BUILDING KNOWLEDGE MODELING: INTEGRATING KNOWLEDGE IN BIM

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ABSTRACT

Fragmentation of construction information has been challenging in the AEC/FM (Architectural, Engineering, Construction, and Facility Management) industry for a long time, and caused significant difficulties of information management. This fragmentation is also reported to be a major contributing factor to loss of knowledge. Several methods and tools have been developed to solve the problems of fragmentation and mitigate loss of knowledge. Building Information Modeling (BIM) has emerged as one of the tools, and is mainly intended to build a repository of shared digital building information models. In the meanwhile, to increase the productivity and efficiency, knowledge management (KM) plays an important role in construction lifecycle processes by managing the corporate knowledge, which provides organizations with competitive advantage. However, current BIM models are information-centric with little focus on knowledge modeling. Similarly, BIM and the process to transform construction information into knowledge are isolated, causing a major drawback in harvesting the vast amount of potential knowledge from models. Therefore, there is a fundamental need to embed knowledge modeling within BIM and the resulting models. Currently, very little known research has been conducted in this area. The paper aims to highlight the importance of Building Knowledge Modeling (BKM) and to explore and outline the possibilities and approach to knowledge modeling integration within BIM. It conducted an integrative and comprehensive review of literature and the state-of-the-art of BIM and KM, including developments and current status of BIM and KM implementation and industry adoption, as well as other related topics. The critical factors and key benefits associated with BKM implementation are also highlighted. The paper concludes by proposing the development of a framework and its constituents to facilitate BKM. Recommendations are also formulated for future research directions in this area.

Keywords: Building Information Modeling (BIM), Knowledge Management (KM), Building Knowledge Modeling (BKM)

1. INTRODUCTION

The problem of fragmented design and construction processes has been challenging the construction industry for a long time, and Building Information Modeling (BIM) has been adopted to reduce the impacts of fragmentation in recent years (Campbell 2007). BIM is defined by the National BIM Standard as “a digital representation of physical and functional characteristics of a facility”, and it 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” (BSA 2012). It is a database to generate, exchange and manage all the building data and statistics, a platform for different project members to communicate and share information, and a tool to create comprehensive and object-oriented building models.

A large amount of information is exchanged and potential lessons learned are generated in BIM activities. However, current knowledge management (KM) practice is an independent process, and no systematic approach or procedure has been established to capture those lessons learned in BIM. This would lead to the loss of knowledge that will have negative impacts on BIM design and collaborations. Therefore, an integrated approach to conduct knowledge management within the scope of BIM is needed, so that the knowledge derived from the validation process of lessons learned can be stored in the knowledge management system (KMS) that may be useful for later stages and future projects. The paper intends to develop a new Building Knowledge Modeling (BKM) approach that will integrate BIM and KM to fully capture and reuse knowledge in BIM activities, and facilitate building lifecycle design and operation.

2. HISTORICAL PERSPECTIVE-FROM BDM TO BIM

2.1 Data, Information and Knowledge

The concepts of data, information and knowledge are closely related (Kock et al. 1997), and it is commonly known that knowledge has a higher level than information, and information has a higher level than data (Tuomi 1999).

Data is a set of raw facts

Davenport and Prusak (2000) indicated that "data is a set of discrete, objective facts about events", and "provides no judgment or interpretation and no sustainable basis of action". Data are syntactic entities and patterns without meaning, and exists in usable or non-usable forms without any significance beyond the existence (Aamodt and Nygård 1995; Bellinger et al. 2004).

Information is structured and interpreted data

Information is structured data with meanings, and is generated from the interpretation process of data (Aamodt and Nygård 1995; Davenport and Prusak 2000). Ackoff (1990) defined information as "data that are processed to be useful, providing answers to 'who', 'what', 'where', and 'when' questions".

Knowledge is refined information

According to Stewart (1998), knowledge has become the most important resource and asset for companies today. Knowledge is dynamic "justified true belief", and it is created by individual and organization interactions in the society (Nonaka et al. 2000). It is the "application of data and information", and it answers "'how' questions" (Ackoff 1990). Knowledge is created through cognitive efforts and contains judgment compared to data and information (Tuomi 1999).

In summary, data is a carrier and storage of information and knowledge, and a media for information exchange and knowledge transfer (Kock et al. 1997). Kock et al. (1997) indicated that information is descriptive and related to the past and the present, while knowledge can be used to predict the future within a certain limit. The role of knowledge is to facilitate the processes of transforming data into information through data interpretation, deriving new information from existing through elaboration, and acquiring new knowledge through learning (Aamodt and Nygård 1995).

2.2 Buildling Information Modeling (BIM)

BIM has been widely adopted in the architecture, engineering, and construction (A/E/C) industry with 3D computer-aided design (CAD) technologies (Taylor and Bernstein 2009). The objective of BIM is to build a building information model that represents the functional and physical features of a facility virtually prior to building it physically, and the basic premise is collaboration among different team membership and stakeholders in all phases of a construction project (Smith 2007). Unlike traditional 3D modeling technologies, BIM provides a collaborative platform for different disciplines to share and exchange information (Eastman et al. 2011) and an interactive environment for project management throughout the lifecycle of a facility.

The traditional way of communication in the A/E/C industry was done by drawings printed on papers, and the process was further facilitated by the development of the CAD technologies (Goedert and Meadati 2008). However, graphical elements (e.g. lines, symbols, etc.) in drawings and CAD files only represented 2D geometry of a facility, and no information related to building components was included (Howell and Batcheler 2005). Later on, although 3D CAD emerged and complex drawings could be turned into vivid 3D graphic prototypes, the models usually became useless at the preconstruction stage and the benefits were "seldom realized post-construction due to the breakdown in continuity of data collection" (Goedert and Meadati 2008). Furthermore, data was still shared and exchanged among project teams via a printed set of plans that were stored and managed in fragment (Taylor and Bernstein 2009). As stated by Chen et al. (2009) and Davenport and Prusak (2000), data is "computerized representations of models and attributes of real or simulated entities", and exists in the form of "syntactic entities and patterns without meaning". Therefore, drawings and 2D/3D CAD technologies can be categorized as Building Data Modeling (BDM), which can simulate the components of a facility with sufficient data size and storage (e.g. drawings, spreadsheets, etc.), but is not capable of representing more comprehensive information such as relationships between data and symbols (Smith 2007).

According to Howell and Batcheler (2005), object-oriented CAD systems (OOCAD) has been developed recently, and it can represent relationships between building elements with both graphic and non-graphic attributes assigned to them. BIM is the latest generation of OOCAD systems with the inclusion of parametric 3D geometric and functional information, which enables the function to represent complex building component relationships. Data is interpreted into information prior to being stored in BIM models, and all information will be easily retrieved and modified by different project teams. Relationships and meanings of the elements in a BIM model are clearly defined, therefore different project disciplines can collaborate together through one single virtual model.

3. CURRENT STATUS OF BIM

Although the adoption process of BIM by the A/E/C industry was slower than 2D/3D CAD technologies (Whyte et al. 2002; Whyte et al. 1999), it has been widely used in construction projects nowadays. The functions of BIM have been expanded from information exchange and clash detection into a larger field of applications. A good BIM application should have 6 key characteristics (Campbell 2007; Dace 2006): digital (capacity to simulate design and construction phases), spatial (3D representation of complex construction conditions), measurable (with quantifiable and query-able data), comprehensive (building performance, constructability, project schedule, etc.), accessible (enabling information sharing to the whole project team through an interoperable platform), and durable (reflections of as-built conditions throughout the lifecycle of a building).

Different researches classified BIM uses into different categories. Campbell (2007) indicated that BIM can be implemented in 10 aspects: design visualization (visualize and communicate design intentions), design assistance & constructability review (assist the design team and help perform constructability review), site planning & site utilization (study and estimate site conditions), "4D" scheduling and sequencing (visualize and optimize construction sequences), "5D" cost estimating (facilitate the quantity survey of building components for cost estimation), integration of subcontractor and supplier models (incorporate detailed data from subcontractors and vendors into BIM models), systems coordination (identify and resolve conflicts between different systems prior to the installation), layout & fieldwork (facilitate the layout of materials and systems on site), prefabrication (assist in the prefabrication of building components), and operations & maintenance (support facility maintenance and management). By comparison, the Computer Integrated Construction (CIC) Research Program in the Pennsylvania State University defined 25 BIM uses in plan, design, construction, and operation phases (Messner et al. 2011).

A successful BIM system can help reduce lifecycle cost and cycle time and enhance sustainable product quality (Rogers 2008), and a number of challenges still exist in accomplishing the full promise of BIM applications (Smith 2007). Different projects use different delivery methods and contract types, and based on specific project requirements, the deployment of BIM systems relies on most advanced applications from different vendors. Users are more accustomed to sharing information and files by traditional digital/paper documents rather than sharing objects directly on building information models. Moreover, the real-time graphic and interoperability features of BIM are often challenged by "integrating spatial, graphic, and tabular data in countless proprietary file formats" (Campbell 2007).

North American Chapter of International Alliance for Interoperability (IAI) and the Facility Information Council (FIC) have launched the "building SMART" program, and it aims to enable "the dynamic and seamless exchange of accurate, useful information on the built environment among all membership of the building community throughout the life cycle of a facility" (IAI 2007). With the efforts to promote open standards in BIM applications, the efficiency and accuracy of information exchange will be greatly improved.

4. POTENTIAL KNOWLEDGE INTEGRATION IN BIM

BIM is a key technology for the integration of project management and building information. Building information modeling and model generation is an evolutionary process, and it is critical for us to capture knowledge in this process from one stage to another. However, current BIM approach is not matured enough to generate and capture knowledge, and knowledge management is a stand-alone process separated from BIM implementation. What if knowledge, the refined information, is integrated into BIM?

4.1 Knowledge Management

Knowledge management plans, organizes, motivates, and controls individuals and information systems to improve the organization's knowledge assets and production efficiency (King 2007). Davenport and Prusak (2000) delineated that the content of knowledge management processes is knowledge generation, knowledge codification and coordination, and knowledge transfer. Bhatt (2001) indicated that knowledge management contains five processes: creation, validation, presentation, distribution, and application. According to King (2007), knowledge management processes include acquiring, creating, refining, storing, sharing and utilizing knowledge. By properly implementing these processes, knowledge management can help accelerate the organization's improvement.

The significance of knowledge management and well-designed knowledge management systems has been fully recognized (Tan et al. 2010; Elgobbi 2010), and the knowledge management has become one of the major fields for business thinking and decision making processes (Udeaja et al. 2008). In the survey conducted by KPMG (2003), a large portion (80%) of the participating companies recognized knowledge as their strategic assets, and some representatives even indicated that a potential 6% of annual revenue was due to the failure of knowledge management. The objective of knowledge management is to increase the productivity and the behavior of team works through a knowledge sharing platform (Ribino et al. 2009). In order to achieve success, an organization should perform knowledge management activities as a whole, and motivate individuals to facilitate the process (King 2007).

Tan et al. (2010) summarized different process models and incorporated them into four processes: knowledge capture, knowledge sharing, knowledge reuse, and knowledge maintenance. Knowledge capture is to identify and store knowledge, and evaluate information captured; knowledge sharing is to exchange and transfer knowledge to a person or an organization through some media like documents, phone, and the internet; knowledge reuse is to re-apply knowledge stored for innovation; and knowledge maintenance is to archive and refine knowledge in the repository, and keep the necessary information up-to-date.

The implementation of knowledge management in organizations should enable knowledge transfer cross different projects, as well as capturing and storing knowledge in an efficient way (Kamara et al. 2002). The organization's knowledge resources and innovation ability should be improved in the management process (Tan et al. 2007).

4.2 Integration of Knowledge

Current BIM applications are information-assisted building modeling technologies with sufficient element-related information assigned to each part of the model. Knowledge management is a separate and independent process, with no integration with BIM implementation. As a result, the BIM and the KM approaches have to be managed and maintained separately, thus lowering the efficiency of project collaboration. As both of them are implemented throughout the lifecycle of a project and knowledge is the higher level of information (Liu et al. 2013), it is practical and feasible to break the border of them and integrate into Building Knowledge Modeling (BKM).

Chen et al. (2009) did a similar research regarding the visualization process. In a typical search process, a user will provide the input data and control parameters into a visualization tool in order to get a satisfactory collection of results. To reduce the search space in the process, an additional pipeline that displays information about the input data is added to enable the information-assisted visualization. In such a system, the visualization efficiency and effectiveness would be improved by replying on the information abstracted from the data. Furthermore, knowledge from the user is an important part of the visualization system and inadequate certain domain knowledge usually decreases the performance quality. Therefore, a knowledge-based system that stores expert knowledge is inserted to facilitate the process by enabling domain knowledge sharing and reusing between different users.

BIM can be improved in the same way, by expanding information exchange into knowledge sharing with the integration of a fully functional KMS (as shown in Figure 1). The BIM applications and KMS (which stores knowledge in a KM repository) are connected and operated simultaneously to satisfy information exchange requirements of BIM uses and knowledge capture, sharing, reuse and maintenance requirements of KM. This is the core of the proposed BKM approach in this paper.

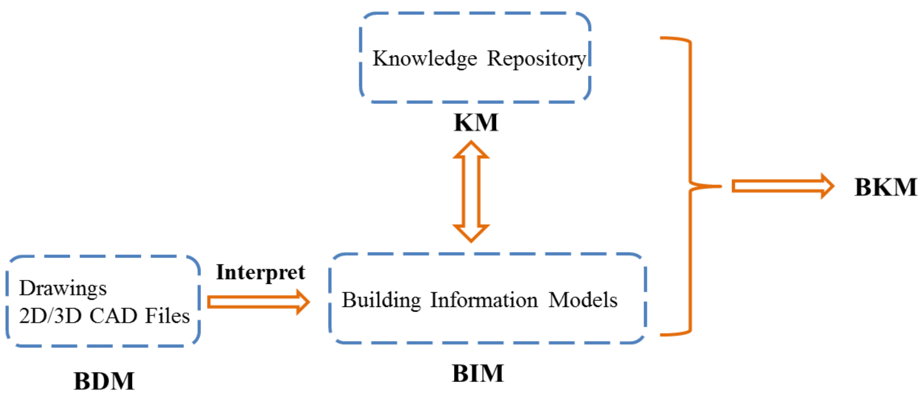

Figure 1: Development of BDM, BIM and BKM

The expansion of BIM to BKM was explored by Fruchter et al. (2009) with the integration of three software environments: TEKLA (BIM software platform), RECALL (KM software to capture and reuse digital knowledge), and TalkingPaper (KM software to collect document hard copies). A TEKLA-Structure system was developed to fully manage data, information and knowledge in building models with the integration of RECALL and TalkingPaper through hyperlink. Fruchter et al. (2009) indicated that a successful BKM approach can help reduce rework, wasted time and project duration, increase possibilities for innovation and keep the organization ahead among other competitors, and provide training resource for new employees.

5. TOWARDS BKM

5.1 Overall Concept

Based on the discussion above, BKM can be defined as an integrated process and multimedia technology to capture potential knowledge in the building information modeling process, and serves as the core for team collaboration and knowledge management via building models throughout the lifecycle of a facility. A basic premise of BKM is the integration of knowledge capture, sharing, reuse and maintenance with the communication of all involved parties in plan, design, construction and operation phases.

The goal of a successful BKM approach is to enable team collaboration and building knowledge management in the lifecycle of a facility with the integration of BIM and KM processes. It is proposed to be implemented by an intermediate integration module called *'Knowledge+'* that is used to connect BIM application and KMS to expand BIM uses and facilitate knowledge capture and sharing within the scope of BIM (as shown in Figure 2). The module provides the functions of capturing lessons learned in BIM activities, facilitating the communication between BIM and KM processes, and supporting knowledge retrieval and reuse in the lifecycle of a facility. HTTP protocol is proposed to be adopted to enable the information exchange mechanism between the BIM application and KMS. Lessons learned from BIM activities are captured and sent to the KMS by *Knowledge+* so that they will be validated by related team members/experts, and stored in the KM repository. Meanwhile, *Knowledge+* is also used to retrieve previous knowledge from the KMS to facilitate design and collaboration processes on the BIM platform.

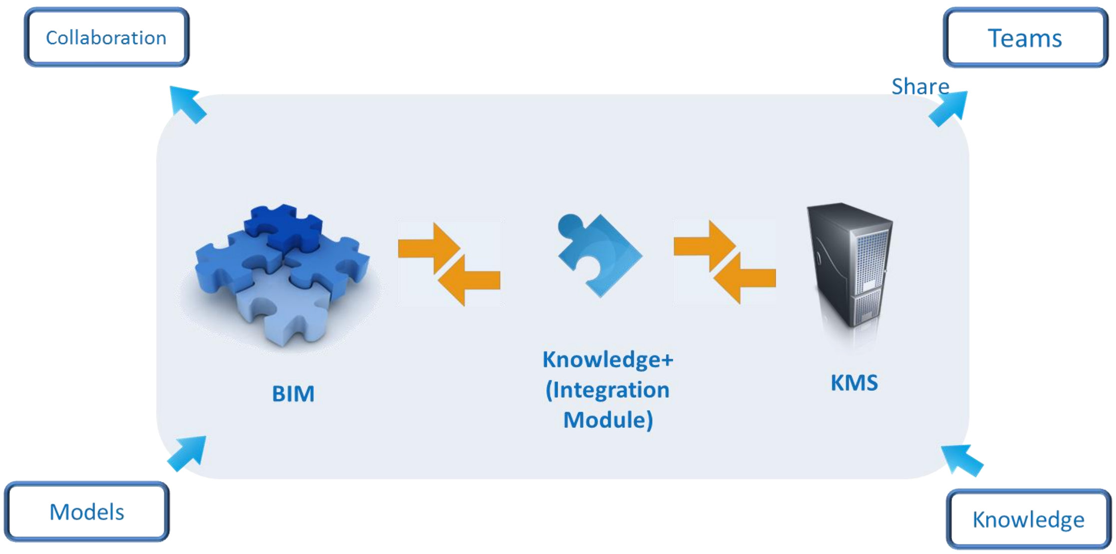

Figure 2: Integration of BIM application and KMS

5.2 Scenario

A scenario regarding airflow analysis was developed within the research of BIM Data Hub (a project focusing on developing a central repository of building information) to demonstrate the applicability of the BKM approach. Current work in this project focuses mainly on retrieving domain specific information according to exchange requirements specified in MVDs, so that energy analysis can be conducted based on the data from IFC models (Jiang et al. 2012; Yu et al. 2013). The goal is to convert the data to OpenStudio file format and interact with energy analysis tools. BIM Data Hub consists of a BIMserver that holds building information and a query function module that is used to extract useful information. The ideal workflow (as shown in Figure 3) is within the scope of BIM. In airflow analysis, required building information could be retrieved from BIM models as an IFC file and sent to BIM Data Hub, and the content in the file is then expected to be transformed and documented in the OpenStudio file format for airflow analysis.

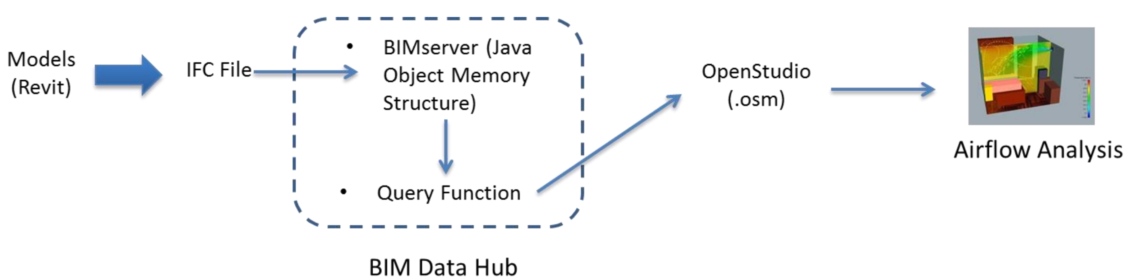

Figure 3: BIM use case in airflow analysis

To expand the use case into BKM, let's consider the internal partition design of an energy efficient retrofit building. The partition is first designed by the architect in the early design phase, and it may not be energy efficient from the perspective of the energy engineer. The partition type inside a building is one of the key components that will influence airflow, and open partitions are important for natural ventilation (Heerwagen 1996). If the initial design does not satisfy this energy efficient requirement, the architect will need to collaborate with the energy engineer to change the partition design, and this would cause a schedule delay and redundant work. After the design is finished, this potential partition design knowledge in energy efficient retrofit buildings would be lost as no KM mechanism is built in the BIM design process. By comparison, Figure 4 shows the adoption of the new BKM approach in this case. The lessons learned of partition design are identified and recorded by *Knowledge+* module, and then the content is sent to KMS for knowledge management (validation, store and maintenance) so that other team members can get access to this new knowledge in later phases or future projects. This procedure is represented by arrow 1 and 2. Arrow 3 and 4 represent knowledge retrieval and reuse. If similar cases happen in the future, the architect could send a knowledge retrieval request to *Knowledge+* module that will trigger the query function of KMS for previous partition design knowledge. This BKM approach enables a more efficient project management way by reducing the amount of rework and collaboration efforts.

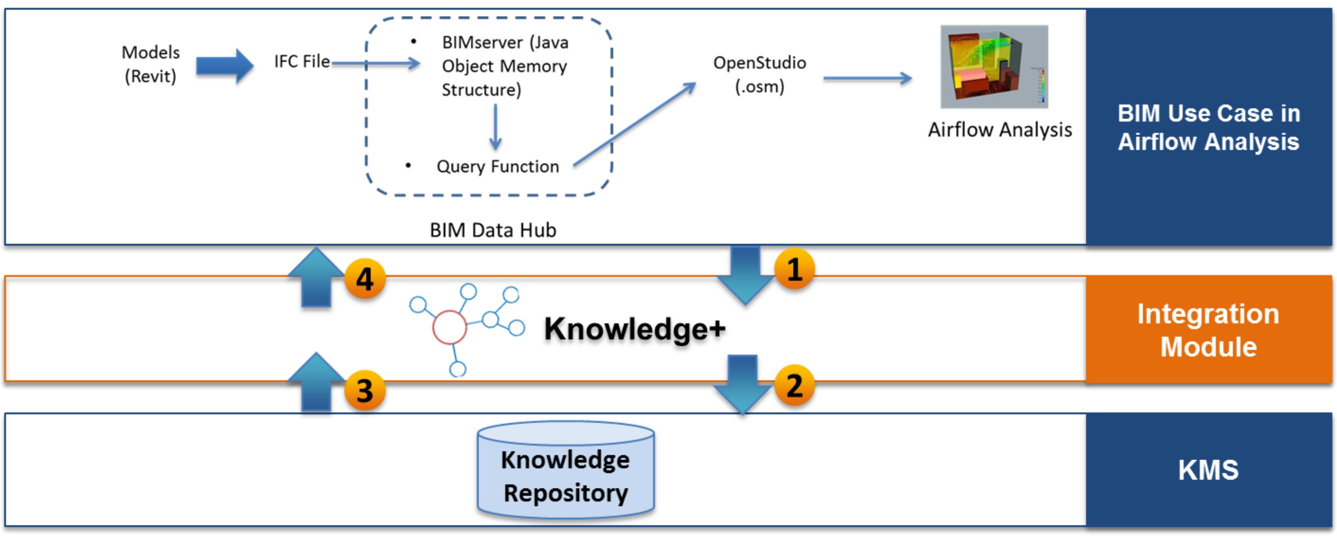

Figure 4: Expand to BKM use case

For the system implementation, the use case is developed based on the environments of CAPRI.NET(a web-based KMS) and Autodesk Revit. The technical solution for the scenario is illustrated in Figure 5. *Knowledge+* module will be built by using the Revit .NET API and Microsoft Visual Studio as a plug-in into Revit. When the architect designs the partition to improve energy performance, he/she will be prompted by the plug-in to input new lessons learned from the internal partition design process. Next, *Knowledge+* will post a request through HTTP to the KMS, and lessons learned will be validated by experts. New knowledge is generated through this process, and it helps avoid knowledge loss in BIM activities. As for knowledge reuse, the request for previous knowledge of partition design in energy efficient retrofit buildings from the architect will be captured by *Knowledge+*. The module will then send out parameters through HTTP to trigger the query function of KMS. Once the knowledge is located and retrieved in the knowledge repository of KMS, it will be transmitted through HTTP protocol back to *Knowledge+* and displayed on its interface in the BIM application that can help the architect with BIM design activities. As a result, a bi-directional connection is created between BIM and KM that would greatly benefit project efficiency and productivity.

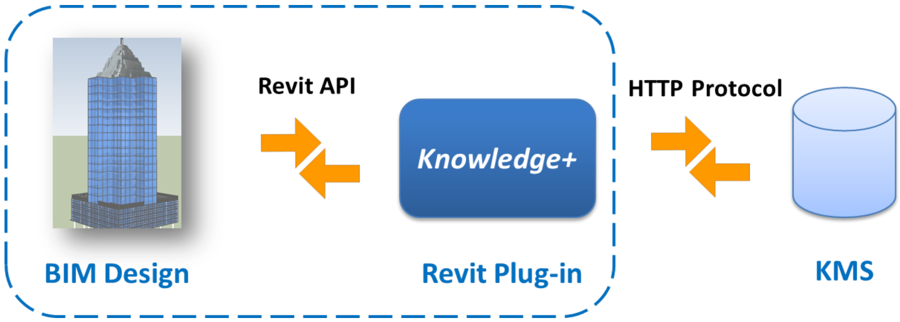

Figure 5: Technical Solution

6. CONCLUSION

BIM has been widely adopted in the A/E/C industry with the objective to build a virtual facility model prior to building it physically to facilitate design and collaboration. It originated from BDM, which managed a construction project by unstructured data (2D drawings, traditional CAD technologies, etc.). KM is critical to increase the productivity and efficiency of a project. It equips organizations with competitive advantages and facilitates business thinking and decision making processes.

From the analysis in the paper, we can see the possibility and feasibility of the BKM approach by integrating knowledge capture and reuse in BIM uses with the integration module *'Knowledge+'*. A successful BKM strategy is capable of capturing, sharing, reusing and maintaining knowledge simultaneously in the communication and collaboration processes throughout the building lifecycle. The BKM approach enables a comprehensive building information and knowledge management method to facilitate project management and team collaboration. By managing building digital models and related knowledge within one single process, working efficiency and productivity will be greatly increased compared to managing knowledge separately, and a large amount of time and efforts to locate and reuse domain knowledge will be saved. Additionally, redundant and unnecessary rework can be reduced by fully utilizing expert knowledge to facilitate energy efficient design. Future research in this area includes the development of *Knowledge+* module and validation of the BKM approach in real construction projects.

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