AN APPROACH TO INTEGRATE CHANGE AND KNOWLEDGE MANAGEMENT IN CONSTRUCTION WORKFLOWS

Abdou Karim Jallow, Post-Doctoral Scholar, ajallow@engr.psu.edu
Fangxiao Liu, PhD Candidate, fzl116@psu.edu
Sanghoon Lee, Post-Doctoral Scholar, sanghoon.lee@engr.psu.edu
Chimay J. Anumba, Professor and Department Head, anumba@engr.psu.edu
John I. Messner, Professor, jmessner@engr.psu.edu
Department of Architectural Engineering, The Pennsylvania State University, University Park, PA 16802, USA

ABSTRACT

The Architecture, Engineering and Construction (AEC) project delivery process is complex and knowledge-intensive with numerous changes during the lifecycle process. Managing changes and knowledge is critical to enable effective and innovative delivery of high-quality products and services. Unfortunately, current processes do not provide enough support for concurrent management of changes and knowledge in an integrated fashion. Typically isolated, change and knowledge management (CKM) processes can work in silos but without integration, they may not function effectively as part of the holistic construction workflows. Ultimately, the disjunction results in major weakness in the ability and agility of project teams and building managers to manage knowledge effectively and respond appropriately to changes. Consequently, this can lead to implementing changes with adverse impacts, and inadequate capture and management of lessons learned. Therefore, there is a vital need to embed CKM processes within the overarching construction workflows. The paper aims to present a novel approach to fuse CKM processes within the entire construction workflows, and highlight the associated benefits. Initially, the paper conducted an integrative and detailed review of related work to digest the theoretical underpinnings and research efforts in this area. This was followed by a preliminary investigation of industry problems and requirements for CKM on an energy efficient retrofit project. Subsequently, an integrated building lifecycle process model (IBLPM) was adopted to identify and map-out key stages where potential change and knowledge activities would be required. These activities were then modeled at those key stages as triggers for CKM processes. This approach makes CKM as integral components of construction workflows within IBLPM. The integrated approach arguably demonstrated that the integrative approach can be practical and has the potential to enable better management of changes and knowledge as part of the workflows rather than being performed disjointedly. Finally, a proposal for future research work is briefly described.

Keywords: changes, Change and Knowledge Management (CKM), construction, knowledge, process, workflow

1. INTRODUCTION

Change and knowledge management (CKM), as a systematic approach in energy efficient retrofit projects, is an essential part of a successful project. Often, projects stumble by running over budget, creep out of schedule, and/or fail to achieve owner's goals or value proposition and do not provide benefits. A major contributing factor to this is change, which is inherent in construction projects (Smith, Merna and Jobling, 2006). This is due to the sheer number of changes and the associated complex tasks to manage changes; the information and knowledge accumulating over the lifecycle of buildings, and the need for project teams to work more efficiently and effectively to achieve owner's goals. Project team members are usually aware of the importance and necessity of change management, and knowledge generation and utilization, however they generally allocate a lower priority to these activities than the primary project goals. The significance of managing changes and dependencies is that if they are poorly or inadequately managed, changes initiated and implemented during the design, construction and operations of buildings could have negative impact on energy efficiency goals. Similarly, knowledge assets are often disconnected from project teams. Consequently, lack of access to the right knowledge by project teams could result in retrofitted buildings which do not meet owner's goals for energy efficiency. This creates change and knowledge management-oriented project processes. However, these processes are isolated and performed independent of each other; resulting in a gap between the two and limits the opportunity to implement their required interactions adequately. Recently, an integrated CKM approach and process was developed (Liu et al., 2013). It is prudent that the integrated CKM is extended and embedded into the construction workflows. Therefore, this paper aims to present an approach to incorporate change management and knowledge management processes within the overarching lifecycle construction workflows.

The second section of the paper reviews theoretical background of change and knowledge management, and their basic concepts and application in AEC. The third section discusses the methodology and methods employed in the study of this paper; in particular, how the integrative approach was designed and developed. The fourth section outlines the concept of the integrative approach with basic definitions and examples for demonstration purposes. The fifth section presents the analysis of the approach with consideration on its anticipated impact towards energy efficient retrofitting and the AEC in general. The final section concludes the paper with a summary of key points and a brief outline of further work in this area.

2. RELATED WORK

To make commercial building space in the United States 20% more energy efficient by 2020, the "Better Building Initiative" of the United States Government aims to implement this through cost-effective upgrades (White House, 2011). Such upgrades include retrofitting for energy efficiency. In the quest to operate buildings more efficiently, facility managers often require a tool that can assist them for decision-making regarding various alternatives of a retrofitting project (Zhu, 2006). This requires robust project management processes and systems. Various project teams are involved in retrofitting, each having multiple tasks to accomplish, sometimes in a number of related processes at different implementation stages. With multiple sources of knowledge, it is vital that adequate measures are in place to make the appropriate knowledge available for the different tasks to be performed. Records (2005) indicated that doing knowledge management (KM) right would mean that measures are in place to organize what knowledge are appropriate for each task in an overall process flow. This would mean asking the questions: *How do we analyze what we have learned to do it better? How do we harvest the knowledge for reuse? What knowledge do employees need to perform their tasks and how do we provision the knowledge at the point of need?* (ibid).

KM as a management activity is an integral component that contributes towards competitive advantage. Ruikar, Anumba and Egbu (2007) highlight that KM can help organizations to become faster, smarter and more innovative, and also can help maintain long-term competitiveness of the construction industry. Several other researchers have also emphasized the importance of knowledge as a critical resource in construction project, and the necessity of KM to create innovation and improve productivity of the industry (Anumba, Egbu and Carrillo, 2008; Tan et al., 2007; Kazi, 2005; Forcada, 2013). Changes during a construction project are inevitable and can occur at any stage (Smith, Merna and Jobling, 2006). These may be changes on various project variables such as owner requirements, design changes, cost, schedule, quality and performance targets amongst others. Changes can present either adverse or favorable effects on a project, and need adequate processes and systems in place to manage them when they are identified. Change management as emphasized by Rajabi and Lee (2009), is very important to reduce the risks and costs and maximizes the benefits of major changes. Lack of or inadequate knowledge of future states of project variables is also considered as one of the main sources of changes in construction (Motawa et al., 2003). Similarly, the importance of change management is recognized as an important management activity, which can help reduce or avoid errors and related effects on cost and schedule over-runs. This led to the development of systems to help manage changes (Zhao et al., 2010; Motawa et al., 2007; Soh and Wang, 2000; Hegazy, Zaneldin and Grierson, 2001). However, despite this trend and the development of a number of systems that provide change management, none is identified to be integrated with KMS within the workflows. Although KM perspective has been introduced to manage project change through which project teams can resolve and learn from change events (Senaratne and Sexton, 2008).

Management tools such as change management and knowledge management processes and systems are amongst such useful tools. There is a very close link between these two processes, and with the construction workflows. For example, when changes are initiated, approved and implemented, there is potential for knowledge to be generated. This has been recognized by Egbu (2006) who identified managing changes as one of the main triggers of construction knowledge production. Senaratne and Sexton (2008) also found that different forms of knowledge are created during project change process within construction projects, however the important role of knowledge in managing changes is not well appreciated. Similarly, project teams often require knowledge to assess and implement changes, in particular when no prior experience exists to deal with a particular change. However, CM and KM are separate and function independent of the workflows. In their work on integrating risks and business process models in the process management discipline, zur Muehlen and Rosemann (2005) identified similar links between risk modeling and business process models. This led to the development of risk-aware process management and illustration of process-oriented risk management and risk-oriented process management (ibid). Fewings (2013) discussed that standard project management systems have been set up in construction but have not always delivered best value for the client through the value chain. Porter (1985) defined the value chain as the sets of interconnected activities an organization performs to deliver a valuable products or services. Porter differentiates these activities as primary activities and support activities. Primary activities are directly concerned with the creation or delivery of a product or service, which are each linked to support activities that help to improve their effectiveness or efficiency. The ability to perform particular activities and to manage the interactions between them is a source of competitive advantage (ibid).

3. METHODOLOGY

In order to understand the theoretical perspective and similar work in change and knowledge management (CKM), a review of related work was conducted. This review was based on the most important aspects of CM and KM, and their application within construction. Specifically, various sources such as journals, conference papers and books were reviewed to identify common grounds and application in various aspects of construction projects. This review led to the identification of research gaps, and coupled with industry requirements, resulted in the formulation of ideas for an integrated approach. The paper also learned from other industries such as information systems & technology and manufacturing amongst others. Following the initial comprehension of the theory, an investigatory interview on CKM practices was conducted with two project managers involved in two projects (i.e., a retrofitting and construction of a new building). The aim of the interview was to investigate the practice of CKM in the projects, and to determine the need to integrate CKM in the overarching workflows. The objectives were to: (i) investigate the existence of any formal and agreed processes for CM and KM being used by the project team; (ii) understand the project's approach and requirements of CKM; and (iii) identify key areas to collaborate and help review (if already exist) or support the development of processes and tools for CKM (if non-exist).

In order to identify and map-out the key stages where potential change and knowledge management activities would be required in the construction workflow, this paper adopted the current Integrated Building Lifecycle Process Model (IBLPM), which is an extension of the earlier Integrated Building Lifecycle Process (IBLP) (Lee et al., 2012). The process model depicts design processes of key building elements/services classified in OmniClass. The model is divided into four major phases: conceptualization, criteria design, detailed design and implementation documents (AIA, 2007). Design activities for each building element were modeled on individual swimlanes in an integrated fashion across the phases. One of the swimlanes (*i.e., the integration swimlane*) shows activities which require multiple stakeholders (i.e., at least two or more teams) to perform a task together. This swimlane was used to embed the change and knowledge management activities within the IBLPM. To identify the key stages for CKM, we concentrated our efforts on studying and analyzing the activities of the design processes of the IBLPM focusing on where *design reviews*, *value engineering* and *decisions* are made, which all have the potential for change and/or knowledge to be generated or managed. In addition, were insufficient understanding lacks, industry experts and academics were approached to determine such stages. To embed the CKM within the

IBLPM, Business Process Model and Notation (BPMN) signal events (OMG, 2011) are used as the integration mechanism at those key stages, which trigger the change and/or knowledge management processes. The signal events are used to communicate back and forth (i.e., sending and receiving general communication within and between the IBLPM and the CKM processes).

4. THE INTEGRATIVE APPROACH

4.1 Development of the Integrative Approach

As discussed earlier, the IBLPM was adopted to develop the integrative CKM approach within the overarching workflows. The process was modeled using BPMN method (OMG, 2011) to demonstrate an integrated process in the design phase of a construction project. Several hundreds of activities are performed and coordinated within a project, and these vary for every project stage. The process model identified design activities in conceptualization, criteria design, detailed design, implementation document, and operations and maintenance sub-phases along with detailed CKM processes that support effective management of any changes that occur and lessons learned within the IBLPM. The philosophy of this approach, shown in Figure 1, was developed adapting the value chain model (Porter, 1985) and classified the activities under two categories: (i) primary activities and (ii) support activities.

- The *primary activities* comprise the typical construction activities that are executed across the building lifecycle stages (i.e., project initiation, design, construction and operations). Each stage will have specific activities to be executed in order to complete that stage.
- The *support activities* include the management activities such as managing changes and knowledge, risk management, cost analysis, etc. These are used to support the construction processes. Often, these activities are not specific to any particular stage, but run across all the stages.

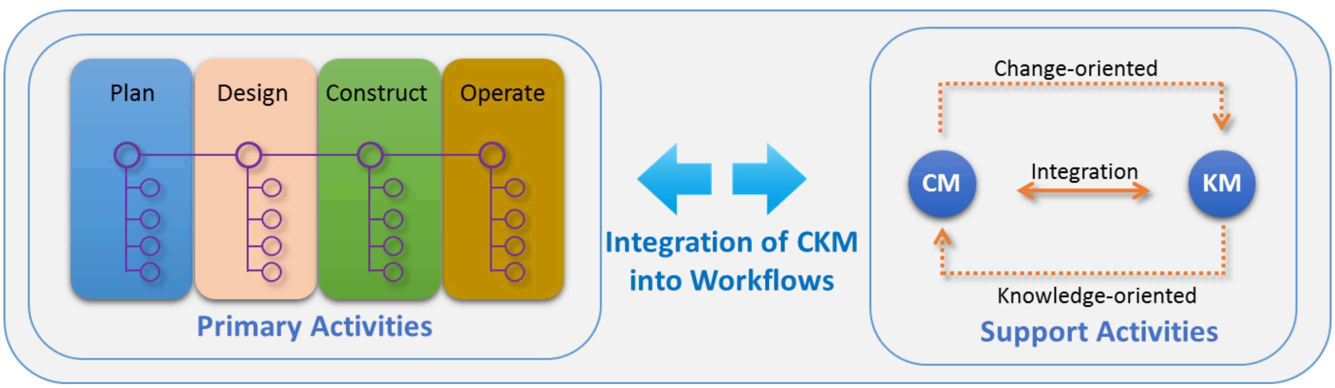

Figure 1: CM & KM Integration Model in the construction workflows

Various factors relating to managing changes and knowledge in construction were considered, which guided the development of the approach. These factors were considered from the perspective of general construction activities but with most focus on energy efficient retrofitting. This paper is adamant that a successful construction project implementation requires a paradigm shift from managing individual processes to integrating activities. This should include integrating the support activities and the primary activities in a combined fashion. To address this issue, this paper adapts zur Muehlen and Rosemann (2005) philosophy and proposes a combined CM and KM embedded in the construction workflows. In this approach, managing changes will need to be 'knowledge-aware', and knowledge management process should be 'change-aware'. This creates a knowledge-oriented change management process and change-oriented knowledge management process. As a result, the development process was split into three main steps. Firstly, the IBLPM was reviewed to familiarize with the tasks and to understand the interactions between the activities. Secondly, the process activities were examined thoroughly to identify and map-out the key stages where CKM activities would be required. Thirdly, CKM processes were embedded within the IBLPM by modeling the triggers at the key stages.

The CKM triggers were embedded in the 'integration' swimlane of the IBLPM where at least two or more project team members would be required to perform a task. This was deemed to be ideal because CKM involves collaboration between different participants. To identify the key stages, the paper adapted Records (2005) and asked the following questions: (i) *Which activities require collaboration with two or more team members? (ii) Which activities would require a decision/s to be made? (iii) Which activities require iteration? Is revision possible? (iv) Are changes possible after performing certain activities? (v) What knowledge is required to perform the tasks? (vi) Can any lessons be learned from performing an activity? (vii) How is the lessons learned harvested? (viii) Is knowledge often available at the point of need?*

Deliberations and answers generated from these questions led to the identification of the key stages for CM and KM for each of the building element/system design process. However, it was impractical to map them on each swimlane, but on the integration swimlane where all activities merged for key collaboration tasks. BPMN signal intermediate events (as shown in Figure 2), which include 'send' (for signal sending) and 'receive' (for signal receiving) types, were adopted to achieve the integration of CKM with IBLPM (OMG, 2011). A sample of the mapped CM and KM triggers are shown in Figure 3. For the purpose of demonstrating how CKM is embedded in the IBLPM, the paper uses some of the key stages as examples. These are discussed in section 4.2 and 4.3.

Figure 2: Signal Intermediate Events

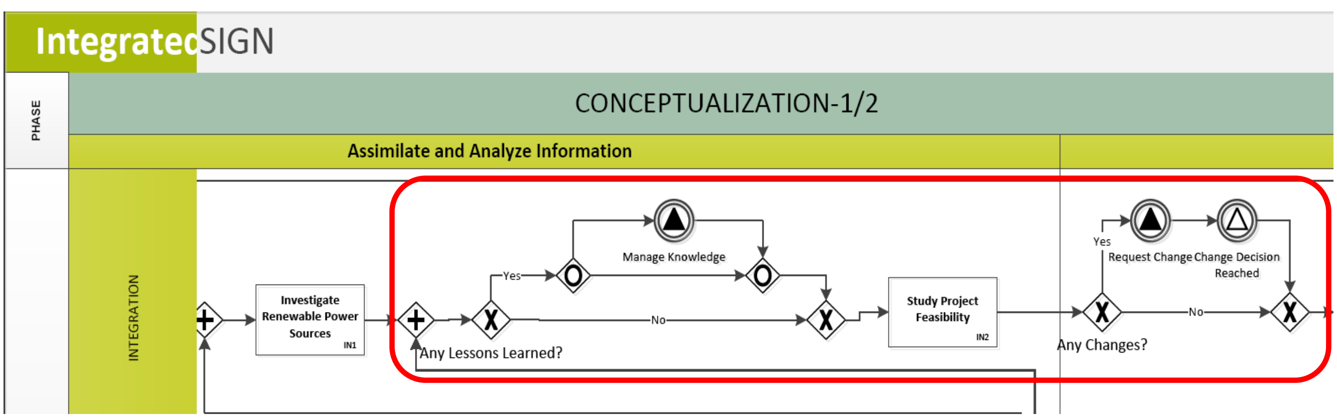

Figure 3: The integration swimlane showing embedded CM and KM in the conceptualization phase of IBLPM

4.2 Integration of CM process in IBLPM

During the course of a project, changes can be requested by different stakeholders depending on their roles. For example, as shown in Figure 4(a), an owner is required to make a decision on the post-design documents, and there is the possibility that a change may be required. Depending on the degree of the changes (i.e., if any changes are required), a change request would be generated. This will then trigger the 'change management process' as shown in Figure 4(b) with the 'request change' trigger. The request will then be routed through the change management process for assessment and approval. At the end of the approval process, the outcome (*i.e., Change Decision Reached on the change management process in* Figure 4(c)) will be captured and sent to the main process for the implementation of the change (if approved). The outcome of the change request is modeled as *'change decision reached'* in Figure 4(a). Similarly, other change requests will also be managed in this way to incorporate the change management process in construction workflows.

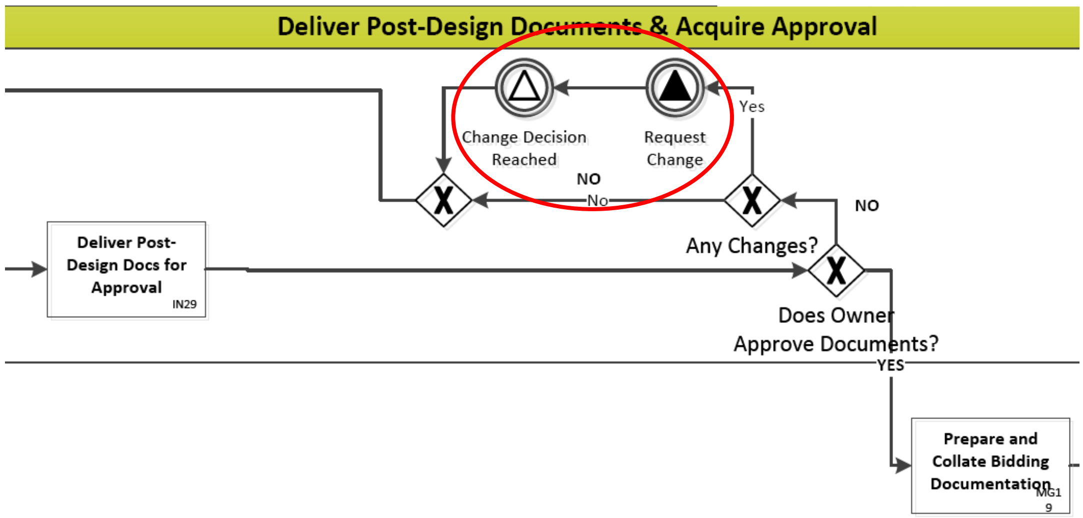

Figure 4(a): Change management triggers embedded in IBLPM

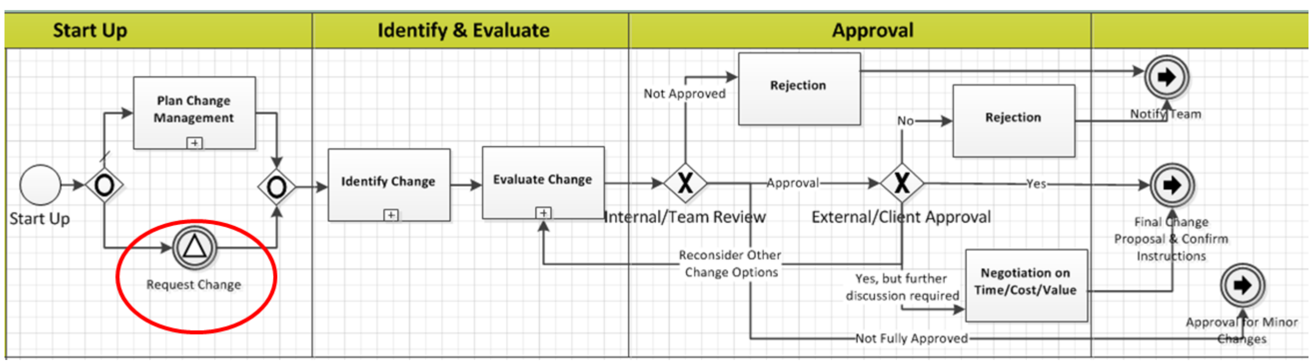

Figure 4(b): Change request trigger in the CM process

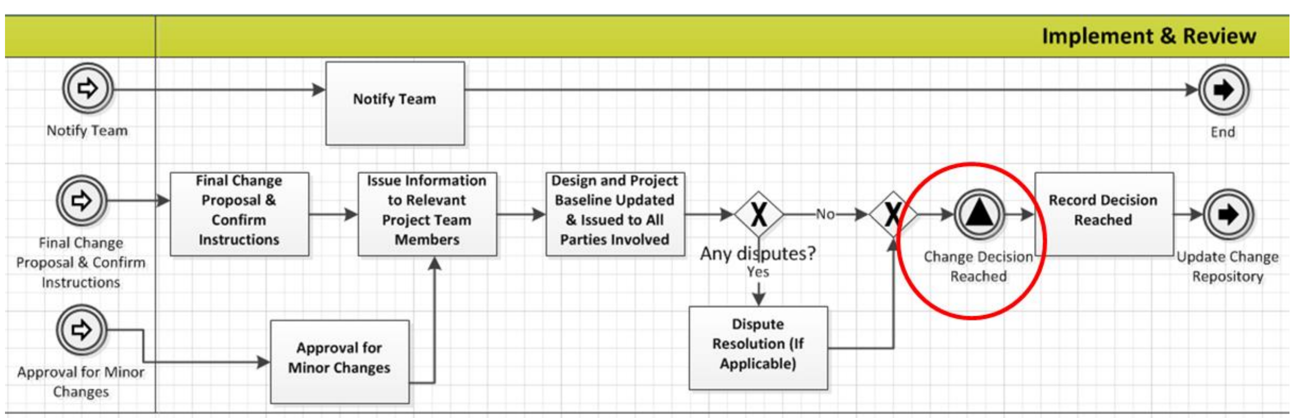

Figure 4(c): Change decision captured in the CM process

4.3 Integration of KM process in IBLPM

Potential lessons learned in the construction workflow need to be captured and managed for future use according to the KM process. As shown in Figure 5, for example, any lessons learned following the 'identification of potential energy load reduction strategies' at "Preliminary Studies" of the conceptual stage of the design should be captured, validated and stored for future use. Therefore, a knowledge management trigger was embedded in the workflow to capture the lessons learned (if any), which will trigger the KM process as indicated with the 'manage knowledge' trigger in Figure 6. The KM process will then be followed through. It is important to note that project team members will determine if there was any lessons learned, although intelligent system support can also be used to support this process.

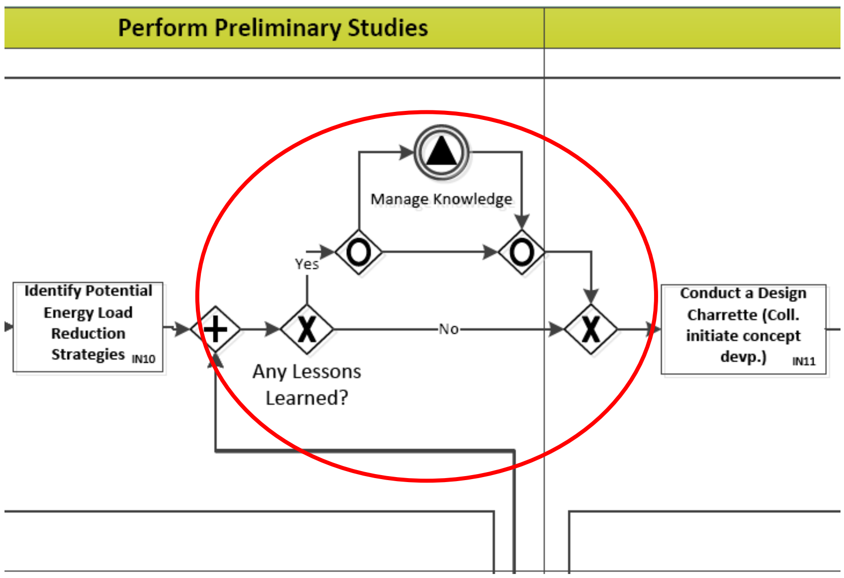

Figure 5: Example of Integration of KM in IBLPM

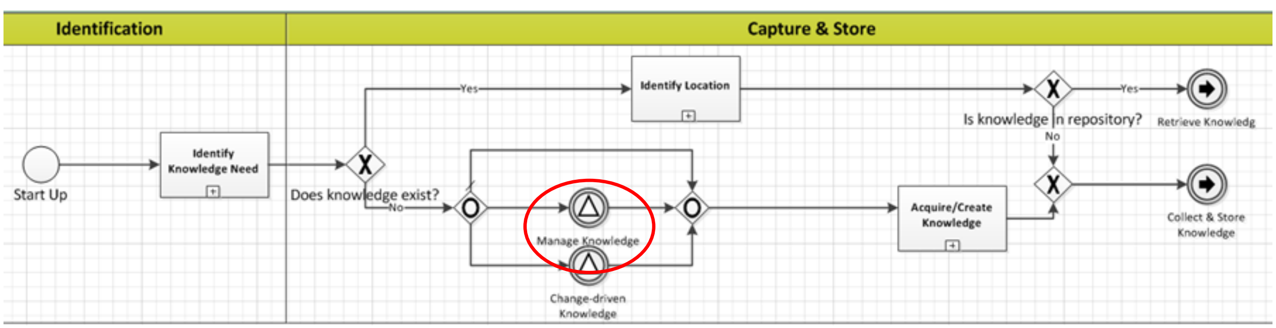

Figure 6: KM trigger in the KM process

4.4 Tool implementation of the integrated approach

There is the need for a system to implement the integrated approach. Such a system should have a process flavor as an aspect of the need for simultaneous management of changes and knowledge as construction activities are performed. This will require an automated system functionality, a web-based platform to support collaborations and access from anywhere, and features such as information exchange, process coordination and integration between systems should be included. To implement this integration, tools must address the necessary functionalities and features including automation, and information capture, storage and distribution; in addition to the previous. Initially, CAPRI.NET has been identified to be extended and used as the knowledge management system (KMS). The system is intended for the 'live' capture and reuse of project knowledge. It is capable of storing tacit knowledge generated from experience or lessons learned by project teams, as well as explicit knowledge from other sources; for example, knowledge generated from annotations on drawings during design reviews. The planned extension is to develop a change management module, which enables project teams to capture and store any associated lessons learned from those changes. Over the past years, information exchange has received great attention requiring integration between applications to facilitate interoperability. In this approach, interoperability matters immensely to enable information to be exchanged. Therefore, integration between the applications (i.e., the change management system (CMS) and CAPRI.NET as the KMS) is proposed to be implemented using web services or application program interface (API). This will implement the combined change & knowledge management system (CKMS). It is also suggested that the system will integrate with a BIM model server in order to enable updates of changes resulting from energy analysis to the BIM models. Figure 7 represents a high-level view of the proposed system (CKMS). Project teams operating at the construction workflow level will interact with the system via a cloud-based user interface whilst performing their tasks.

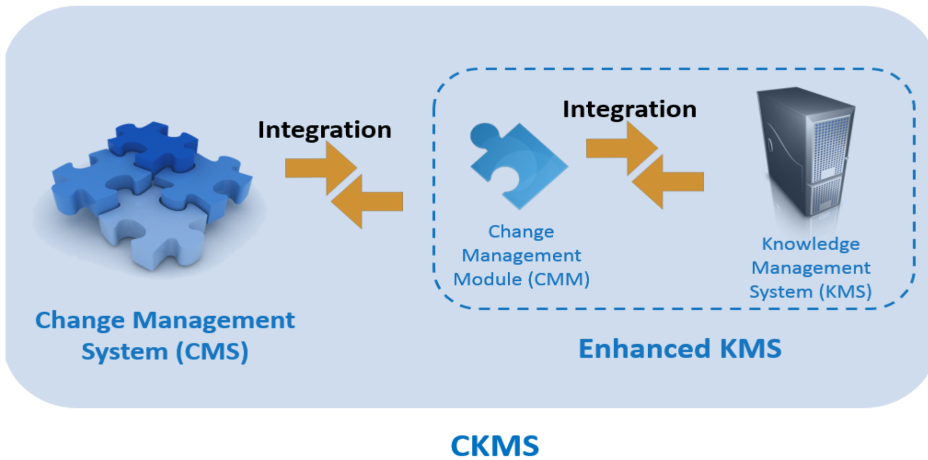

Figure 7: The high-level view of the proposed CKMS

5. ANALYSIS AND DISCUSSION

Today's construction projects, including energy efficient retrofits, increasingly adopt integrated delivery approaches aimed at bringing the different disciplines and systems together. This should also include bringing the various project management protocols such as CKM together in the overall process. One of the major causes of design defects is lack of the right knowledge at the right time. As a result, energy analysts make assumptions on design parameters during energy simulations. This could have detrimental effects to achieving energy efficiency goals, which can result in changes and costs to escalate. Consequently, putting standard processes and systems in place to make knowledge available when required cannot be overemphasized. The embedded CKM activities are integral of the entire workflows. They facilitate the integration of the various disciplinary inputs to the collaborative and integrated design process by clearly indicating critical stages where changes need to be managed, and where the capture and reuse of knowledge is required fundamentally. In particular, this includes knowledge-intensive activities within the workflows to support advanced energy retrofitting. This integration undoubtedly plays a key role in change and knowledge management-oriented project processes, and contributes to the delivery of successful projects. This is relevant because at every stage where a decision has to be made, there is a probability for change. There is also potential for lessons to be learned when performing project activities and during the process of managing and implementing changes. Consequently, it is important that lessons learned are captured, validated and stored within the knowledge management system for use in later stages and in future projects. For example, to identify potential energy load reduction strategies, an energy modeler may recommend for changes on building window glazing in order to reduce the cooling load by 20% to achieve energy performance goals. In this example, lessons learned from the rationale of the changes to achieve this reduction could form potential knowledge for use in a subsequent stage or future projects. Therefore, such lessons and the associated changes should be captured and managed adequately during the execution of the workflow activities. Similarly, an HVAC plan indicates conflicts with the luminaires because a duct conflicted with the location of some luminaires. Eventually it was agreed and recommended that the luminaires be changed to pendants in order to avoid conflict with the ducts. In this scenario, capturing the rationale of the changes, and the solutions to the problem can generate valuable knowledge for future engineers and projects.

When implemented carefully, projects can start to uncover areas of incoherence in the construction processes, in particular in retrofitting and begin to drive towards a more coherent application of project management processes. CKM fused along with other project management tools and forms a well-established practice that works alongside the more traditional construction activities within a project. Without an integrated approach to CKM in the workflows, project managers and other team members involved in managing changes and knowledge will have difficulties engaging other team members to be proactive in these processes. It will also be difficult to incorporate the holistic view of CKM and streamlining them to the construction processes, and not separate ad-hoc activities. The embedded CM and KM in the workflows can contribute in standardizing the processes for projects teams. In this way, CKM activities will be regarded as part of the entire construction process and not to be perceived as separate and ad-hoc.

6. CONCLUSIONS

In this paper, an approach, which embeds change and knowledge management processes within construction workflows, is developed and presented. The approach can ensure that the CKM processes are executed as part of the workflows instead of being performed independently. When fully adopted and implemented, the integrative approach of CM and KM embedded in the overarching construction workflows can contribute towards the effectiveness of decision making, in particular when it counts on energy efficient retrofit design and construction. The limitation of this paper is that the integrative approach has not been validated yet. However, as part of an ongoing broader research, two case study projects have been identified for the validation and demonstration of its applicability. Future work includes the development of an IT tool to implement the integrative approach as a proof-of-concept. The tool will be divided in two components: (i) an automated process management system to implement the change management process, and (ii) a ‘change module’ as an add-in to be embedded in the knowledge management system. The purpose of this module is to serve as a repository of lessons learned through changes, which will then be validated, and the knowledge derived from it will be stored in the KMS. The application of this approach is been investigated in the Energy Efficient Buildings Hub (EEBHub) Project at the Navy Yard in Philadelphia.

ACKNOWLEDGMENTS

We recognize the invaluable contribution of Dr. Robert Leicht, other faculty and graduate students at the Architectural Engineering Department, Penn State. We also thank the Department of Energy (DOE) for their support of the EEB Hub project whose funding enable the research presented in this paper. Any findings, conclusions, or recommendations expressed in this paper are those of the authors only.

REFERENCES

AIA. (2007). “Integrated Project Delivery: A Guide”. http://www.aia.org/groups/aia/documents/pdf/aiab083423.pdf (March 2012).

Anumba, Chimay J., Egbu, C., & Carrillo, P. (eds.) (2008). “Knowledge management in construction”. Wiley-Blackwell, Oxford.

Egbu, C. (2006). “Knowledge production and capabilities – their importance and challenges for construction organisations in China”. *Journal of Technology Management in China*, 1(3), 304-321.

Fewings, P. (2013). “Construction Project Management: An Integrated Approach”. 2nd(ed.), Routledge, Abingdon.

Forcada, N., Fuertes, A., Gangolells, M., Casals, M., & Macarulla, M. (2013) “Knowledge management perceptions in construction and design companies”. *Automation in Construction*, 29, 83-91.

Hegazy, T. , Zaneldin, E., & Grierson, D. (2001). “Improving design coordination for building projects. I: Information model.” *Journal of Construction Engineering and Management*, 127(4), 322–329

Kazi, A. S.(ed) (2005). "Knowledge Management in the Construction Industry: A Socio-Technical Perspective", London: Idea Group

Lee, S., Liu, Y., Chunduri, S., Solnosky, R., Messner, J., Leicht, R., & Anumba, C. J. (2012). "Development of a Process Model to Support Integrated Design for Energy Efficient Buildings." In: Issa, R. and Flood, I. (eds) The Proceedings of the ASCE International Conference on Computing in Civil Engineering, June 17-20, Clearwater beach, Florida, USA, 261-268.

Liu, F., Jallow, A., Anumba, C., & Messner, J. (2013). "Integration of change and knowledge management processes in energy efficient retrofit projects". Proceedings of 2013 ASCE International Workshop on Computing in Civil Engineering, Los Angeles, CA, USA.

Motawa, I. A., Anumba, C. J., El-Hamalawi, A., Chung, P. W. H., & Yeoh, M. (2003). "An Innovative Approach to the assessment of Change Implementation in Construction Projects." In: Anumba, C. J. (ed.), *Innovative Developments in Architecture, Engineering and Construction*, Proceedings of the 2nd International Conference on Innovation in Architecture, Engineering and Construction. Loughborough, UK, June 25-27, Millpress, Rotterdam, 729-739.

Motawa, I.A., Anumba, C.J., Lee, S. & Peña-Mora, F. (2007). "An integrated system for change management in construction." *Automation in Construction*, 16, 368–377.

OMG. (2011). "Business Process Model and Notation (BPMN)." <http://www.omg.org/spec/BPMN/2.0/> (Accessed October 2012).

Porter, M. E. (1985). "Competitive advantage: Creating and sustaining superior performance". Free Press, New York.

Rajabi, B.A., & Lee, S.P. (2009). "Change Management in Business Process Modeling Survey," In: Proceedings of the International Conference on Information Management and Engineering, April 3-5, Kuala Lumpur, IEEE, 37-41.

Records, L. R. (2005). "The Fusion of Process and Knowledge Management". BPTrends, September (2005)(http://www.bptrends.com/publicationfiles/09-05%20WP%20Fusion%20Process%20KM%20-%20Records.pdf) [Accessed June 2013).

Ruikar, K., Anumba, C. J., & Egbu, C. (2007). "Integrated use of technologies and techniques for construction knowledge management". *Knowledge Management Research & Practice*, 5, 297-311.

Senaratne, S., & Sexton, M. (2008). "Managing construction project change: a knowledge management perspective". *Construction Management and Economics*, 26, 1303-1311.

Smith, N. J., Merna, T., & Jobling, P.(eds.). (2006). "Managing risk: in construction projects". 2nd(ed.), Oxford Wiley-Blackwell.

Soh, C., & Wang, Z. (2000). "Parametric coordinator for engineering design." *Journal of Computing in Civil Engineering*, 14(4), 233–240.

Tan, H. C., Carrillo, P. M., Anumba, C. J., Bouchlaghem, N., Kamara, J. M., & Udeaja, C.E. (2007). "Development of a methodology for live capture and reuse of project knowledge in construction". *Journal of Management in Engineering*, 23(1), 18-26.

White House. (2011). "President Obama's Plan to Win the Future by Making American Businesses More Energy Efficient through the "Better Buildings Initiative"". Office of Media Affairs. [online] Available at: http://www.whitehouse.gov/the-press-office/2011/02/03/president-obama-s-plan-win-future-making-american-businesses-more-energy [Accessed December 2012].

Zhao, Z., Lv, Q., Zuo, J., & Zillante, G. (2010). "Prediction System for Change Management in Construction Project." *Journal of Construction Engineering and Management*, 136(6), 659–669.

Zhu, Y. (2006). "Applying computer-based simulation to energy auditing: A case study". *Energy and Buildings*, 38(5), 421-428.

zur Muehlen, M., & Rosemann, M. (2005). "Integrating risks in business process models". In: Proceedings of the 2005 Australasian Conference on Information Systems (ACIS 2005), Manly, Sydney, Australia, Paper 50.