure 2). When an instance of a structural column is created in the model, the shared parameter is displayed as a property.

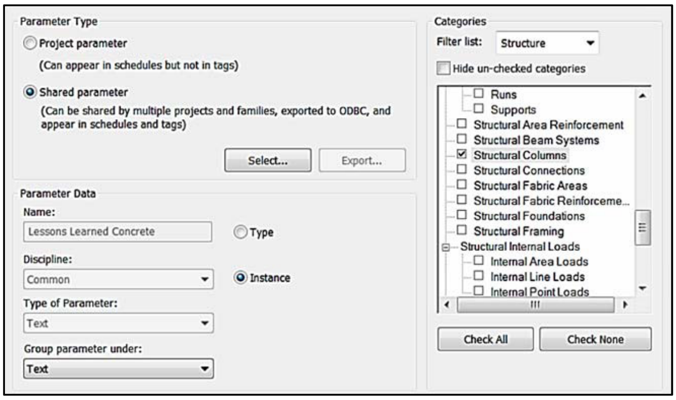

Fig 2. Shared Parameter for Structural Columns

The Shared Parameters can be defined either as "*Instance Parameters*" or as "*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 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.* The information regarding the location, type, owner name, project stage, name of the designer can be extracted from the IFC file. This information may be valuable in the future to find more information about the context in which knowledge was generated. Once the relevant project related information is extracted, the user 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

"Location Mark" of the element. This will identify the location of that particular element in the model. If another user wants to get the complete context under which this information was entered, they can refer to the BIM model. The following figure (figure 3) shows a snippet of an IFC file exported from the model showing the lessons captured and associated with a structural concrete column.

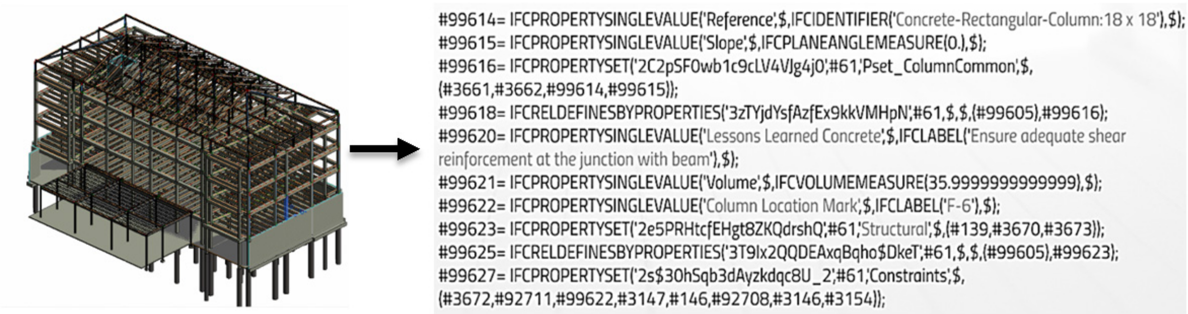

Fig 3. A Snippet of the exported IFC file

6. Classification of the Generated Knowledge

The extracted knowledge from the BIM model contains lessons that are attached to specific building components/ assemblies in the model. The classification of the knowledge will be specific to the functional specialization of the organization. The knowledge can be classified hierarchically by phase, i.e. Design (Schematic / Detailed Design), Construction. In the next step, these lessons can be classified based on specific sub discipline (Architectural, Civil / Structural, Mechanical Systems, Electrical Systems, Plumbing, Heating, Ventilation and Air Conditioning Systems). A construction firm could further classify the knowledge using categories such as Means and Methods, Cost, Installation etc. The ontology and taxonomy used for the classifying the knowledge will be dependent on the firm's specialization. UNIFORMAT II classification can be used to classify the lessons learned (Figure 4). For example, a design firm's classification of the knowledge generated will entirely be different from the classification of an MEP trade contractor. A structural design firm will likely be more interested in the lessons concerning the design of the structure, cost impact of the design, etc. and they classify lessons based on the type of the structure (Steel, Concrete etc), the type of design element (beams, columns) etc. where as an electrical subcontractor may be more interested in the lessons on the design and installation of electrical conduits, cable trays and electrical equipment in the building and his classification will be categorized accordingly.

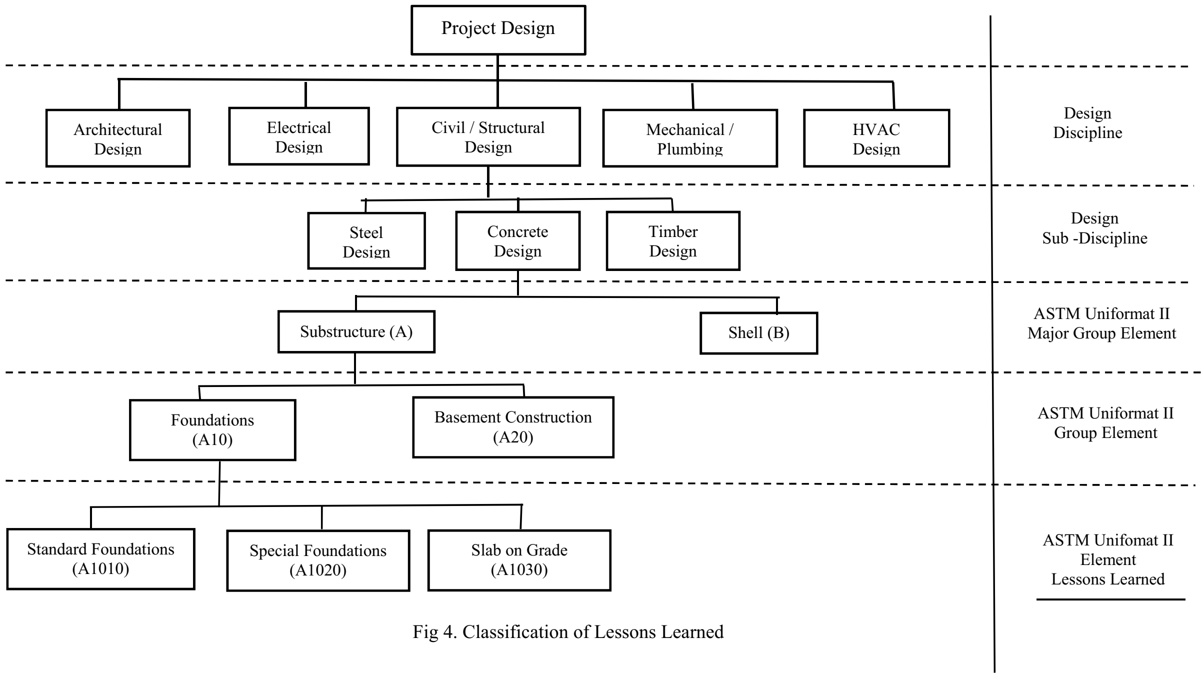

Fig 4. Classification of Lessons Learned

7. Review and Validation

The process of review and validation can be performed by subject area experts immediately after the lessons learned in the project are classified. The objective of this process is to ensure the accuracy and appropriateness of the information. When classifying the information as code requirement, best practice or lessons learned, the expert check for the correctness and completeness of the lessons added. Any additional details necessary, like the exact reference to the code/code section, any additional comment explaining the lesson are added by the experts during this phase. The experts also decide on which lessons are useful and can be reused. Depending upon the size of the project, the review and validation can be performed after the completion of the project for small and medium projects; for large projects it is advisable to perform this process after the completion of each stage in the project or once after a specified period of time-interval or after completion of each milestone. Each option has its advantages, after the completion of each stage the lessons specific to that stage can be collected and reviewed, for review after a specified period of time the process will always be carried out according to a schedule and the experts and managment can plan accordingly. Similarly, review conducted after every milestone will have all the lessons collected for every milestone. Depending upon the organization's culture and management's preference, this review may be scheduled. Once validated, all the useful knowledge is then disseminated.

8. Dissemination

In order for the process described above to yield benefits, the knowledge captured using BIM models, it needs to be stored in a centralized database which users can access. Each user should be assigned a specific role so that information is made available to the user based on their role and responsibility in the project and the organization. This database may be set up as a relational database with tables representing project information, project team information, a knowledge reporsitory for each discipline, information about the contributors etc. In Keeping with the significant trend in the AEC industry towards cloud computing, the database can have an internet / intranet access to ensure an efficient dissemination of the knowledge generated. A representative schema of the tables in such a relational database is shwon below. The users can query the database using a web interface and quicky access the relevant knowledge, information about the project where this knowledge was generated, the contributor, project team etc. The schema shown in the following figure (figure 5) can be extended based on organizational requirements.

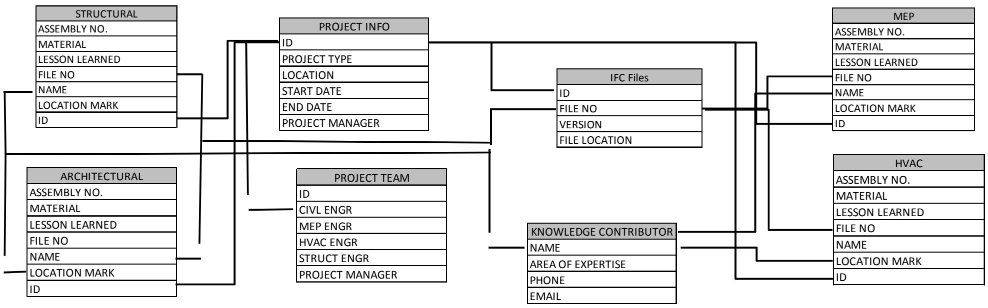

Fig 5. Database

9. Building Information Models and Knowledge Management

The following figure (figure 6) describes a conceptual framework for using the method described in this paper for enhancing Knowledge Management Systems in an AEC organization.

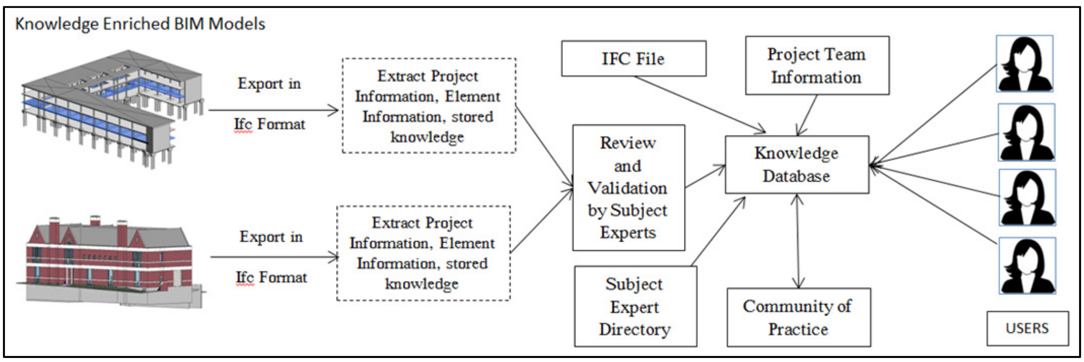

Fig 6. Conceptual Framework

The ideas described in this paper can be implemented as follows:

1. Create and deploy appropriate Shared Parameters, preferably at the beginning of the modeling process.
2. As new lessons are learned, knowledge is generated through design reviews, errors and ommissions, request for information from contractors and unique situations encountered at the site, these can be stored in the BIM model.
3. Export the BIM model in the IFC format at various stages of the design process and during the construction phase.
4. Extract the Lessons Learned, innovative ideas generated in this process.
5. Classify the lessons learned, new ideas generated.This information is then classified and vetted by experts in the subject area.

6. 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 abount 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.

10. Concluding Remarks

Knowledge Management is one of the critical strategies for improving the performance of AEC organizations by enabling the capture of lessons learned, best practices and innovative ideas and solutions. Building Information Models can be leveraged to improve the effectiveness of existing KM practices. 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. The procedure developed in this paper is currently being implemented at a design consultancy in the US.

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References

[1] Ferrada, X., Serpell, A. (2014). Selection of Construction Methods for Construction Projects: A Knowledge Problem. ASCE Journal of Construction Engineering and Management, 140(4)

[2] Lin, Y.-C., Wang, L.-C., Tserng, H. P., and Jan, S.-H. (2005). Enhancing Knowledge and Experience Exchange through Construction Map-Based Knowledge Management System. Construction Research Congress 2005: Broadening Perspectives, American Society of Civil Engineers, San Diego, California.

[3] Ping Tserng, H., and Yu-Cheng Lin.(2004). Developing an Activity-Based Knowledge Management System for Contractors. Automation in Construction 13 (6),(pp 781–802).

[4] Carrillo, P. and Chinowsky, P. (2006). Exploiting Knowledge Management: The Engineering and Construction Perspective. ASCE Journal of Management in Engineering, 22(1), 2–10

[5] Yang, L.-R., Chen, J.-H., and Wang, H.-W. (2012). "Assessing impacts of information technology on project success through knowledge management practice." Planning Future Cities-Selected papers from the 2010 eCAADe Conference, 22(0), 182–191.

[6] Fong, P.S.W. (2005). Aspects of Learning and Knowledge in Construction Projects. Construction Research Congress 2005: Broadening Perspectives American Society of Civil Engineers, San Diego, California.

[7] Dave, B., and Koskela, L. (2009). "Collaborative knowledge management—A construction case study." Automation in Construction, 18(7), 894–902.

[8] Goedert, J. and Meadati, P. (2008). Integrating Construction Process Documentation into Building Information Modeling. ASCE Journal of Construction Engineering and Management, 134(7), 509–516. (Tan et al. 2012).

[9] Tan, H., Carrillo, P., and Anumba, C. (2012). Case Study of Knowledge Management Implementation in a Medium-Sized Construction Sector Firm. ASCE Journal of Management in Engineering, 28(3) 338–347

[10] Meadati, Pavan, and J. Irizarry. "BIM–a knowledge repository." Proceedings of the 46th Annual International Conference of the Associated Schools of Construction, Retrieved November. Vol. 12. 2010.

[11] Egbu, C., Anumba, C., Quintas, P., Hutchinson, V., Hayles, C., & Ruikar, K. (2003). "Techniques and technologies for knowledge management." Knowledge Management for Sustainable Construction Competitiveness Project, Partners in Innovation (CI 39/3/709) Work Package, 3.

[12] Wu, J.-W., Tseng, J. C. R., Yu, W.-D., Yang, J.-B., Lee, S.-M., & Tsai, W.-N. (2012). An integrated proactive knowledge management

model for enhancing engineering services. Automation in Construction, 24(0), 81–88
[13] Rezgui, Y., and Miles, J. (2011). Harvesting and managing knowledge in construction: from theoretical foundations to business applications. Spon Press.
[14] Robertson, Maxine, Carsten Sørensen, and Jacky Swan. "Survival of the leanest: intensive knowledge work and groupware adaptation." Information Technology & People 14.4 (2001): 334-352.
[15] Carrillo, PM, Robinson, HS, Anumba, CJ, Al Ghassani, AM (2003) IMPaKT: A Framework for Linking Knowledge Management to Business Performance, Electronic Journal of Knowledge Management, 1(1), pp.1-12.
[16] Cheung Y. C., Anumba C. J., Carrillo P. M. & Robinson H. S.(2003) 'CLEVER_KM - An Innovative Tool to Assist in the Development of Knowledge Management Strategy', Proceedings 2nd International Conference on Construction in the 21st Century (CITC-II), Hong Kong. 10-12, pp 406-413.
[17] Lin, Y.-C., Wang, L.-C., Tserng, H. P., and Jan, S.-H. (2005). Enhancing Knowledge and Experience Exchange through Construction Map-Based Knowledge Management System. Construction Research Congress 2005: Broadening Perspectives, American Society of Civil Engineers, San Diego, California
[18] Hai Chen Tan, Patricia M. Carrillo, Chimay J. Anumba, Nasreddine (Dino) Bouchlaghem, John M. Kamara, and Chika E. Udeaja (2007). "Development of a Methodology for Live Capture and Reuse of Project Knowledge in Construction." J. Manage. Eng., 23(1), 18–26.
[19] Rezgui, Yacine. 2006. Ontology-Centered Knowledge Management Using Information Retrieval Techniques. Journal of Computing in Civil Engineering, 20 (4): 261–70.
[20] El-Gohary, Nora M., and Tamer E. El-Diraby. (2010). Domain Ontology for Processes in Infrastructure and Construction. Journal of Construction Engineering and Management 136 (7), 730–44.
[21] El-Gohary, Nora M., and Tamer E. El-Diraby. (2011). Merging Architectural, Engineering, and Construction Ontologies. Journal of Computing in Civil Engineering, 25 (2): 109–28
[22] Wang, Han-Hsiang, Frank Boukamp, and Tarek Elghamrawy. (2011) Ontology-Based Approach to Context Representation and Reasoning for Managing Context-Sensitive Construction Information. Journal of Computing in Civil Engineering, 25 (5): 331–46.
[23] El-Diraby, Tamer E. (2013). Domain Ontology for Construction Knowledge. Journal of Construction Engineering and Management 139 (7): 768–84.
[24] Construction Industry Institute (2013) Transferring Experiential Knowledge from the Near-retirement Generation to the Next Generation, Research Summary # RS-292.
[25] Javernick-Will, A. (2012). "Motivating knowledge sharing in engineering and construction organizations: the power of social motivations." Journal of management in engineering, 28(2): 193-202.
[26] Zhang, Xi, Patricia OrdóñEz De Pablos, and Zhongyun Zhou. "Effect of knowledge sharing visibility on incentive-based relationship in Electronic Knowledge Management Systems: An empirical investigation." Computers in Human Behavior 29.2 (2013): 307-313.
[27] Soibelman, Lucio, et al. (2003) "Design review checking system with corporate lessons learned." Journal of construction engineering and management 129.5, 475-484.
[28] Caldas, C., G. Gibson, R. Weerasooriya, and A. Yohe. (2009). Identification of Effective Management Practices and Technologies for Lessons Learned Programs in the Construction Industry. ASCE Journal of Construction Engineering and Management, 135 (6): 531–39.
[29] Yang, L.-R., Chen, J.-H., & Wang, H.-W. (2012). Assessing impacts of information technology on project success through knowledge management practice. Planning Future Cities-Selected Papers from the 2010 eCAADe Conference, Automation in Construction 22(0), 182–191