

Knowledge Management in Construction using Building Information Modeling (BIM)

by

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Abstract

Knowledge is generated in all the phases of a construction project during its lifecycle. It is stored in multiple formats (pdf, dwg, ifc, etc.) and is present at multiple locations (pdfs, cds, RFIs, etc.) in a project environment. This makes knowledge management in a construction project difficult. Various tools and techniques have been proposed in the past for successful implementation of the Knowledge Management (KM) process in organizations but none of them have had any significant impact on the overall process. Building Information Modeling (BIM) can be the technology which can help in overcoming some of the drawbacks of the previous models and has the potential to be a powerful tool in helping organizations to successfully implement KM. BIM is a combination of technology and processes which helps in the design, construction, operation and maintenance of a facility. Among the many possible future uses/applications of BIM, Knowledge Management can be one of them. This research work presents a methodology to capture and store knowledge using Autodesk Revit®, the most widely used BIM software in the construction industry. This study also proposes BIM as a tool which facilitates the overall knowledge management process of an organization. The proposed methodology has been tested in a BIM consultancy firm and found to be useful in capturing and storing lessons learned in the BIM model. The observations and the validation process are presented in this study along with the applications and advantages of the proposed methodology.

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Chapter 1 Introduction

1.1. Overview

A typical construction project can be broadly classified into three phases during its lifecycle:

1. Pre-Construction phase
2. Construction Phase and
3. Post-Construction Phase

These phases can further be sub-divided into several categories. The pre-construction phase consists of initiation, feasibility, schematic design, design development, construction document etc. Depending on the type and size of the project, it can have few or all the sub-stages. Not all projects go through all the sub-phases and these phases can be sequential or simultaneous, sometimes a project can go through a few stages (planning, execution etc.) multiple times. Once the construction drawings are prepared and the project gets all the necessary clearances, the owner bids the project and hires a contractor to construct the facility. The project then proceeds to the construction phase, where it is built and the post-construction phase consists of closeout, ownership operations and maintenance. From the owner's perspective, the project life cycle of a constructed facility may be illustrated as the Figure 1.1 shown below.

Whatever may be the size or the type of the project, every project has situations where something new or better is learned. In most of the projects at one point or another, mistakes are made either by the designer, engineer, contractor, sub-contractor, worker etc. and lessons are always learned from these mistakes. Knowledge is generated from addressing those mistakes and from the solutions developed in response to them.

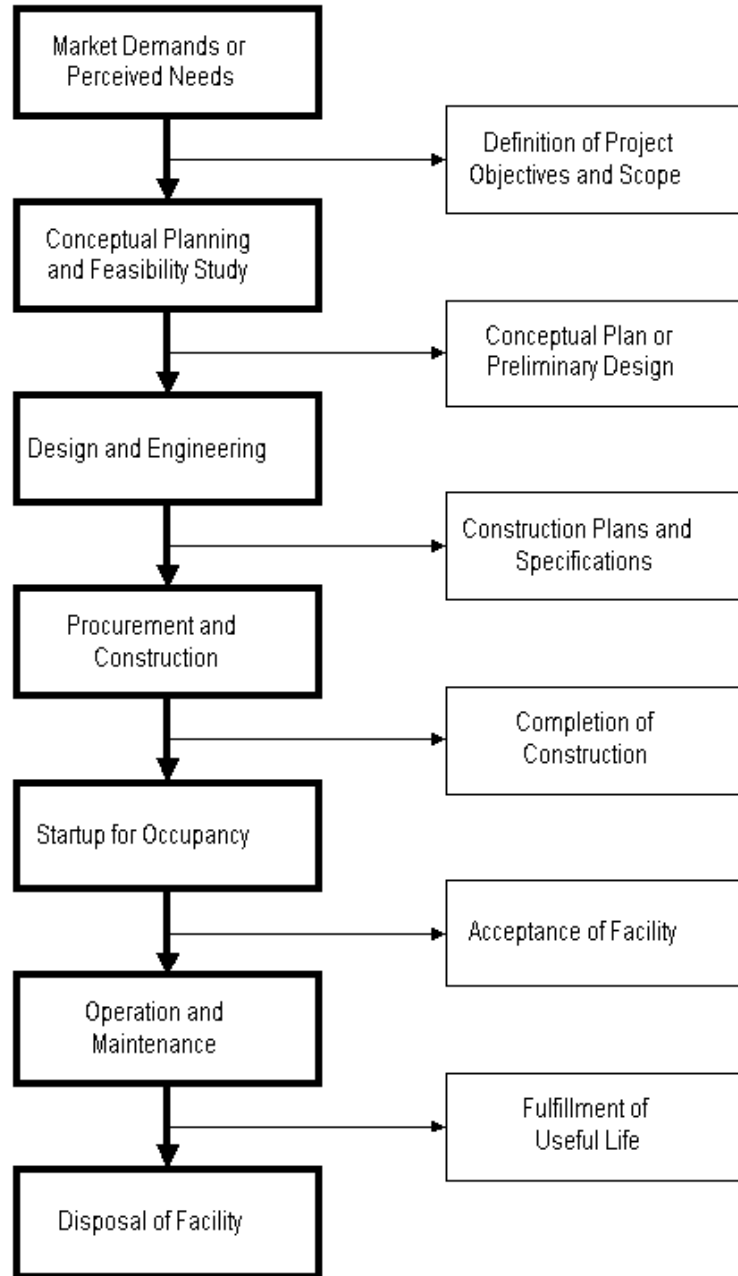


Figure 1.1: The project lifecycle of a completed facility (Chris Hendrickson, 2008)

During the design phase, the designer carries out the design from the initial input of the owner, then initial design goes through multiple changes and once the design is mature enough it is submitted to the stakeholders. These stakeholders can be anyone in the construction industry including but not limited to general contractors, facility users, operations and maintenance

personnel, suppliers, consultants etc. The stakeholders give their feedback on the design and the design is revised accordingly. The design then goes through the value engineering process and constructability analysis and the design is completed. During the whole process, there will be many instances where knowledge is generated.

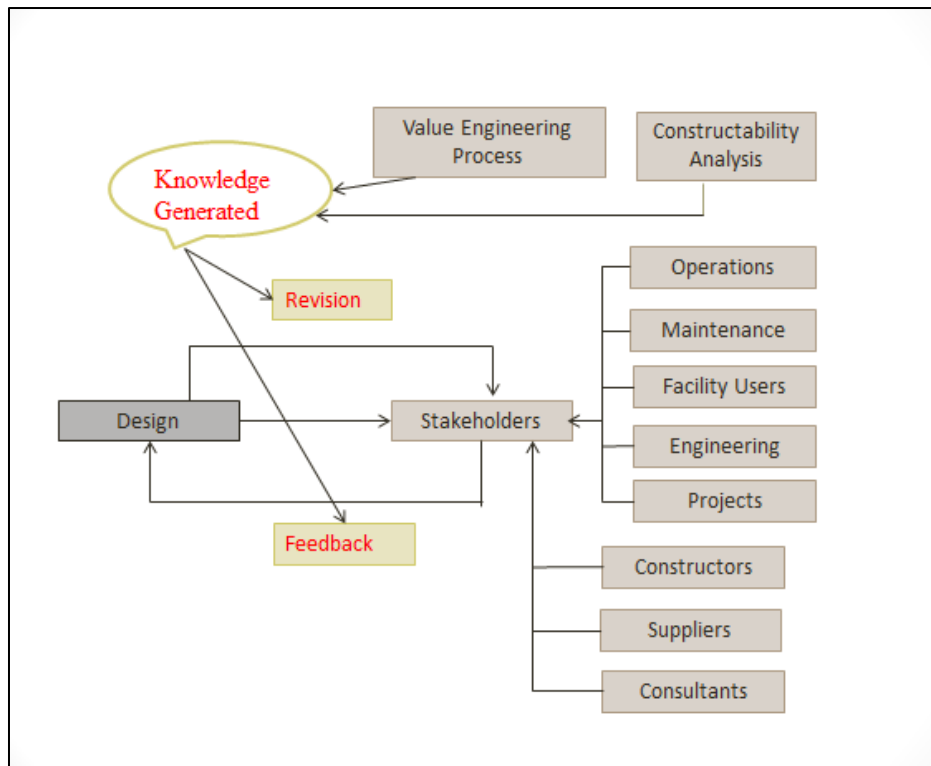


Figure 1.2: Knowledge generation situation during design phase

Similarly during the construction phase, there can be new things learned about the construction means and methods. There are methods more efficient than the current ones. There can be knowledge about the use of technology to carry out a particular process or to keep track of a particular process, there can be new knowledge about the selection of the material for a particular type of construction or knowledge related to safer methods, knowledge about the safety on the project, punch lists to cover all the things done on a project. There are so many situations during the life cycle of a construction project, where new things are learned. Some or

most of the lessons learned can be useful for future projects. Hence if we can store that knowledge and reuse in future projects, the repetition of the past mistakes can be avoided completely or reduced greatly.

The knowledge generated in construction projects is scattered across multiple formats at various locations. The knowledge learned in a design phase is stored in the design documents, the knowledge generated during a construction phase can be present in an RFI, etc. Managing all this knowledge from the structured as well as unstructured documents is important to learn new things and be more efficient on the field and not repeat any of the past mistakes. Hence knowledge management can be considered as an important factor to increase the efficiency of the construction industry as a whole.

Knowledge Management

Knowledge Management (KM) can be defined as a systematic and organized attempt to use knowledge within an organization to transform its ability to store and use knowledge to improve performance (Rezgui, Hopfe, & Vorakulpipat, 2010). An organization's competitive advantage depends on harnessing and using the knowledge of its employees to meet its business objectives, for continuous improvement of the organization, and to avoid repetition of errors and mistakes from past projects (Tan et al., 2009). Dave and Koskela (2009), also argue that 'knowledge' is a significant resource of an organization and when used effectively, it provides competitive advantage to the construction organizations. Retaining knowledge (lessons learned) generated in a project is crucial for an organization's development and for it to stay ahead of the competition. Every project in the construction industry can be considered to be unique in its design, execution, budgetary limitations, environmental and organizational conditions. Despite

the uniqueness of the construction projects, there are often situations where the designers and construction professionals have to refer to the knowledge generated in the previous projects or best practices followed in order to solve a problem at hand. Most of the times, the required knowledge to address a difficult or problematic situation in a project is possessed by an experienced project member (generally a project manager), who is familiar with similar types of situations from past projects. Therefore, it is important to retain such knowledge possessed by the experienced project personnel to be used after their departure from the organization or retirement from the industry. It can save both the time and money spent on addressing such issues. As Dave and Koskela (2009) put it, “Reuse of existing organizational knowledge gained via past experience can greatly reduce the time spent on problem solving and increase the quality of work.”

Each project team in a construction project consists of many stakeholders who contribute their area of expertise for the successful completion of a project and after the completion, most of the project members move on to other projects. The splitting of the project team and the fragmented nature of the construction industry allows critical mistakes to be repeated and hence knowledge management can be considered an important factor to enhance organizational performance. Capturing the knowledge generated in the construction projects and sharing it among the project team members is important to avoid repetition of previous mistakes and to prevent finding the same solutions to similar problems over and over again. The construction industry is very competitive in nature with low profit margins, which makes knowledge management appear attractive (Carrillo & Chinowsky, 2006).

Despite the growing awareness of Knowledge Management (KM) by the construction industry, limitations such as knowledge loss due to time lapse in capturing the knowledge, high

staff turnover and reassignment of people to other projects still remains a problem. Therefore, it is crucial to capture the knowledge and present it in a format that will facilitate its reuse during and after the execution of the project (Tan et al., 2006). Implementation of knowledge management in construction can be very effective with the use of Information and Communication Technologies (ICT) tools but the industry has been relatively slow in adopting these technologies when compared to other industries (Dave and Koskela, 2009). However, Dave and Koskela (2009) argue that the construction industry has made significant efforts to embrace the solutions offered by ICT during the last decade. While ICT does not necessarily apply to all of the issues of knowledge management, it can certainly act as a tool which supports the KM process in capturing knowledge, storing it in a database and finding a lesson learned or an expert or a recorded source of knowledge using online directories and searching databases; sharing knowledge; access to information on past projects and working together in virtual teams among others (KPMG, 1998 in Tan et al., 2009). This study proposes BIM as an ICT tool to capture, store and share knowledge in the construction industry. This study also suggests that BIM can be an effective tool in enhancing the effectiveness of some of the existing KM models.

1.2. Research Objectives

The primary objective of the research is to develop a methodology to capture, store and disseminate knowledge created in the Engineering and Construction projects using Building Information Modeling.

Other objectives of the research include:

- i. To propose a method to extract the knowledge captured using BIM models.
- ii. To propose a method to store the knowledge extracted.
- iii. To validate the developed methodology with the help of BIM experts

- iv. To develop an example model explaining the methodology.

1.3. Organization of the Study

This thesis presents an innovative methodology to capture, store and disseminate knowledge created in the construction projects using Building Information Modeling. The discussion of this thesis document is organized as follows:

Chapter 1 – Introduction: This chapter begins with the explanation of various phases in construction during which knowledge can be generated, it is followed by explaining where the knowledge is located in a construction project. Knowledge Management and its importance in construction projects is then discussed. The research objectives of the study are then outlined which is followed by the organization of the study.

Chapter 2 – Literature Review: A brief introduction of knowledge and taxonomies of knowledge is given. It is followed by the Knowledge Management processes and explanation of some of the important Knowledge Management (KM) models in the construction industry. Finally, the drawbacks associated with current KM practices are explained.

Chapter 3 – Building Information Modeling: This chapter explains what Building Information Modeling (BIM) is and the phases it can be used. It is followed by the explanation of current project delivery models in construction. The inefficiencies of the traditional practices are explained which is followed by the benefits of using BIM. The statistics of McGraw Hill SmartMarket Report 2014 are discussed briefly and the challenges for using BIM are explained.

Chapter 4 – Parametric Nature of BIM and Knowledge Management: This chapter explains the parametric nature of BIM, the difference between family, family types and instances in Revit®

Platform and how changing any of these properties effect the entire BIM model and how it can be leveraged to capture, store and disseminate knowledge in the construction projects.

Chapter 5 – Knowledge Extraction and IFCs: This chapter explains how the knowledge stored in a BIM model can be extracted and the different ways in which the knowledge output can be modified based on user preference and the uses associated with it. It is then followed by the explanation of Industry Foundation Classes (IFC), how knowledge can be extracted using ifc and the usefulness of ifc in the exchange of information among the construction organizations.

Chapter 6 – The Validation Process: This chapter explains how the validation process of the proposed methodology was carried out in a BIM consultancy firm. The roles of different project team members is explained, followed by the discussion of the focus group meetings and how the methodology was implemented in the organization.

Chapter 7 – Illustrative Example: This chapter illustrates the whole Knowledge Management process developed in the study using an example project. The chapter begins with the details of the project, it is then followed by explaining how the knowledge is captured in the model, how the captured knowledge is extracted from the BIM model, the validation process of the lessons extracted and how the lessons are stored in the knowledge base of the organization.

Chapter 8 – Conclusion and Future Research: This chapter explains the applications of the proposed methodology and additionally identifies the potential for future research that can be conducted to continue the research effort.

Chapter 2 Literature Review

2.1 Introduction

2.1.1 Knowledge Definition

Knowledge can be defined by distinguishing among knowledge, information and data. A commonly held view is that data is raw numbers and facts, information is processed data, and knowledge is authenticated information (Vance 1997 in Alavi and Leidner, 2001). The content, structure, utility or accuracy cannot effectively distinguish information and knowledge. Knowledge is information which is possessed in the minds of the individuals: it is personalized information related to facts, procedures, concepts, interpretations, ideas, observations, and judgments. This may or may not be new, useful, accurate or unique (Alavi and Leidner 2001).

Once the information is processed through the mind of individuals it is converted to knowledge. Similarly, when knowledge is articulated or presented in the form of words, graphics, text or other forms, it becomes information. An underlying assumption is that the individuals share a common knowledge base to arrive at the same level of understanding of data or information. Another implication is that the systems designed to support knowledge in organizations may not appear drastically different from other forms of information systems but the user will be able to assign meaning to the information and capture some of their knowledge from the information or data (Alavi and Leidner 2001).

Knowledge may be viewed from several perspectives (Alavi and Leidner 2001): (1) a state of mind, (2) an object, (3) a process, (4) a condition of having access to information, or (5) a capability.

If knowledge is viewed as a state of mind, the focus should be to expand individual's personal knowledge and then apply it to the organization's requirements. Knowledge can be

considered as a thing that can be stored and manipulated when viewed as an object. Alternatively, knowledge can also be considered as a process of knowing and acting simultaneously. This perspective focuses on the application of expertise. The fourth view defines knowledge as a condition of having access to the information. This can be viewed as an extension to knowledge as an object with a special emphasis on accessibility of the knowledge objects. This knowledge facilitates access to the content and retrieval of any information. The perspective of knowledge as a capability has the potential to influence future action (Carlsson et al. 1996).

These different views of knowledge lead to different perceptions of knowledge management (Carlsson et al. 1996). If knowledge is viewed as a process, then the knowledge management should focus on the process of creating, sharing and distributing knowledge. If knowledge is compared to information access, then knowledge management focus should be on building knowledge stocks and managing them. If knowledge is viewed as a capability, a knowledge management perspective focused on understanding the strategic advantage of know-how and creating intellectual capital should be developed. Each perspective suggests a different strategy for knowledge management and a different perspective of the role of systems in support of knowledge management.

Figure 2.1 summarizes the various views of knowledge and their implications for knowledge management and knowledge management systems.

Perspectives		Implications for Knowledge Management (KM)	Implications for Knowledge Management Systems (KMS)
Knowledge vis-à-vis data and information	Data is facts, raw numbers. Information is processed/interpreted data. Knowledge is personalized information.	KM focuses on exposing individuals to potentially useful information and facilitating assimilation of information	KMS will not appear radically different from existing IS, but will be extended toward helping in user assimilation of information
State of mind	Knowledge is the state of knowing and understanding.	KM involves enhancing individual's learning and understanding through provision of information	Role of IT is to provide access to sources of knowledge rather than knowledge itself
Object	Knowledge is an object to be stored and manipulated.	Key KM issue is building and managing knowledge stocks	Role of IT involves gathering, storing, and transferring knowledge
Process	Knowledge is a process of applying expertise.	KM focus is on knowledge flows and the process of creation, sharing, and distributing knowledge	Role of IT is to provide link among sources of knowledge to create wider breadth and depth of knowledge flows
Access to information	Knowledge is a condition of access to information.	KM focus is organized access to and retrieval of content	Role of IT is to provide effective search and retrieval mechanisms for locating relevant information
Capability	Knowledge is the potential to influence action.	KM is about building core competencies and understanding strategic know-how	Role of IT is to enhance intellectual capital by supporting development of individual and organizational competencies

Figure 2.1: Knowledge Perspectives and Their Implications (Alavi and Leidner (2001))

2.1.2 Taxonomies of Knowledge

The knowledge that exists in organizations can be divided into two types: tacit and explicit. Tacit knowledge is the knowledge stored in the minds of individuals. This type of knowledge is gained by personal experience, lessons from seniors or experts, and involvement in a specific situation etc. Construction industry is fragmented in nature, thus management of tacit knowledge is important to the construction industry. Every construction project has unique

conditions and requirements. Therefore every project generates substantial amount of knowledge during its execution. Also, because of the construction project's dynamic nature, new challenges are being faced regularly for which solutions are developed by the project team members wherever possible. However the knowledge generated by this way is mostly remained in minds of project team members. This type of knowledge is known as tacit knowledge. The explicit knowledge on the other hand is the type of knowledge which can be codified, articulated, and communicated. Significant efforts have been made by the construction sector to develop and implement systems to manage capturing, storing and retrieval of explicit project related information (Dave and Koskela 2009). Some examples of explicit knowledge include organization maps, different code books, procedure manuals, document management systems, intranets and extranets, etc.

Tacit and explicit knowledge are not two distinguished states of knowledge, but they are mutually dependent and reinforcing qualities of knowledge: tacit knowledge forms the necessary background to interpret and develop explicit knowledge (Alavi and Leidner 2001). For individuals to truly exchange knowledge, they must share a common knowledge base (a common subject, common field or discipline). As discussed by Ivari and Linger (1999), if tacit knowledge is necessary to the understanding of explicit knowledge, then in order for Individual B to understand Individual A's knowledge, there must be some overlap in their underlying knowledge bases.

Theoretical developments in the area of knowledge management are influenced by the distinction among various types of knowledge (Alavi and Leidner 2001). Therefore, it is important to understand the concept of knowledge and knowledge taxonomies. Also, the design of the type of knowledge management system of an organization depends on the need to support

the type of knowledge required by an organization and flow among the different types of knowledge. Various types of knowledge an organization can focus on when developing a knowledge management system are shown in Figure 2.2.

Knowledge Types	Definitions	Examples
Tacit	Knowledge is rooted in actions, experience, and involvement in specific context	Best means of dealing with specific customer
Cognitive tacit:	Mental models	Individual's belief on cause-effect relationships
Technical tacit:	Know-how applicable to specific work	Surgery skills
Explicit	Articulated, generalized knowledge	Knowledge of major customers in a region
Individual	Created by and inherent in the individual	Insights gained from completed project
Social	Created by and inherent in collective actions of a group	Norms for inter-group communication
Declarative	Know-about	What drug is appropriate for an illness
Procedural	Know-how	How to administer a particular drug
Causal	Know-why	Understanding why the drug works
Conditional	Know-when	Understanding when to prescribe the drug
Relational	Know-with	Understanding how the drug interacts with other drugs
Pragmatic	Useful knowledge for an organization	Best practices, business frameworks, project experiences, engineering drawings, market reports

Figure 2.2: Knowledge Taxonomies and Examples (Alavi and Leidner (2001))

2.1.3 Knowledge Management Processes

Despite the overall process being the same, KM processes have been given different names and are referred to as differently by various researchers. Bhatt (2001) describes the KM processes as the sequence of knowledge creation, knowledge validation, knowledge presentation, knowledge distribution and knowledge application. Demarest (1997) observed that all the processes of KM need not necessarily be a sequence but stages like discovering, structuring and the use of knowledge can exist simultaneously. Each KM process differs in the focus and level of

detail: few do not consider issues of knowledge being obsolete, while others do not find the need to validate the knowledge (Tan et al., 2009). As discussed in Chapter 1, the overall KM process consists of four processes based on the models developed within the context of construction. They include 1. Knowledge Capture, 2. Knowledge Sharing, 3. Knowledge Reuse and 4. Knowledge Maintenance.

The following table contains different terms used by different researchers for the same overall KM process.

Author(s)	Knowledge management processes
Robinson et al. (2001)	<ul style="list-style-type: none"> • Discovering, locating and capturing • Organisation and storage • Sharing and transferring • Modifying and applying • Archiving and retirement
Kululanga and McCaffer (2001)	<ul style="list-style-type: none"> • Acquiring • Creating • Sharing • Storing • Utilizing
Rollett (2003)	<ul style="list-style-type: none"> • Planning • Creating • Integrating • Organizing • Transferring • Maintaining • Assessing
Tiwana (2000)	<ul style="list-style-type: none"> • Acquisition • Sharing • Utilization
Bhatt (2001)	<ul style="list-style-type: none"> • Creation • Validation • Presentation • Distribution • Application

Mertins et al. (2001)	<ul style="list-style-type: none"> • Create • Store • Distribute • Apply
Soliman and Spooner (2000)	<ul style="list-style-type: none"> • Create • Capture • Organize • Access • Use
Davenport and Prusak (2000)	<ul style="list-style-type: none"> • Knowledge generation: acquisition, dedicate resources, fusion, adaptation and knowledge networking • Knowledge codification and coordination • Knowledge transfer

Table 2.1: Various Knowledge Management Process Models (Tan et al.(2009))

Based on the various KM models developed within the context of construction (Tan et al., 2009), the Knowledge Management consists of four main processes: 1. Knowledge Capture, 2. Knowledge Sharing, 3. Knowledge Reuse and 4. Knowledge Maintenance

1. Knowledge Capture:

This process comprises of three sub-process:

- i. Identifying and locating knowledge:* This process deals with identifying different types of knowledge to be managed and the location of various knowledge situations. This process also identifies people with different skill set within the organization. The process of capturing knowledge can be done internally (within an organization) or externally (recruiting staff from other companies).
- ii. Representing and storing knowledge:* This process deals with indexing, organizing and structuring knowledge in a format specific to the organization. This process also includes details like the context to where the learning situations were created, where the knowledge can be useful and what are the conditions for reuse.

iii. *Validating knowledge:* Validating knowledge comprises of verification of the knowledge for its correctness, accuracy and completeness before it is shared and evaluation of the importance of the knowledge to be stored to prevent knowledge overload problems.

2. Knowledge Sharing:

This process deals with provision of right knowledge to the right person at the right time or within the shortest possible time. This process can take place between people, a person to computer and computer to computer.

3. Knowledge Reuse:

This process deals with the reuse of knowledge through either adaptation of the existing knowledge or by the application of existing knowledge such as re-application of an already identified best practice. The reuse of knowledge by adaptation involves innovation, the process consists of re-conceptualizing the problem and searching for ideas (knowledge), evaluating and analyzing the ideas in-depth and selecting the best idea and developing the idea fully to be adapted to the particular situation (Majchrzak et al. 2004).

4. Knowledge Maintenance:

Knowledge may become obsolete over time due to the development of a discipline, change in rules, employment of new theories and information (Bhatt, 2001). Therefore it becomes crucial to update the database of an organization from time to time with the appropriate changes. Knowledge maintenance consists of reviewing, updating and refining the existing knowledge to keep it accurate and up-to-date and to remove obsolete data from the database (Rollett, 2003).

2.2 Knowledge Management Practices

Organizational knowledge management has existed in different forms for quite some time, some examples include, training manuals, procedure and policy documents, forums for

innovation, safety registers, etc (Dave & Koskela, 2009). According to Alavi and Leidner (2001), in the IT literature, a knowledge management system refers to a class of information systems applied to manage organizational knowledge. Another popular definition by Ruggles (1997) describes KM tools as the “technologies used to enhance and enable the implementation of the sub-processes of KM.” KM practice depends significantly on the use of various KM tools to perform the KM sub-processes. KM tools can be either IT-based or non-IT based. The knowledge management systems are developed to support and enhance the knowledge management process (i.e. to capture, share and reuse knowledge). Some of the important KM techniques and technologies used by the construction industry include:

2.2.1 Traditional document management systems

In the construction industry, the primary means of conveying information during the lifecycle of a project are the Construction Documents. Even though they are produced using computer based software (2D or 3D), most of the time these are exchanged on a paper-based medium for contractual and legal reasons. These documents by nature tend to be unstructured, which can cause problems during the later stages of a project. Construction industry is facing a challenge in the mining, codification and re-use of the knowledge stored within these documents (Rezgui and Miles, 2011).

2.2.2 Post Project Reviews

Post Project Reviews (PPRs) are the debriefing sessions conducted at the end of a project to capture knowledge generated in the project. This knowledge can include any new lessons learned during the execution of the project or the best practices identified in the project or it can be knowledge identifying the causes of the problems/failures in the construction process or any mistakes identified in the design and how these issues were addressed by the project team during

the execution of the project. Organizations usually conduct PPRs individually at one of their office locations after the completion of a project. The term is also used interchangeably with Debriefing, Post Project Appraisal, After Action Review, Project Post-Mortem, Post Implementation Evaluation, Project Audit, Project Closeout and Post Completion Review (Tan et al., 2009).

After the completion of a project, the project teams are usually split up to be transferred to other projects where their skills are needed. Hence PPRs are considered as the final opportunity for the organization to capture the lessons learned in a project. PPRs give the project personnel an opportunity to learn valuable lessons which they can implement/transfer into subsequent projects. However, for this technique to be effective, adequate time should be allocated for those who were in a project to participate (Egbu et al., 2003). But insufficient time allocation is one of the common problems identified, loss of important insights due to time lapse in capturing the learning is considered as another main problem for PPR (Tan et al., 2009). Hence, a successful technique would capture the lessons as soon as they are discovered and would make them available to other project personnel for review.

2.2.3 Communities of Practice (CoPs)

Communities of Practice (CoPs) can be defined as ‘group of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis’ (Wenger et al., 2002 in Tan et al., 2009). The term Communities of Practice (CoPs) is often used interchangeably with communities of knowing, knowledge communities, knowledge networks, learning communities, communities of interest and thematic groups (Tan et al., 2009). Usually CoPs consists of a group of individuals who possess different skill sets, experience backgrounds and development histories but work together

in order to achieve commonly shared goals (Tan et al., 2009). CoPs provide a platform for its members to find solutions by pooling their experience, expertise and ideas. Industry/organization wide best practice guides and new knowledge can be produced from the interactions and discussions of CoPs members during a brainstorm session. Web based forums or webinars or web conferencing can be used to carry out the discussions by members who are geographically dispersed. A common sense of purpose and a real need to know what each other knows usually holds the members of CoPs together (Egbu et al., 2003).

2.2.4 Lessons Learned Programs (LLPs)

Lessons Learned can be defined as knowledge gained from experience, for the purpose of improving future performance and a Lessons Learned Program involves the “people, process and tools that support an organization’s collection, analysis, and implementation of validated lessons learned” (CII, 2007). According to a study conducted by CII (2013), the construction industry is most likely to face more number of retirements of the individuals from the baby boomer generation. These potential retirees possess a knowledge inventory accrued through many years of experience in the construction field. Often this knowledge is the foundation to innovative solutions, reduction in the repetition of past mistakes, enhancing overall efficiency and enabling new growth strategies. Traditional practices aim to replace individuals who are about to retire but often do not consider how to retain their knowledge prior to their departure (CII, 2013). The study also reveals that there is a shortage of qualified individuals who will be able to fill the gap and the organization’s approach of promoting mid-level employees to fill the gap fails to retain the experiential knowledge possessed by these departing individuals. The high rate of retirement of the most experienced individuals creates a knowledge gap from the previous generation to the current generation. This can have both operational and cost implications. Cost implications

include the additional cost of replacing the retired employee. This can vary from 50 percent to 150 percent of the departing employee's salary in addition to the new hire's salary (Perrin, 2005 in CII, 2013). Operational implications include increase in critical errors, repetition of mistakes, reduced efficiency, reduction in the ability to innovate and reduced ability to pursue growth strategies by the organizations, etc. Hence implementing an effective knowledge management strategy which retains the knowledge possessed by these individuals is most crucial to overcome these issues.

2.2.5 Training

Organizations usually conduct training programs for the new hires, employees being promoted or those changing job descriptions. Training can be broadly classified as conventional training, which is instructor-led mainly involving face-to-face interactions and training aided by Information and Communication Tools (ICT), which involves online training, web-based training or computer based training (Zahm, 2000).

2.2.6 Intranet and Extranet

Intranet is a technology which is used to share information or computing services within an organization. They can also be used to manage internal documentation by the construction companies. Similarly, extranet is used to share information outside an organization with a controlled access. Extranets can be viewed as an extension of an organization's intranet that is extended to users outside the organization, usually partners, vendors and suppliers. Extranets are used to manage documentation by all or most of the companies involved in a project.

These are perceived as a logical development and migration of existing traditional document management systems into web-based forms (Rezgui and Miles 2011; Nitithamyong

and Skibniewski, 2006). Such systems enhance the ability to share and update documents in a consistent and structured approach within and among organizations. They improve the overall quality of the documents by providing up-to-date and timely information. Useful functionality like key-word based search or full-search mechanisms can be included with the extranets. This class of information systems is commonly referred to as web-based project management systems (WPMS) (Rezgui and Miles 2011). Few examples of such systems include Buzzsaw and Constructware by Autodesk; ProjectWise by Bentley; ProjectTalk by Meridian Project Systems; PrimeContract by Primavera etc.

2.2.7 Knowledge bases

“Knowledge bases are repositories that store knowledge about a topic in a concise and organized manner.” (Egbu et al., 2003). These knowledge bases can consist of information that can be found in a book, code or a website; or they can be human knowledge, lessons learned or best practices followed by an organization or industry etc. Knowledge bases can be very effective and a powerful tool to the employees of an organization if it is updated frequently with the validated information and if it can be accessed quickly by the employees when they need it.

2.2.8 Data and Text Mining

Data and Text Mining refers to the process of extracting meaningful knowledge or high-quality information from text documents. This process involves structuring the input text and deriving patterns within the structured data. Typical text mining tasks include text categorization, concept extraction, document summarization, text clustering, document summarization, sentiment analysis and entity relation modeling. This approach is very useful for identifying hidden relationships in the data and creating new knowledge (Egbu et al., 2003). The main

purpose of this technology is to support knowledge discovery process in large document collections (Tan et al., 2009).

2.2.9 Groupware Systems

Groupware refers to programs that help people work together collectively, enhance communication and share knowledge while located remotely from each other. Groupware systems are also referred to as collaborative software, and it is an integral component of a study known as Computer-Supported Cooperative Work (CSCW). Groupware services can include sharing of database access, collective writing, sharing of calendars, electronic meetings where each person is able to display information to others etc. From a construction perspective, groupware has the potential to help manage and track information, documents, users and the application they use (Rezgui & Miles, 2011). Rezgui & Miles (2011) also state that groupware systems offer the potential to maintain ‘project-memory’ and record all the lessons learned in a way that promises re-use. Some examples of groupware include Microsoft Exchange and Lotus Notes, both of them facilitate e-mail handling, calendar sharing etc. However Tan et al., (2009) argue that groupware is less efficient for the exchange of more complex information. Also, there is a strong reluctance in the construction sector to adopt or fully use a workflow-based process or a groupware solution (Rezgui & Miles, 2011).

2.3 Shortcomings of current practices

Post Project Reviews are the most common approach used in the construction industry for the capture of learning (Orange et al., 1999). The shortcomings of this method as discussed include insufficient time allocation for the review. Sometimes, the review is not conducted as the relevant project personnel have already moved on to other projects. Also there is always the

problem of loss of the important details due to time lapse in capturing the learning during the PPRs. Few of the shortcomings of other practices include (Tan et al., 2009):

- No mechanism to store the knowledge as soon as it is created. The project members should have to either wait till the end of the project to discuss the lessons during the PPRs by the time they might have already forgotten about the issue.
- Also the knowledge created in a project is scattered across various team members. No one retains a complete set of knowledge generated during the project. There is also no proper channel to store all the knowledge at a particular place.
- Even if the knowledge or learning is stored, the intent behind the decisions that are made is often not recorded or documented. There is no proper visualization to what the lesson is about or there is difficulty in tracking the people involved in the decision-making process and who understands the context of making the decision (Khalfan et al., 2002).
- The knowledge gained during the project is often poorly organized and there are seldom processes for disseminating useful knowledge to other projects (Tan et al., 2009; Khalfan et al., 2002).
- No proper mechanism for capturing the knowledge or no proper means and methods to share the knowledge captured.

Chapter 3 Building Information Modeling

3.1 Introduction

Building Information Modeling (BIM) is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct, operate and maintain a facility. It is a methodology that generates, exchanges and manages a facility's data throughout its lifecycle (Bilal, 2013). The National Building Information Modeling Standards (NBIMS) committee defines BIM as, “a digital representation of physical and functional characteristics of a facility forming a reliable basis for decisions during its life-cycle; defined as from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the lifecycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder.” BIM can be used across various phases of construction and the building information model consists of information related to the whole project life cycle. As explained by Ganah and John (2013), this building information model can be 3D (visualization and coordination of project), 4D (integrating time), 5D (including cost estimating), 6D (procurement and thermal properties analysis), 7D (operational applications lifecycle), 8D (integrated project delivery) – right up to ‘nD’ (a term that covers any other information needed for construction and running of a facility). With the BIM software, an accurate digital model with precise geometry, building element properties, spatial relationships etc., can be developed. Figure 3.1 shows various phases across which BIM can be used.

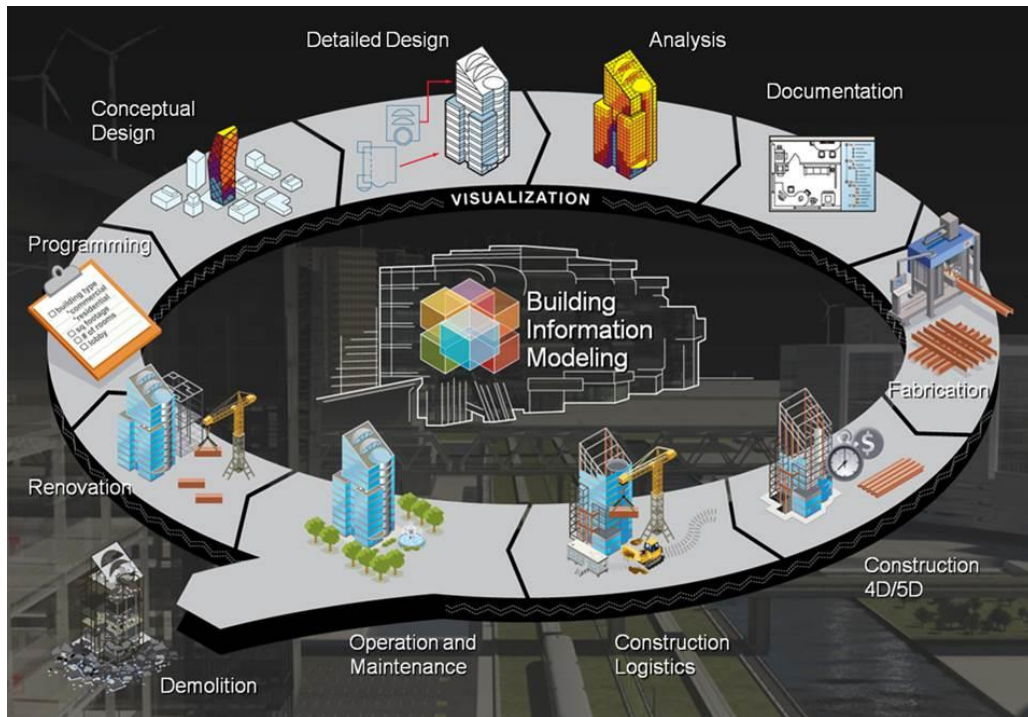


Figure 3.1: Use of BIM during various phases of construction (www.buildipedia.com)

3.2 The Current Business Models in Construction

As discussed in the previous chapter, most of communication between the project teams is carried out using 2D drawings. These paper-based modes of communication often include errors and omissions which cause delays, extra-costs and miscommunication between various parties in a project team. Another common problem associated with 2D based communication during the design phase of construction is the amount of time and money it takes to generate information like cost estimates, quantity estimates, energy-use analysis, structural details etc. Since these activities do not take place during the design phase, value engineering must be done to address the inconsistencies, which often results in the compromises to the original design (Eastman et al., 2011). The most common contract methods used in the US construction include:

3.2.1 Design-Bid-Build

Design-Bid-Build method is a project delivery method in which the owner hires both the architect and general contractor for the design and construction of the facility. In the design phase the owner hires an architect, who is responsible to produce design and bid documents, including all the construction drawings and technical specifications. The architect generally hires other entities to assist in designing the structural, mechanical, electrical, plumbing and fire protection components of the building. The final set of the drawings and specifications produced must contain all the details to facilitate general contractors in bidding for the project. Because of the potential liability, usually architects choose to include fewer details in the drawings or insert language indicating that the drawings may not be relied up on for dimensional accuracy (Eastman et al., 2011).

The next stage is the bid stage, which can be “open”, in which any qualified bidder may participate or “select”, in which only a limited number of contractors are invited to bid. The contractors are sent a set of drawings and specifications for estimation purposes. The general contractor calculates the quantities required with the help of bids from the sub-contractors and arrives at a price and submits his bid. In this method, usually the contractor with the lowest responsible bid wins. The contractor and the sub-contractors bids the project based on the drawings provided by the architect. If these drawings are inaccurate or incomplete, the estimates will be wrong and the costs associated with these will become a problem at a later stage in the project.

During the construction phase of the project, often there are many doubts and issues that need clarification from the designers and sometimes due to unanticipated conditions on the site the design needs to be changed. The contractor or the sub-contractor generally files a Request for

Information (RFI) which needs to be addressed by the architect or the concerned party. Following that a Change Order (CO) will be issued and all the concerned parties are notified about the change. Sometimes, other trades have to make changes because of this. All this involves cost and time and sometimes leads to disputes in the project.

Because of the uncertainty in the drawings and inaccuracy in the design it is difficult to fabricate material offsite (Eastman et al., 2011). Therefore, fabrication and construction usually are taken place on site after the exact conditions of the site are established. This can be more costly, time-consuming and prone to more accidents than if it were performed offsite or pre-fabricated.

Because all the drawings and information is provided in 2D, the owner will have hard time understanding the context of the building and the facility management team has to put in more effort to maintain and operate the building. All this process is time-consuming, costly and prone to error. As a result, the DBB is not the most efficient approach to design and construction (Eastman et al., 2011).

3.2.2 Design-Build

Design-build (DB) process is a project delivery system in which the design and construction of a facility is given to a single contracting entity known as design-builder or design-build contractor. The design-build process was developed to simplify the administration of tasks for the owner (Eastman et al., 2011). In this system, the owner awards the project to a design-build team, who is responsible to develop a design that meets the owner's requirements and come up with a total cost and the time needed to complete the project. Based on the information, any modifications requested by the owner are then incorporated into the design and

the plan is approved and the total cost for the project is established. In this model, all the modifications to the design are made earlier in the process which results in a less overall cost and time to incorporate those modifications than if the modifications were made during the construction. The DB contractor then hires any subcontractors needed to get the construction started. After the construction begins, any changes made to the design become the responsibility of the DB contractor, which leaves owner out of the trouble of spending more money for the design related mistakes. But the owner has little flexibility to make any changes to the project after the initial design is approved. The DB model is becoming more common in the United States and the use of BIM within a DB model is clearly advisable (Eastman et al., 2011).

3.2.3 Construction Management at Risk

Construction Manager at Risk (CM at-Risk) is a project delivery method in which the owner hires a construction manager before the design stage and the CM is responsible to deliver the project within a Guaranteed Maximum Price (GMP). The CM is chosen based on the qualifications and the entire operation is centralized under a single contract (AIA, 2005). Typically in this method, the owner hires a designer to furnish all the design services and the construction manager acts as a consultant to the owner during the pre-construction phase. The construction manager then takes the role of a general contractor during the construction. The construction manager is responsible for scheduling, cost control, construction administration and value engineering. Unlike DBB, in this method, the construction manager brings the constructor into the design phase to receive definitive input to arrive at a cost and schedule. CM at-risk is a cost effective and time conscious alternative to the traditional design-bid-build process (AIA, 2005). The advantage of this method is the budget management, reduced liability for the cost overruns to the owner and early involvement of the contractor. Another advantage of this process

is enhanced transparency as all the costs and fees are in the open, diminishing the adversarial relationships between the entities working on the project, while eliminating the bid shopping at the same time (AIA, 2005).

3.2.4 Integrated Project Delivery

Integrated Project Delivery (IPD) is a relatively new project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction (AIA, 2007). IPD teams consists of members including the owner, architect, general contractor, fabricators, building engineers, mechanical, electrical and plumbing contractors and other sub-contractors who work collaboratively throughout the construction. In the IPD system, all the disciplines working on the project work together as one team, which facilitates lower costs, faster delivery times, no litigation, fewer RFIs and Change Orders. Because IPD involves early involvement of all the team members, the knowledge and expertise of all the disciplines are utilized during the early phase and continued throughout the project lifecycle.

IPD makes use of the ideas from lean construction, integrated practice and utilizes technology to solve several problems involved with the traditional construction practices like low productivity, time overruns, waste, quality issues etc., during construction. The tradeoffs that are always part of the design process like the cost, energy, functionality, esthetics and constructability can be best evaluated using BIM (Eastman et al., 2011). Unlike the design-build and other project delivery methods where the contractor or construction manager plays a leading role on the project, the IPD team works collaboratively as a team throughout the project lifecycle.

This study advocated IPD project delivery system because BIM can serve as an integral part of this process. BIM can also be used in other project delivery systems but its effectiveness can be utilized to its maximum in the IPD process.

In IPD projects, the construction managers, designer, owner and at least some key trade contractors are involved from the early stages of design. Thus the members are selected based on their qualifications rather than the bid price criteria. Bring all these key players together at an early stage of the project would allow better communication and higher level of understanding among the participants. Also, the design is carried out with continuous inputs from all the concerned parties about the constructability, cost etc., and allowing designers to incorporate all those factors into a design and come out with the most efficient design.

Building Information Modeling (BIM) can assist the IPD process as members from different disciplines are required to converge around this digital conglomeration of the model to figure out how things work together, address clashes and see how the various parts of the project are shaping up (CMAA, 2005).

3.3 Inefficiencies of Traditional Construction Practices

The study conducted by Center for Integrated Facility Engineering (CIFE) at Stanford University found out that labor productivity in the construction sector has not improved much since 1964, when compared to other non-farm industries (CIFE, 2007). Labor represents about 40 percent to 60 percent of the construction's estimation costs depending upon the type of project but the labor productivity is relatively unchanged since 1964 (Eastman et al., 2011). Also, the literature review conducted on this subject has shown that the construction industry suffers from low productivity, high inefficiency, adversarial relationships among the project team

members, frequent disputes, lack of innovation etc. All these factors result in cost over runs, schedule overruns, safety issues and often the owners are disappointed with the quality of the end product (CMAA, 2005). A traditional construction project consists of three main players: owner, designer and contractor. Each one of them has their own interests which sometimes align with others and sometimes don't. Different project team members come in at different times during the project. The designers comes in early in the process, followed by construction managers (if any) and then after the design is substantially complete, the general contractor and trade contractors come in. Some of the problems which arise because of this include (CMAA, 2005):

- Because the general contractor and trade contractors come in after substantial completion of design, they incorporate their prices with contingencies resulting from the uncertainty/incompleteness in design in which they have little or no involvement. Also because the trade contractors are not involved early in the design process, the designers provide large amount of space to avoid any problems for the trade contractors resulting in larger buildings than needed.
- The constructors get a chance to point out the corrections/mistakes in the drawings only after their final price is provided. This results in change orders, which is an additional cost to the owner. Additionally, trade contractors can influence the design for better constructability and productivity but they are often excluded from the design process.
- The safety factors incorporated into the design will be higher because the designer is not sure who is going to ultimately be involved in the project. They incorporate higher factor of safety keeping in mind the low bidder who can win the project.

- The projects may require redesign after a significant amount of design is completed because the information about cost, constructability etc., will be only available only after completing a substantial amount of design and getting information from other trades.

3.4 Benefits of BIM

Any construction project consists of a separate set of drawings for architectural, structural, mechanical, electrical, plumbing and civil. Also, there are separate set of drawings for telecommunication, landscaping, security, lighting, speaker systems and so on. Each one of these documents represents a part of the project and not everyone have access to all the documents. In most of the cases (or all), a designer from one trade (say electrical), when designing his/her system doesn't refer to other trades in the project (like mechanical, plumbing etc). Most of the times, this may result in the clashes between different trades in a project. Also, the initial drawings are mostly incomplete and the project members realize it only during the construction stage of the project. Hence before starting the work, they produce drawings which include complete information to build that part of the building. Such drawings are known as shop drawings. Thus projects are also filled with many sets of shop drawings. And then the projects have RFIs and Change Orders. Thus, a typical construction project consists of huge number of drawings/documents depending upon the size of the project. And each drawing/document consists of a piece of information about the project. When a change is made in one part of the building, all the documents affected by the change must be updated and reproduced. Sometimes the change may not be reflected accurately in other parts of the drawings. Building Information Modeling (BIM) can be a potential solution to the problems discussed so far. Building Information Modeling (BIM) is a collection of software tools which helps to coordinate the design efforts of multiple disciplines and allow for more automated and facile estimation of

schedule and cost (CMAA, 2005). The benefits and applications of BIM include (Eastman et al., 2011; Azhar et al., 2008):

- *Visualization*: The BIM is a 3 dimensional model with accurate geometry and consisting of all the information related to a building. The model can be easily rendered for visualization purposes and it is dimensionally consistent in every view. Through accurate visualization proposals are better understood. This is particularly important for members who do not possess much technical knowledge about the subject.
- *Increased Building Performance and Quality*: Before developing a detailed building model, a schematic model built would allow for the evaluation of building's functional and sustainable requirements. The owner can view the model to see if it is meeting the requirements and the design alternatives can be analyzed.
- *Better Design*: The parametric modeling nature allows proper alignment, spatial coordination and all the necessary requirements meet, allowing better and effective design.
- *Cost Estimating and Construction Sequencing*: BIM model can be used to create 4D and 5D modeling. Scheduling component and cost component can be added to the 3D BIM model and construction sequencing and cost estimating can be done.
- *Improved Collaboration Using IPD*: In the IPD process, BIM can be used from the beginning of the design to improve the understanding of the project team members about the project requirements, co-ordination of different trades to extract cost data, which can be used to alter/improve the design at early stages without the use of paper exchange and its associated delays.
- *Clash Detection*: Because the 3D BIM models are geometrically accurate, they can be used to check for clashes between different trades in a project. For example, a plumbing system

(pipes) can be checked for clashes with other trades which include electrical, mechanical, structural, fire protection etc.

- *Accurate 2D drawings:* When changes are made to the design, fully consistent and accurate drawings can be generated as soon as the modifications are made. Accurate and up-to-date 2D drawings can be generated with the help of the BIM model whenever needed or required.
- *Fewer RFIs and Change Orders:* If the BIM model has all the necessary information needed to generate an accurate and consistent model, then the need for RFIs and Change Orders will be reduced dramatically unless special site conditions or design changes arise.
- *Plug-ins:* Special “plug-ins” can be “plugged in” into the BIM software to track the modifications or get additional information. For example, a particular plug-in can recalculate the heat gain and loss when the building is rotated on the site. Other plug-ins can focus on LEED certification, energy analysis, cost estimating or construction sequencing (CMAA, 2005).
- *Fabrication/shop drawings:* Generally, fabricators develop shop drawings to install their systems on the field. It is easy to generate shop drawings using the completed BIM model.
- *Facilities Management:* An integrated BIM model can be used by the facilities managements for space planning, renovations and maintenance operations.

3.5 McGraw Hill SmartMarket Report 2014

Since 2007, McGraw Hill Construction has been tracking the business impacts of the technology advances in construction particularly on how BIM is transforming the design and construction process in Asia, North America and Western Europe through its SmartMarket Report series. The 2014 SmartMarket Report analysis includes data from the top nine construction markets in the world including North America, Europe and South Korea and data

from contractors in 10 countries including Australia, Brazil, Canada, France, Germany, Japan, New Zealand, South Korea, UK and US. Some of key finding in the report include:

- Three quarters of the construction companies surveyed reported a positive Return on Investment (ROI) on their BIM program investment. The companies have clear ideas about how to increase the ROI further (Fig 3.1).
- BIM adoption in North America has increased from 28% in 2007 to 71% in 2012. According to the report, adoption by contractors (74%) exceeded architects (70%) in North America. The report also states that 36% of BIM-using contractors in the US and Canada have six or more years of experience (Fig 3.1).
- The survey reports that 60% of contractors currently operate at light (<15% of their projects) or medium (15%-30% of their projects) BIM implementation. This is expected to grow to more than two-thirds operating heavy (31%-60% of projects) or very heavy (>60%) BIM implementation in the next two years.
- North America leads the combined percentage of advanced and expert level BIM users (52% in the US and 44% in Canada) among the contractors.
- The report states that over 75% of North American contractors are currently in the medium to very high BIM engagement level, which takes into account the BIM experience, expertise and implementation levels.

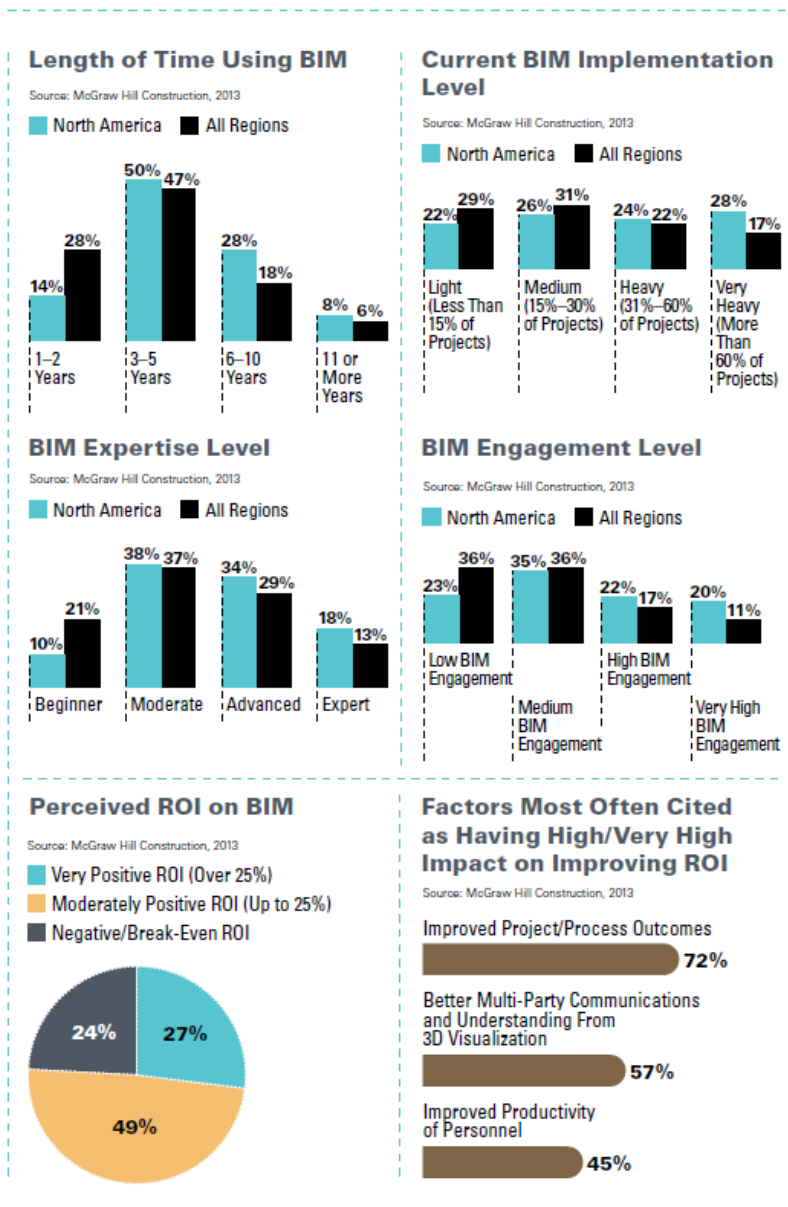


Figure 3.2: BIM engagement level and Perceived ROI on BIM

- The top benefits of BIM cited by contractors include fewer errors and omissions, less rework, lower construction costs. Other top benefits include enhanced organizational image, better collaboration with owners/design firms.
- Contractors across Europe, North America, Australia and Brazil expect that their work involving BIM will increase by 50% on average in the next two years.

- The study also found out that the ROI increase is directly proportional to the contractor's level of involvement with BIM.
- Over the next two years, the contractors are planning to invest significantly to expand their BIM programs, including an increased focus on internal and external collaborative procedures as well as mobile hardware and BIM software.

3.6 Challenges of BIM

BIM is evolving at a rapid pace and a number of organizations have started to adopt the technology to utilize the benefits it provides them but implementing BIM has certain challenges.

Few of them include:

- *Interoperability*: Interoperability is the smooth sharing of information across all the BIM applications and disciplines involved (Niraj and Don 2013). A building information model can be developed using a variety of software. But there is no interoperability among the different software. Also a model created using a latest version of a software cannot be opened in the earlier versions of the same software. Therefore if one organization in a construction project uses one software platform for BIM and another company uses a different one, the co-ordination can be a difficult process. The industry is pushing towards the use of industry foundation classes (ifcs) to overcome the issues of interoperability, but it is still in its initial phases.
 - *Level of Expertise*: Most of the firms in the construction industry have started adopting BIM recently and the level of expertise of the companies and individuals joining the organizations ranges from low level to medium range. There are very few experts in this area of specialization. The level of expertise on BIM makes a huge difference on how well it can be utilized for the benefit of the organization.

- *Cost:* The software associated with BIM is costly and for implementing BIM an organization needs a set of software to carry different activities/processes related to BIM. For example, Autodesk Revit to build the model, Primavera for developing schedule and Autodesk Navisworks to carry out the co-ordination and clash detection etc.

- *Training:* Because most of the software used and industry-wide adoption to BIM is relatively new, the firms need to train its employees on BIM processes, software, its uses and advantages. The transition from the use of very familiar software to new software might take time and effort from both the employees and the organization. Also, even within the BIM software the level of expertise with the software makes a huge difference. An employee with only a minimum knowledge on a BIM software might take more time and any mistake made in one view (or one floor plan) is reflected in the whole model and in every view the mistake is associated with. Hence it is important to train the employees.

Chapter 4 Parametric Nature of BIM and Knowledge Management

4.1 Parametric Nature of BIM

The Associated General Contractors of America (AGC) defines BIM as “the development of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users’ needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility (AGC, 2005; Azhar et al., 2012).”

BIM models are object based models guided by parametric rules. It means that all the elements in the BIM model are objects and all these objects are intelligently combined together with the basic software inherent parametric rules combined with customized/defined parametric rules to form a building information model. This object based parametric modeling does not represent objects with fixed geometry but it rather represents objects by parameters and rules that determine the geometry as well as some non-geometric properties and features (Eastman et al., 2011).

In parametric modeling, an element is designed based on a set of relations and rules which control the properties/parameters of an element. These relations can be defined involving distances, offsets, angles and rules like equidistant from, parallel to, attached to etc. The parameters and rules can be expressions that can be related to other objects as well, thus allowing the objects to automatically update according to the user control or changing contexts (Eastman et al., 2011). An example to explain the parametric nature of the BIM models using Autodesk Revit® platform is presented below:

Consider a set of four windows defined by ‘equidistant from each other’ relation in Revit, when one of the windows is moved, the remaining windows also automatically move to satisfy the equidistant relation. This is one of the simplest parametric rules in Revit and the most basic level of understanding of this software is sufficient to define this rule.

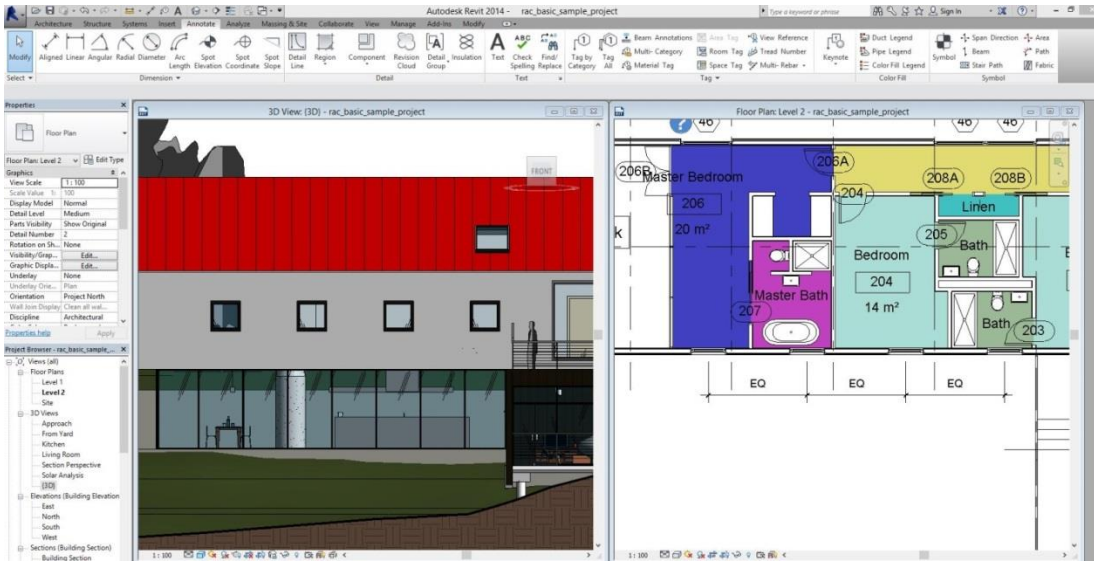


Figure 4.1 Figure showing equidistant relation in the software

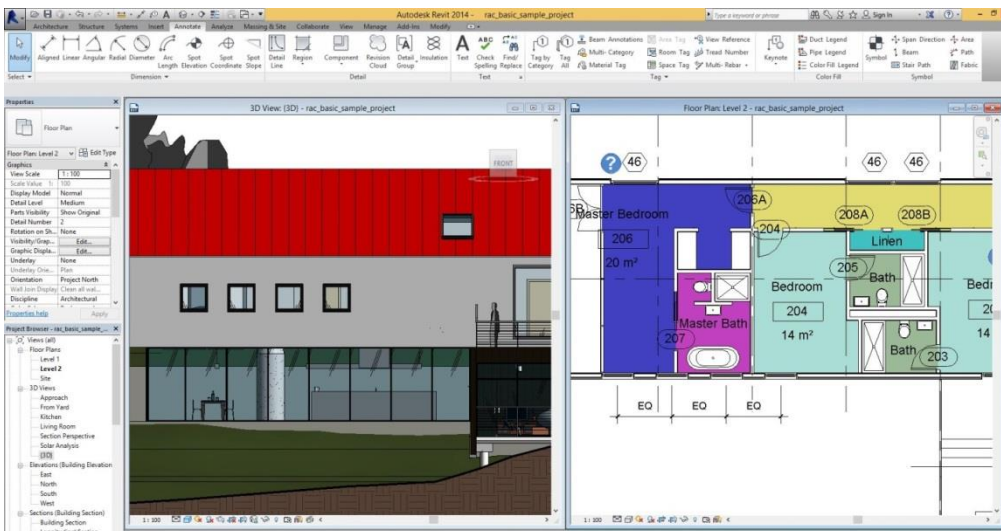


Figure 4.2 Windows maintaining the relation when one of them moved.

Additionally most of the BIM software have certain basic parametric rules and relations pre-defined within them, for example, in Revit a door or a window can only be placed within a wall, they cannot be placed in space. Such rules help the users to avoid certain basic mistakes in the design. Some of the other parametric rules include:

A wall placed along a grid can be locked in its position along with the grid. If the location of the grid is moved the wall also moves along with the grid. However, if one tries to move the location of the wall alone, the software warns you that it is attached to a grid line.

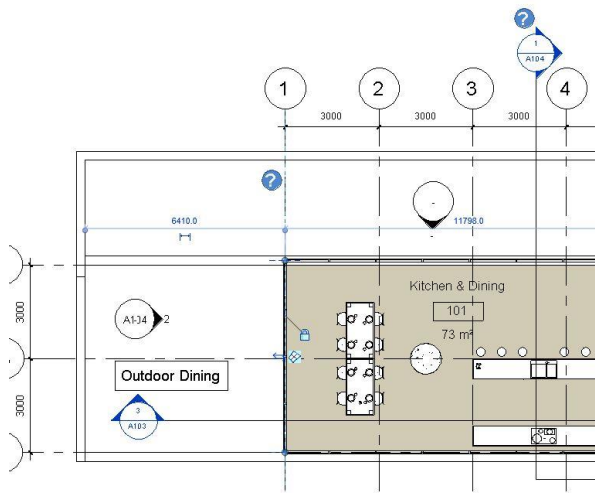


Figure 4.3(a) Wall attached to a grid

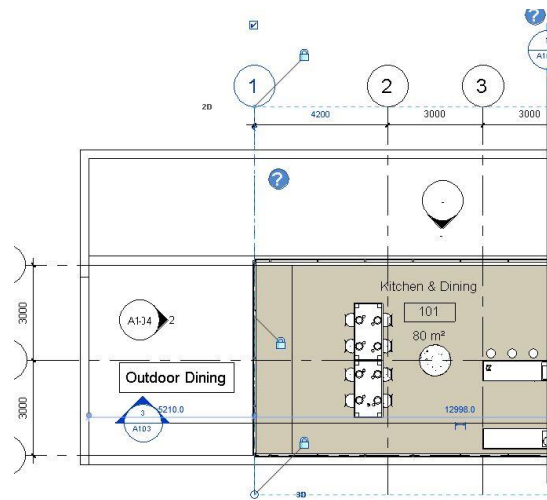


Figure 4.3(b) Wall moving along with the grid

Similarly when placing columns in the BIM model, one can set the base of the column and top level to which it can go. Now, when the elevation of the top level is changed, the column height also changes along with the level.

Alternatively, rules can be defined as requirements the design must satisfy, this allows the designer to make changes while the rules check and update details to keep the design element satisfying the rules and warning the user if the rules cannot be met (Eastman et al., 2011).

4.2 Families, Family Types and Instances

Families are the components such as walls, doors, windows, stairs etc., which are used to build the model. Each family can have multiple *types* (different sizes, different material, different parameter variables etc). And *instance* is each occurrence of the element (family/type) in the model. To elucidate the difference, let us consider the following example in the Revit Platform.

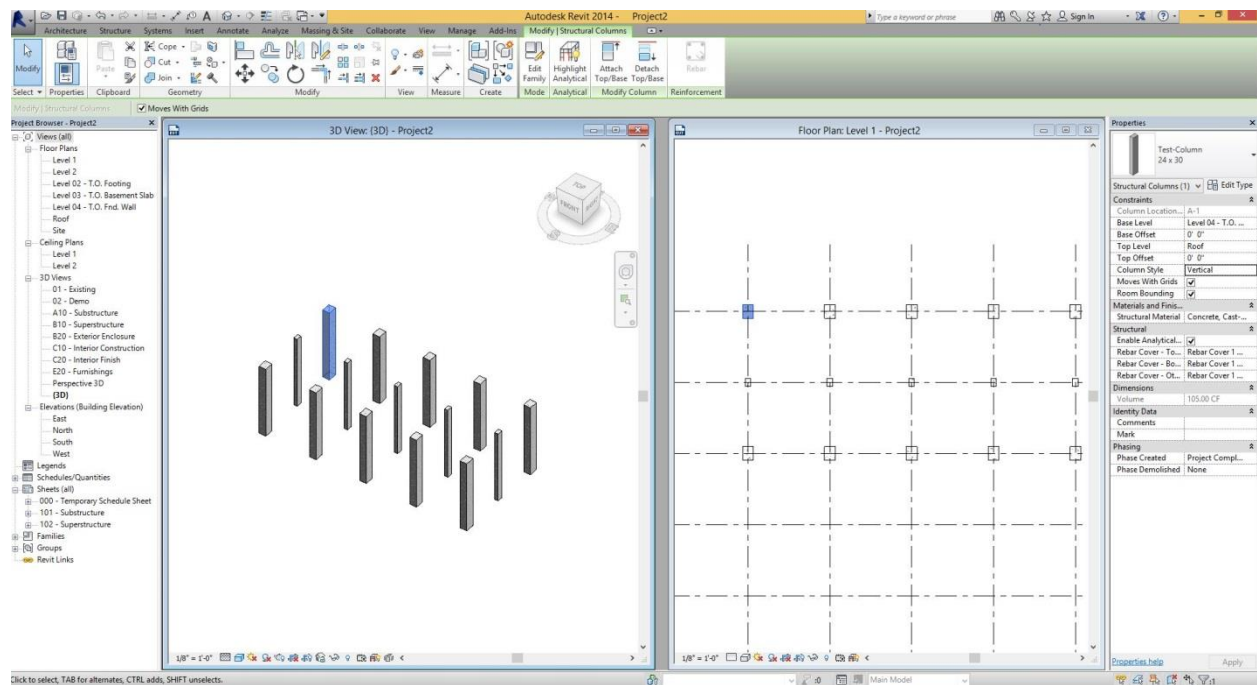


Figure 4.4: Showing difference between family, family types and instances

4.2.1 Family

The example shown above (Fig 4.4) consists of columns from the family “Test-Column” (a custom family created from rectangular concrete column family in Revit). All the columns are created from the same family (i.e. they belong to one family, “test column”). All these columns have similar properties on a family level. Most of the properties on how these columns behave with other objects in the model have been pre-defined by the vendor. However, there are certain properties that can be changed. Fig 4.5(a) shows the properties of the “test column” family.

When any of the properties shown is changed, the change is reflected in each and every element that belongs to the family. For instance, the material of the columns in the example is “concrete”, if we change the material to wood (fig 4.5(b)) in the family properties, all the columns material will be changed to wood and the change is reflected in each and every column. This can be useful if we want to change the property of all the elements belonging to a family.

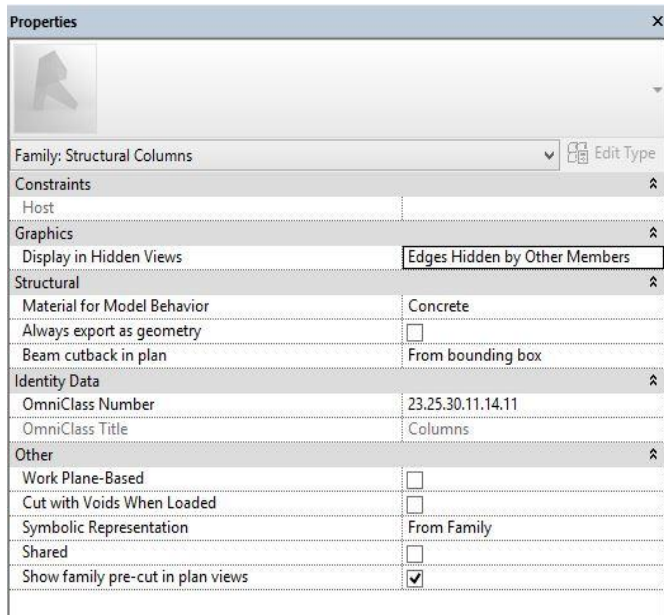


Figure 4.5(a) Family properties of the “Test Column”

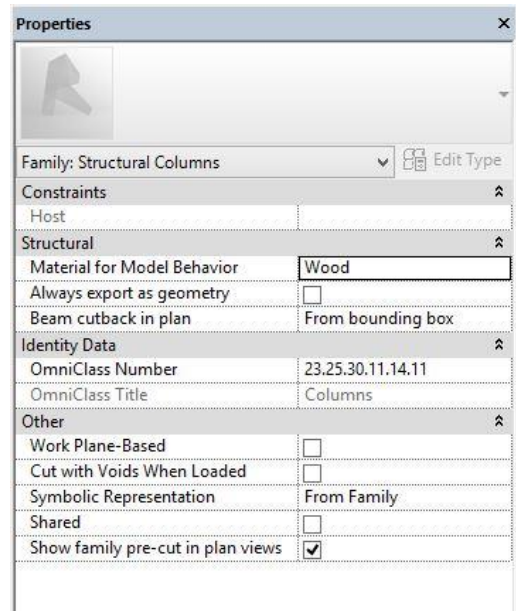


Figure 4.5(b) Material property changed to wood

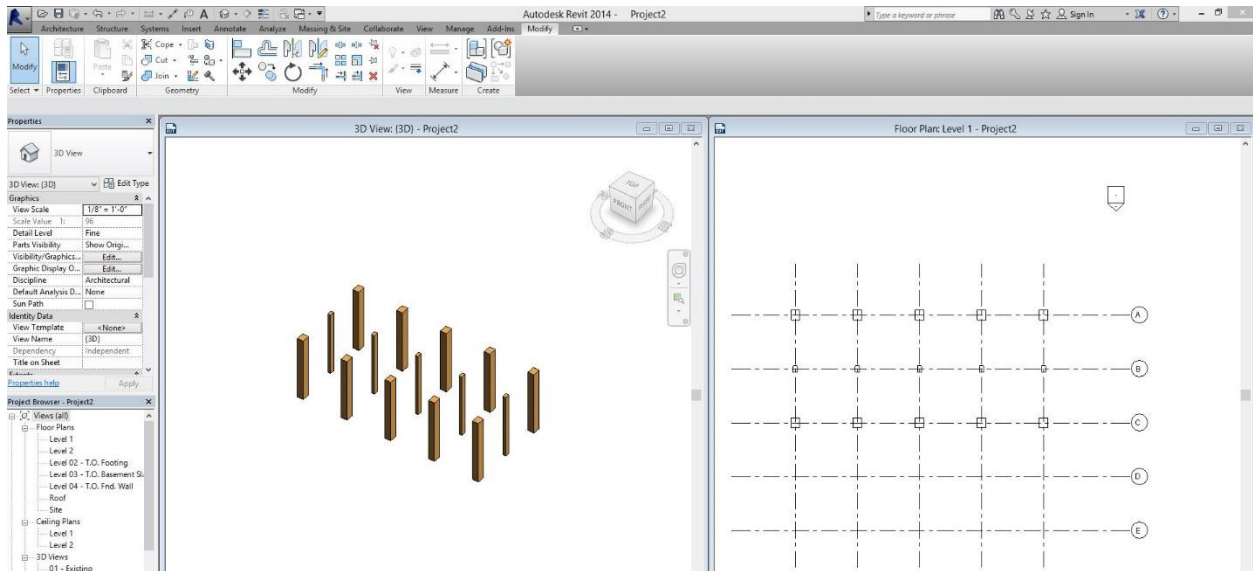


Figure 4.6 The material property of the columns changed to wood

4.2.2 Family Type

In the example, there are two different types of columns (based on different sizes in this example), the top row and bottom row are of the same type (say Type 1) and the middle row is of the other type (say Type 2). The type properties of “Type 1” columns can be seen in the figure 4.7.

It can be seen that the “Type 1” columns have a width parameter of 24” and height parameter of 30”. If any of the properties here are changed, the change is reflected in all the similar types in the model. For example, if we change the width of the columns in this type property to 48”, all the columns of “Type 1” will have a width of 48”. This property can be a very useful feature in BIM and parametric modeling. For example, if a project has a thousand windows of a type and if the architect decides to change the type, the BIM detailer doesn’t have to change the property for each and every window, instead he can change the type property of the window and all the windows in the projects will be changed accordingly. Without parametric modeling, such changes can become extremely cumbersome and error-prone.

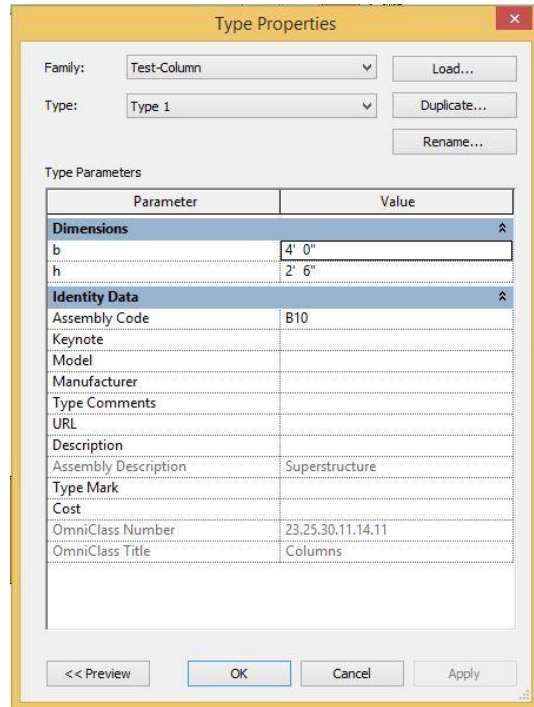
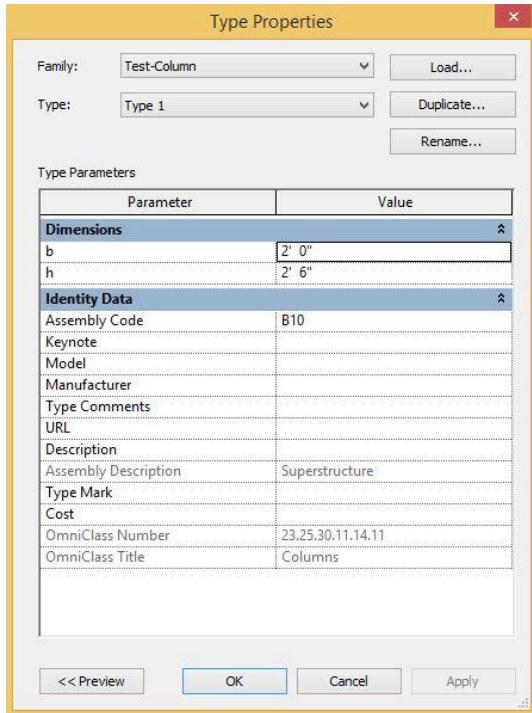


Figure 4.7 Type properties of the Test Column

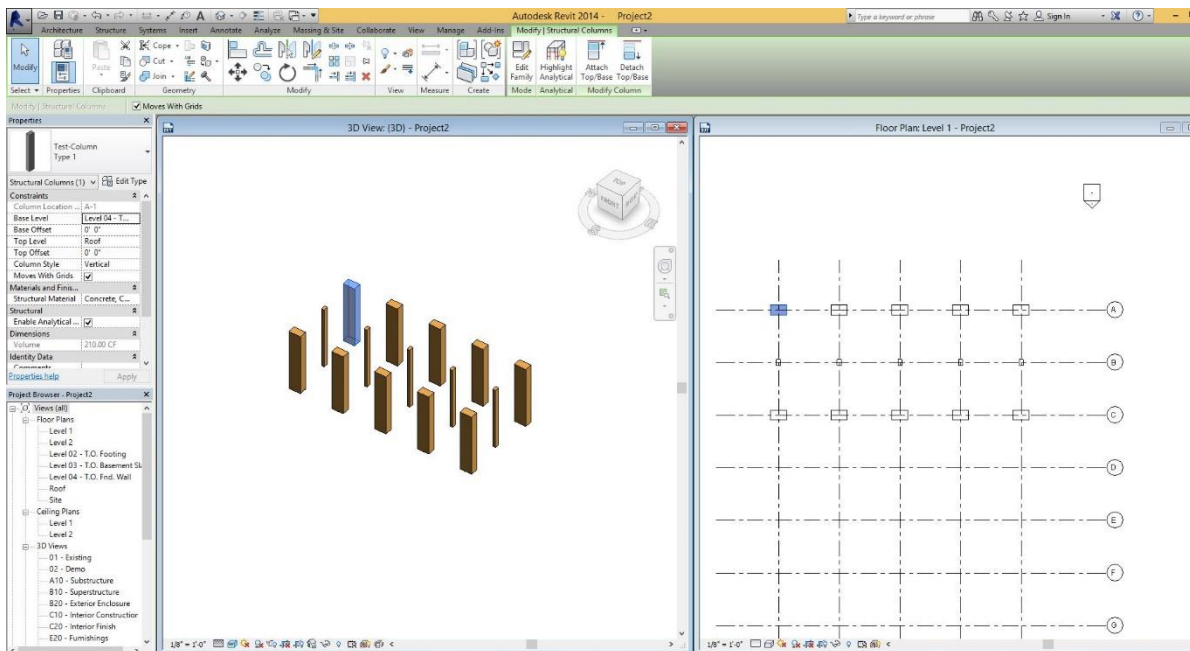


Figure 4.8 Change reflected in the similar “type” columns

4.2.3 Instance

And finally, an instance is each and every occurrence of an element. In the example shown, it has 10 instances of Type 1 columns (first row and third row) and 5 instances of Type 2 columns (second row). And each instance has its own properties known as instance properties.

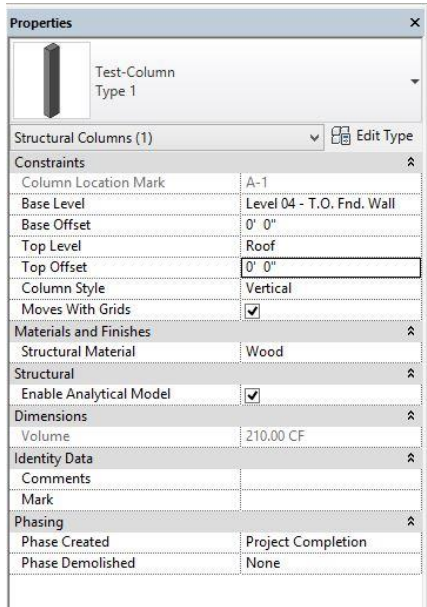


Figure 4.9(a) Instance properties of the selected column

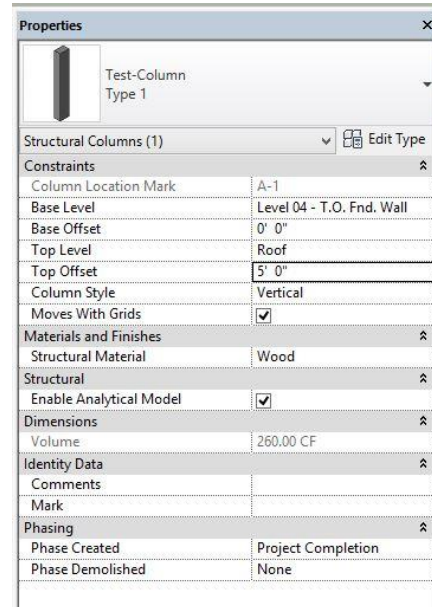


Figure 4.9(b) Top offset of the selected column changed to 5'

Any changes, made here will be applicable only to that particular instance. For example, from the instance properties it can be seen that the top level of the column is upto "Roof" level with the Top Offset set to 0'0". Let us change the top offset to 5', this change will be applicable only to that particular column in the model. This is an important feature if we want to change the property of only a particular instance.

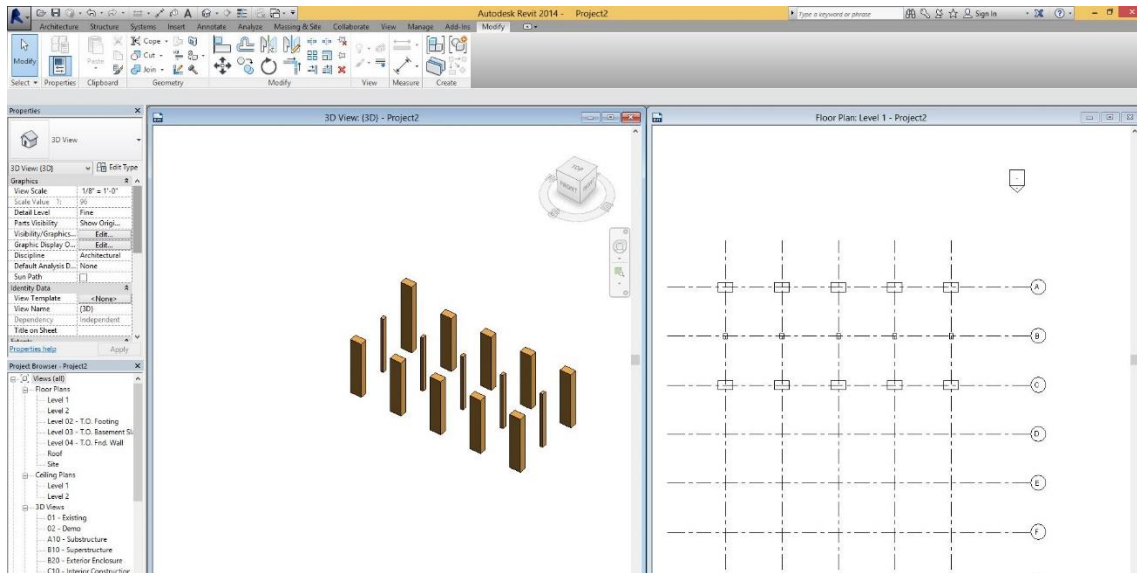


Figure 4.10 Fig reflecting the changed instance parameter of the selected column

This parametric nature of BIM modeling can be leveraged to capture the lessons learned within the model using the difference in the family, family types and instances. The process of capturing the lessons learned is explained in the next section.

4.3 Capturing and Sharing Knowledge using the BIM model

Revit has the feature of creating parameters called “Shared Parameters.” These *shared parameters* can be shared across multiple projects in the Revit platform and they can be of various types (length, text, area, volume, angle, currency etc.). Any number of such parameters can be created and attached to one or more family types in a model. These shared parameters are interpreted the exact same way by the software in every project they are used. This shared parameters feature in the Revit platform can be used to capture and store lessons learned in a project. The steps for the process of creating shared parameters in Revit involve the following steps:

1. First, create a *Shared Parameter File* text (.txt) file. All the shared parameters created in the projects will be stored in this text file (TEST – LL – Sample Project.txt, in the fig).
2. Now create a *Shared Parameter group* (say Knowledge Capture), under which the required parameters can be created and added into the project. The user can create multiple groups to organize the list of shared parameters created.
3. After creating the group, create a new shared parameter (say Lessons Learned) under this group. When creating the new shared parameter, select ‘text’ as the type of the parameter.

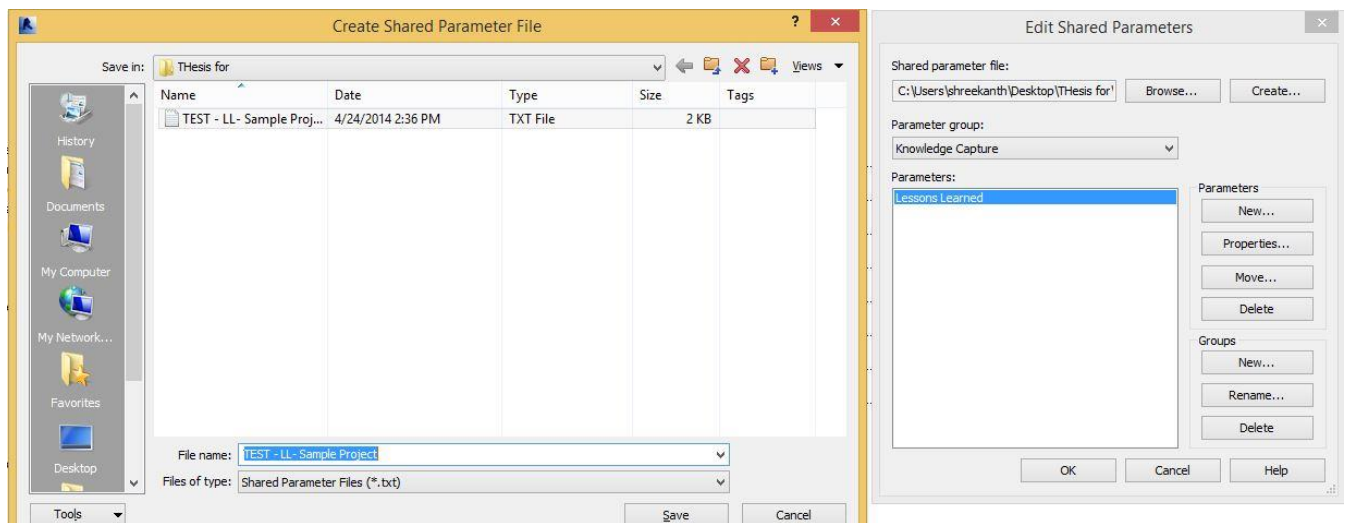


Figure 4.11 Shared parameter text file

Add the parameter to the list of already existing project parameters. Once the shared parameters is added to the project, the user can attach the parameter to any single family/type or multiple families/types within the project. Once the parameters are attached to the elements within the model, it can be used to add any lessons learned and also to share the knowledge. The following section explains the process of capturing knowledge using shared parameters.

4.3.1 Capturing Lessons Learned using the shared parameters

After adding the created shared parameters to the existing project parameters, they can be used to add to the elements in the model and store lessons. The process to capture the lessons learned involves:

1. Add the shared parameters to the list of project parameters in the project as an ‘instance property’ and attach the parameter to all the elements in the model (as shown in figure 4.12).

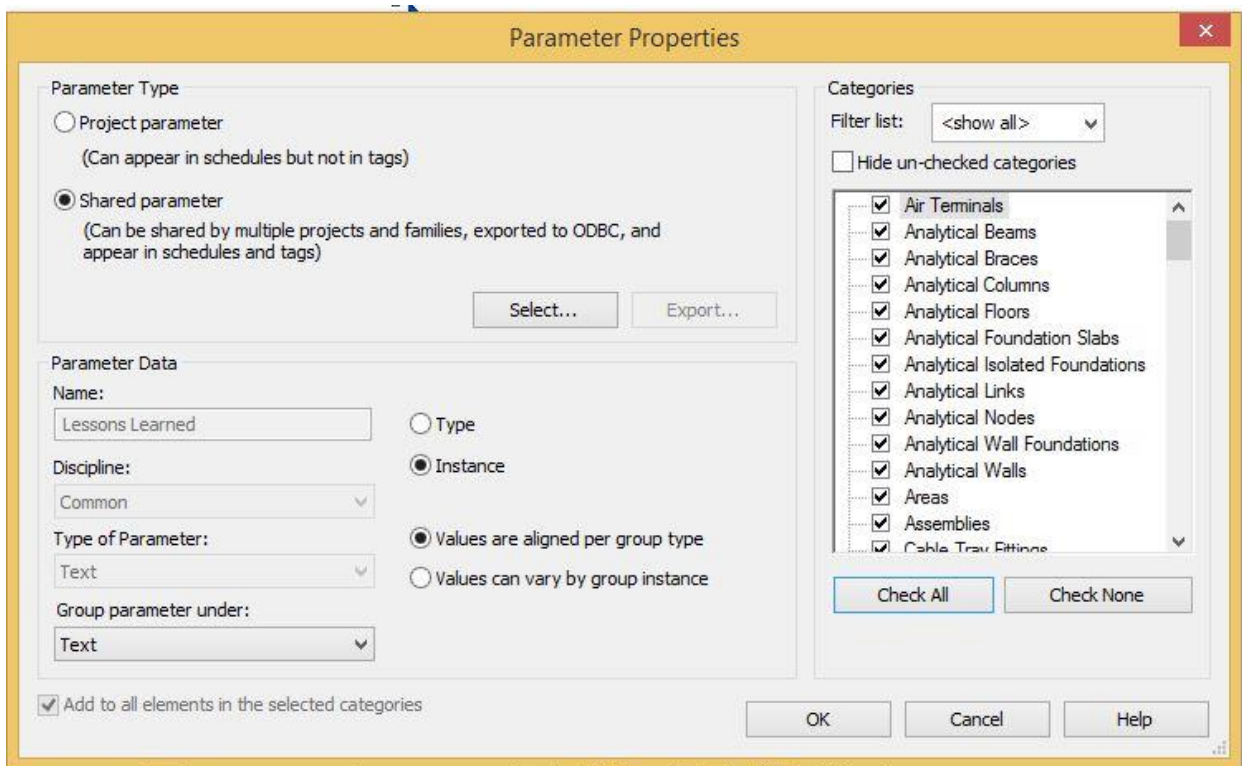


Figure 4.12 Parameter properties dialogue box

2. The “Lessons Learned” *shared parameter* is now attached to all the elements in the model under the “Text” *Group Parameter* (as can be seen in the figure). Any new lessons

learned in the design phase (or during the execution of the project or post construction stage) can be added to this parameter.

3. Since we added the parameter as an instance property, when any element in the model is selected, the “lesson learned” parameter can be seen in the (instance) properties palette of that element (as shown in the Figure 4.13). Various lessons learned (Knowledge Generated) during the life cycle of the project can be added to the building model at the respective location using the “Lessons Learned” parameter created.

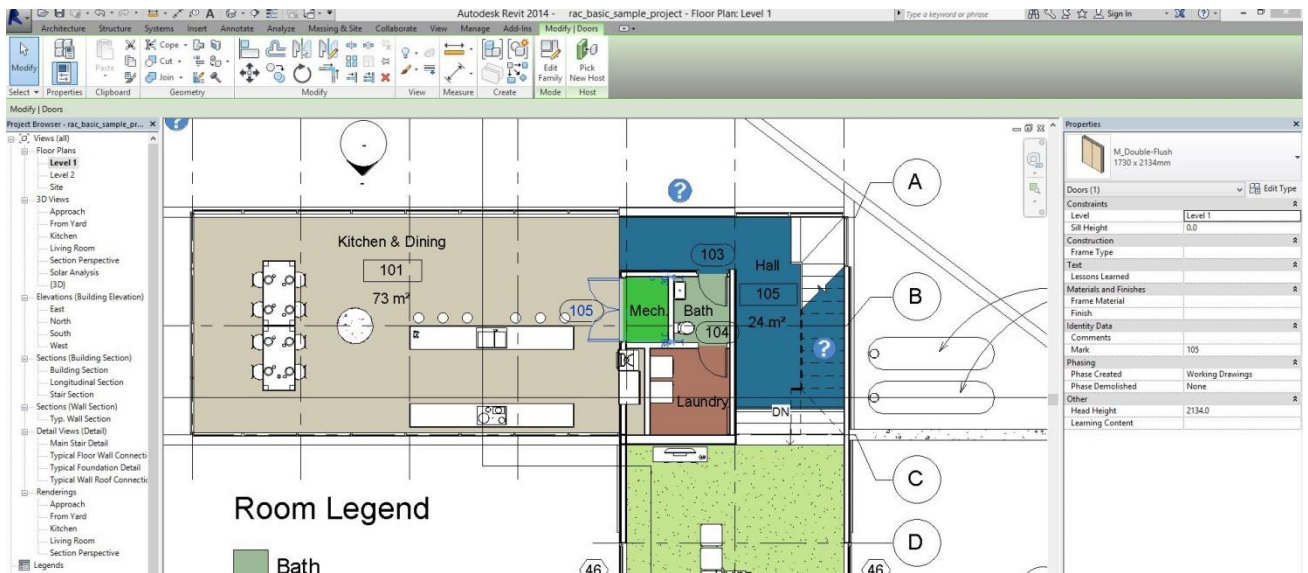


Figure 4.13 Instance properties of the door element selected in the model

4. Because the “Lessons Learned” shared parameter is an instance property of the element, any lesson stored in the element is attached to only that particular element in the project. This can be extremely helpful when reviewing the lessons from the model at a later stage because the exact location as to where the lesson was created can be located.

4.3.2 Knowledge Sharing using shared parameters

As discussed in the Literature Review chapter, knowledge sharing can take place from person-to-person, computer-to-person or from literature to person etc. The knowledge sharing process discussed here refers to software to a person with the help of internet. BIM can be used in conjunction with a knowledge base to share knowledge to the project members in the organizations. The project members can access this knowledge and use it when they need it either for necessity (in crucial situations) or for improving their knowledge on the subject. This knowledge sharing process differs from organization to organization based on how well developed knowledge base it has. This process is almost similar to the Knowledge Capture process discussed in the previous section except that instead of creating only one shared parameter (of instance property) and attaching it to all elements in the model, a number of shared parameters of type property are created and attached to that particular type. The process involves:

1. Create a new *shared parameter group* “Knowledge Sharing”
2. Under this group, create a *shared parameter* (say Door Lessons).

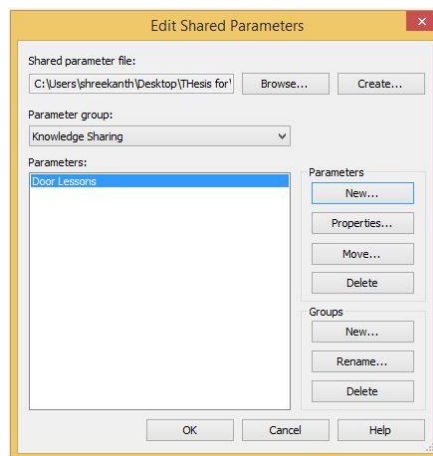


Figure 4.14 creating a new parameter in the edit shared parameter dialogue box

- When adding the newly created shared parameter to the list of project parameters in the model, add it as a *type* property parameter and attach it to only the doors component in the model. (This can be done by checking only the Doors box in the categories section on the right side of the window as shown in the fig).

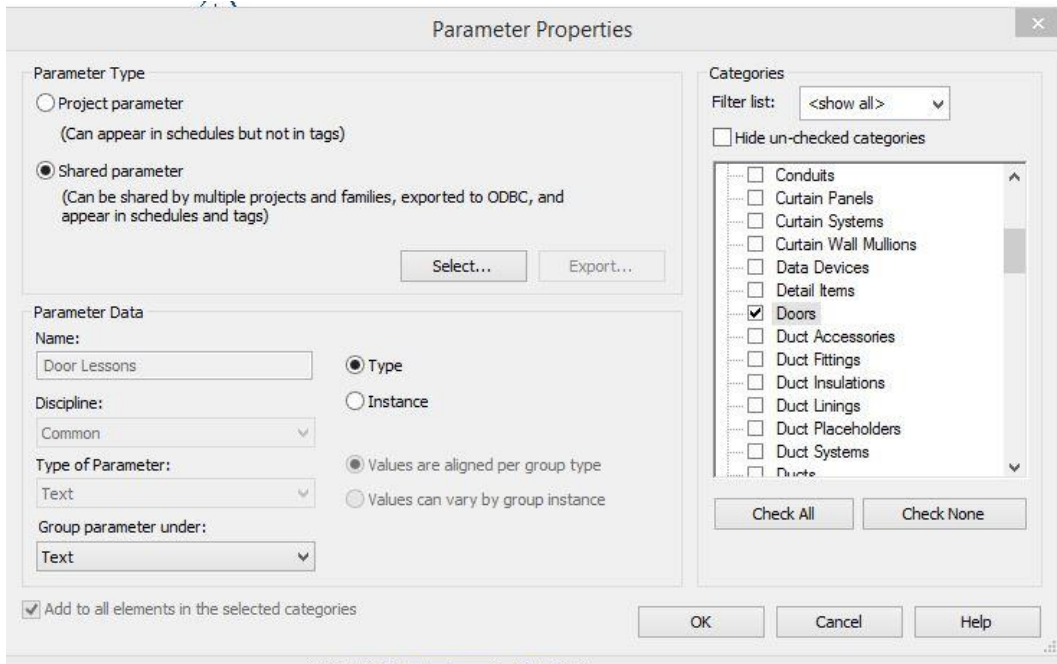


Figure 4.15 Shared parameter associated as a type property

- By doing so, this parameter (Door Lessons) is attached to all the doors in the model as a *type* property (as shown in the fig. 4.16).

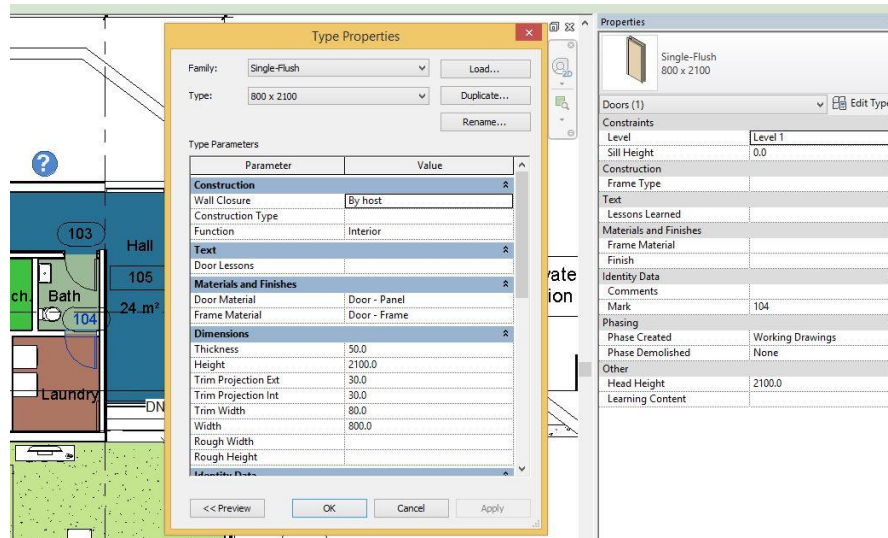


Figure 4.16 Door Lessons Shared parameter grouped under text

5. The advantage with this feature as discussed in the earlier sections is that, if any knowledge is attached to this parameter on any one of the doors in the model, it is attached to each and every *instance* of that *type* in the project. For example, if any link containing all the knowledge about the “Single-Flush 800*2100” is added to the “Door Lessons” parameter in the figure shown above, the link is attached to each and every instance of “Single-Flush 800*2100” in the model.
6. So, if someone needs any information about this type of door, he/she doesn’t have to go that particular instance where it is attached but can access the link by going to any door of that type in the model. If a model has a 1000 instances of “Single-Flush 800*2100” doors, the link is available in all the 1000 instances in the model.
7. Similarly, create various shared parameters (namely column lessons, wall lessons, window lessons, etc.) and attach them to their respective categories (Columns, Walls, Windows, etc.) in the project. After completing this step, attach a link to this parameter

which takes the member to the organization's database containing lessons to that particular category.

As can be observed from the previous two sections, the difference in the *instance* and *type* properties in the software can be leveraged to capture and share the knowledge in the project.

Chapter 5 Knowledge Extraction and the Use of IFCs

Once the model is populated with the lessons learned, it is important to extract all the lessons attached to the model, review the lessons, validate them and then store them in the knowledge base of the organization. Knowledge storage and knowledge maintenance depends upon the organization's established policies and differs from organization to organization. Organizations can use intranets, relational databases, and online blogs etc., to store the knowledge and maintain them from time to time for the benefit of its employees. Maintenance of knowledge depends from organization and organization and no one particular method suits all the organizations.

One more powerful feature of *shared parameters* is that, they can be used in Revit Schedules. Therefore, creating a schedule which includes all the lessons learned in the model has the benefit of listing all lessons learned at one place. There are several advantages with this method. The next section covers the procedure of creating the "Lessons Learned Schedule" and the advantages of this method.

5.1 Creating "Lessons Learned Schedule" using Shared Parameters

Shared parameters appear in the schedules and can be accessed in the model from the schedules. The process of creating a schedule is easy and consists of following steps:

- Revit has the feature of creating schedules using single family category or multi-categories. We can use the multi-category schedule feature to create a schedule containing all the lessons within the model. Create a multi-Category Schedule and name the schedule "Lessons Learned Schedule."
- After naming the schedule, include all the fields/categories that need to appear in the schedule. These fields consist of all the family categories and certain properties of the

elements in the model. Additionally, shared parameters can also be included in the schedule using the “Add Parameter” feature present in the schedule properties. Using these features create a schedule with all the required fields as shown in the fig. 5.1

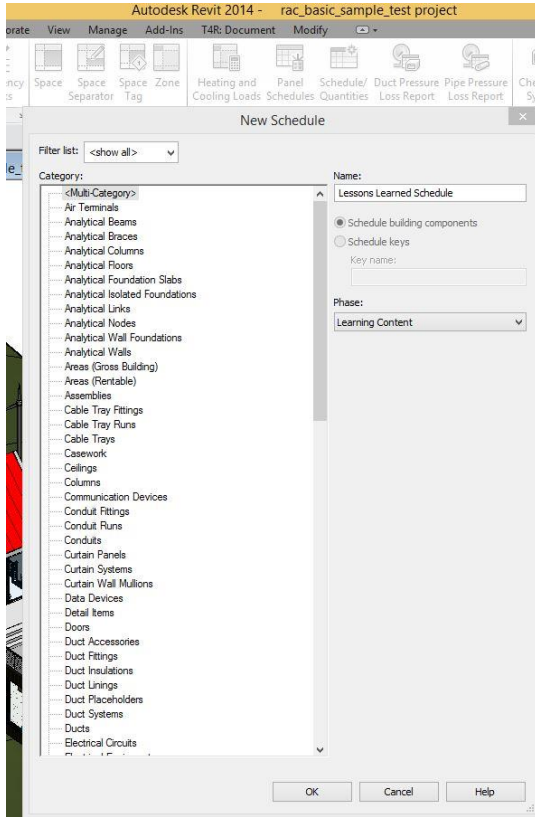


Figure 5.1 (a) Selecting the category of the schedule

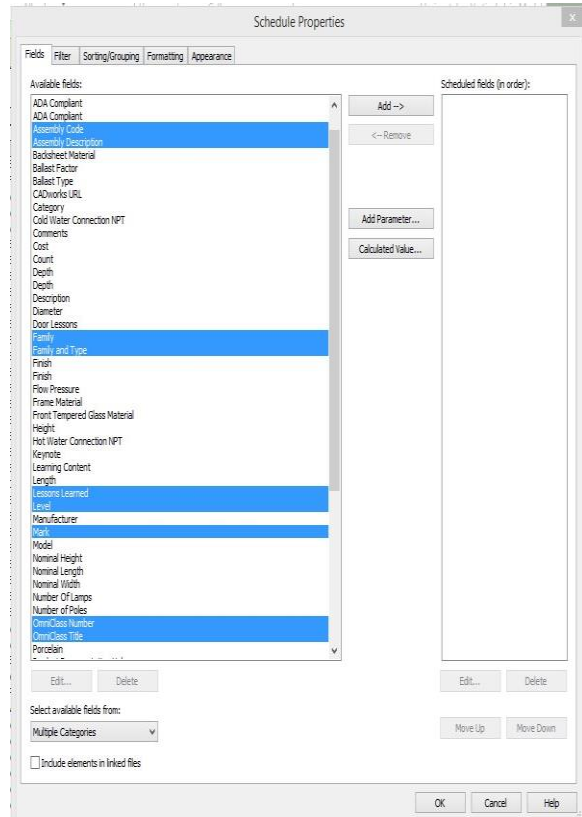


Figure 5.1 (b) Selecting the fields user wants in the schedule

- After the previous step when you click ok, the software gives the schedule which contains all the categories selected in the previous step. This includes all the elements in

the model because the “lessons learned” parameter is attached to all elements in the model.

<Lessons Learned>								
A	B	C	D	E	F	G	H	I
Family	Family and Type	OmniClass Number	OmniClass Title	Assembly Code	Assembly Description	Mark	Level	Lessons Learned
Sink-Ofset-Koher-Vauk-3823_4	Sink-Ofset-Koher-Vauk-3823_4	23.45.05.14.14	Sinks/Lavatories	D2010410	Sinks - Kitchen	1	Level 1	Sink Lesson 1
Faucet-Binck_Reach-Koher-Pureit	Faucet-Binck_Reach-Koher-Pur	23.45.05.17	Mixing Faucets	D2010	Plumbing Fixtures	3	Level 1	
M_Concrete-Round-Column with D	M_Concrete-Round-Column with	23.35.26.11.14.11	Columns	B10	Superstructure		Level 1	
M_Wind Power Generator	M_Wind Power Generator: 9 Mw	23.75.10.31	Wind Energy Equipment				Level 1	
M_Wind Power Generator	M_Wind Power Generator: 9 Mw	23.75.10.31	Wind Energy Equipment				Level 1	wind power generator less
Bathub-TOTO-Nexus-FB7945	Bathub-TOTO-Nexus-FB7945	23.45.05.14.21	Bathubs	D2010610	Bathubs	12	Level 2	
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	103	Level 1	
System Panel	System Panel: Glazed						Level 1	
Entrance door	Entrance door: Entrance door	23.30.10.00	Doors			201A	Level 1	
System Panel	System Panel: Glazed						Level 1	
System Panel	System Panel: Glazed						Level 1	
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	104	Level 1	single door sample lesson
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	202	Level 2	
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	204	Level 2	sample door lesson 3
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	203	Level 2	
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	205	Level 2	
Single Window	Single Window: Standard					18	Level 2	
Single Window	Single Window: Standard					19	Level 2	
Single Window	Single Window: Standard					20	Level 2	
Single Window	Single Window: Standard					21	Level 2	
Curtain Wall Dbl Glass	Curtain Wall Dbl Glass: Curtain	23.30.10.00	Doors			206B	Level 2	
System Panel	System Panel: Glazed						Level 2	
System Panel	System Panel: Glazed						Level 2	
System Panel	System Panel: Glazed						Level 2	
System Panel	System Panel: Glazed						Level 2	
System Panel	System Panel: Glazed						Level 2	
System Panel	System Panel: Glazed						Level 2	
System Panel	System Panel: Glazed						Level 2	
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	206A	Level 2	
M_Skylight	M_Skylight: 1180 x 1170mm	23.30.20.21.14	Roof Windows				Level 2	
M_Skylight	M_Skylight: 1180 x 1170mm	23.30.20.21.14	Roof Windows			23	Level 2	
Single Window	Single Window: Standard					24	Level 2	
Wahl_Hung Bow_804118 W	Wahl_Hung Bow_804118 W						Level 2	
Pocket_Slde_Door_5851	Pocket_Slde_Door_5851: 2.02			C1020	Interior Doors	207	Level 2	
wardrobe1	wardrobe1: wardrobe							
M_Pile Cap-600 Pile	M_Pile Cap-600 Pile: 600 x 600 x	23.25.05.11	Foundation Piles	A1010130	Pile Caps		Foundation	
M_Pile-Steel Pipe	M_Pile-Steel Pipe: 600mm Diameter			A1020130	Piles - Steel Pipe		Foundation	
M_Pile Cap-600 Pile	M_Pile Cap-600 Pile: 600 x 600 x	23.25.05.11	Foundation Piles	A1010130	Pile Caps		Foundation	
M_Pile-Steel Pipe	M_Pile-Steel Pipe: 600mm Diameter			A1020130	Piles - Steel Pipe		Foundation	
M_Pile Cap-600 Pile	M_Pile Cap-600 Pile: 600 x 600 x	23.25.05.11	Foundation Piles	A1010130	Pile Caps		Foundation	
M_Pile-Steel Pipe	M_Pile-Steel Pipe: 600mm Diameter			A1020130	Piles - Steel Pipe		Foundation	
M_Pile Cap-600 Pile	M_Pile Cap-600 Pile: 600 x 600 x	23.25.05.11	Foundation Piles	A1010130	Pile Caps		Foundation	
M_Pile-Steel Pipe	M_Pile-Steel Pipe: 600mm Diameter			A1020130	Piles - Steel Pipe		Foundation	
M_Pile Cap-600 Pile	M_Pile Cap-600 Pile: 600 x 600 x	23.25.05.11	Foundation Piles	A1010130	Pile Caps		Foundation	
M_Pile-Steel Pipe	M_Pile-Steel Pipe: 600mm Diameter			A1020130	Piles - Steel Pipe		Foundation	

Figure 5.2 Lessons Learned Schedule containing all the elements to which the parameter is added

- Depending upon the size of the project, this schedule can be very lengthy. But the schedule can be shortened to include only the elements for which lessons are actually added (i.e. all the elements to which knowledge is not added won't appear in the schedule). This can be done by using the “Filter” option available in the schedule properties. This option can be used to further filter the options like including only the lessons learned on certain levels or including only the lessons learned with specific “Omniclass Title” etc.

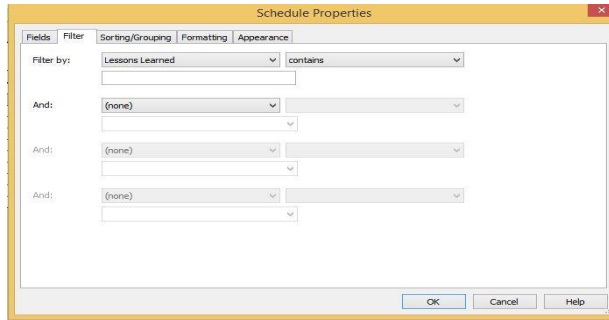


Figure 5.3 Schedule properties dialogue box showing Filter options

<-Lessons Learned-								
A	B	C	D	E	F	G	H	I
Family	Family and Type	OmnClass Number	OmnClass Title	Assembly Code	Assembly Description	Mark	Level	Lessons Learned
Sink-Offset-Kohler-Vauk-3823_4	Sink-Offset-Kohler-Vauk-3823_4	23.45.05.14.14	Sinks/Lavatories	D2010410	Sinks - Kitchen	1	Level 1	Sink Lesson 1
Faucet-Sinch_Reach-Kohler-Purist	Faucet-Sinch_Reach-Kohler-Purist	23.45.05.17	Mixing Faucets	D2010	Plumbing Fixtures	3	Level 1	Faucet sample lesson
M_Wind Power Generator	M_Wind Power Generator: 9 Mc	23.75.10.31	Wind Energy Equipment				Level 1	wind power generator lesso
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	104	Level 1	single door sample lesson
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	204	Level 2	sample door lesson 3
Single Window	Single Window: Standard					93	Level 2	window lesson 1
M_Double-Flush	M_Double-Flush: 1730 x 2134m	23.30.10.00	Doors			105	Level 1	Double door sample lesson
Dining Chair (3)	Dining Chair (3): Dining Chair (3)						Level 1	dining chair sample lesson 2
Dining Chair (3)	Dining Chair (3): Dining Chair (3)						Level 1	dining chair sample lesson

Figure 5.4 Schedule created with the user preferred fields after filtering

- Using the options in the Schedule Properties, the schedule can be further modified according to the user's preferences, the user can sort the lessons based on levels, so that all the lessons attached to elements on a particular level appear together or he/she can sort them based on the Omniclass title, so that lessons that belong to one particular omniclass (family) appear together. This can be the most useful feature as the lessons attached in the model can be organized according to the need of the users/condition.
- Another advantage of this method is that the element to which the lesson is attached can be easily accessed in the model. For example in the figure below, when the wind power generator row is selected, the element in the model is highlighted. This makes sure that we can see to what element the lesson is attached in the model. We can also know to which element the lesson is attached from the columns like "Mark," "Level," "Family and Type," columns in the schedule.

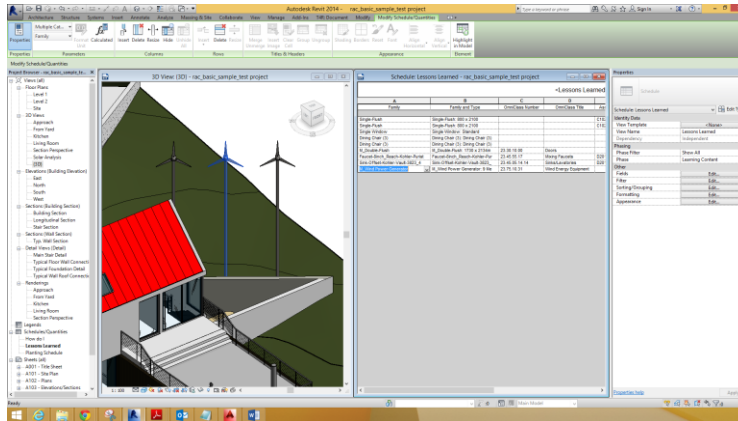


Figure 5.5 Lesson selected in the schedule and the component highlighted in the model

5.2 Exporting the Revit schedule

Once the final schedule is created, it can be exported to text format as shown in the figure using Revit.

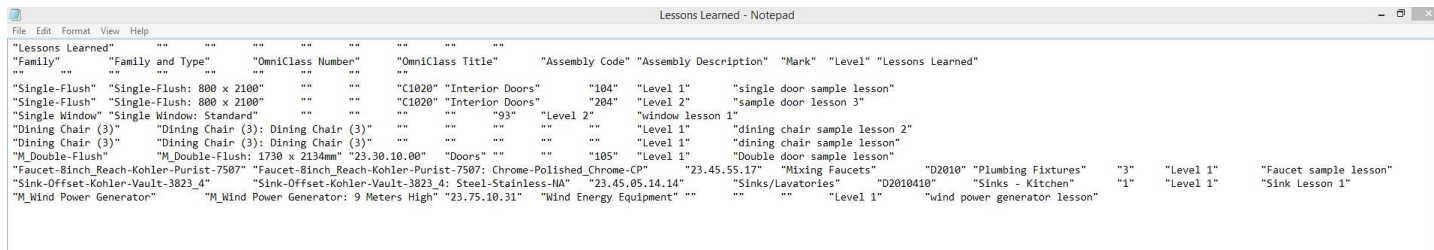


Figure 5.6 Text format of the exported Lessons Learned Schedule from Revit

The text format can then be converted into excel format easily by open the text file in the excel sheet.

Lessons Learned								
Family	Family and Type	OmniClass Number	OmniClass Title	Assembly Code	Assembly Description	Mark	Level	Lessons Learned
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	104	Level 1	single door sample lesson
Single-Flush	Single-Flush: 800 x 2100			C1020	Interior Doors	204	Level 2	sample door lesson 3
Single Window	Single Window: Standard					93	Level 2	window lesson 1
Dining Chair (3)	Dining Chair (3): Dining Chair (3)						Level 1	dining chair sample lesson 2
Dining Chair (3)	Dining Chair (3): Dining Chair (3)						Level 1	dining chair sample lesson
M_Double-Flush	M_Double-Flush: 1730 x 2134mm	23.30.10.00	Doors			105	Level 1	Double door sample lesson
Faucet-Binrch_Reach-Kohler-Purist-7507	Faucet-Binrch_Reach-Kohler-Purist-7507: Chrome-Polished_Chrome-CP	23.45.55.17	Mixing Faucets	D2010	Plumbing Fixtures	3	Level 1	Faucet sample lesson
Sink-Offset-Kohler-Vault-3823_4	Sink-Offset-Kohler-Vault-3823_4: Steel-Stainless-NA	23.45.05.14.14	Sinks/Lavatories	D2010410	Sinks - Kitchen	1	Level 1	Sink Lesson 1
M_Wind Power Generator	M_Wind Power Generator: 9 Meters High	23.75.10.31	Wind Energy Equipment				Level 1	wind power generator lesson

Figure 5.7 Excel format of the Lessons Learned schedule from Revit

5.3 The use of IFC for Knowledge Extraction

The Industry Foundation Classes (IFC) specification is a data format developed by buildingSMART (formerly the International Alliance for Interoperability, IAI) to describe, exchange and share information used within the building and facility management industry sector.

The building information model can be generated using any of the software like Revit, Bentley Systems, ArchiCAD, Digital Project, Vectorworks etc. Each software is unique and takes time for an individual to get some range of expertise using it. The model developed using one software cannot be opened in another platform i.e. there is no interoperability between the software. Also, a model generated in the latest version cannot be opened in the earlier versions of the same software, which implies there is no interoperability within the same platform from the latest version of the software to the previous version.

This is where Industry Foundation Classes (IFC) formats can be used. The IFC is a file format which represents an object-oriented data model based on class definitions that are needed to share information rather than processing it in a particular software. The IFC data model is a neutral and open specification that is not controlled by a singular vendor or a group of vendors.

The IFC facilitates interoperability in the building industry. Most of the above mentioned software have the capability to export the model into IFC format. The IFC files can also be opened using the software i.e. the model can be generated using one software, exported into ifc format and then it can be opened using another software. IFC supports multiple file formats viz. IFC-SPF which is a text format where each line typically consists of a single object record and has the file extension “.ifc”, IFC-XML, which is an XML format having extension “.ifcXML” and IFC-ZIP, which is a ZIP compressed format consisting of an embedded IFC-SPF file and having file extension “.ifcZIP”.

A typical IFC text file of the sample project example used in the earlier sections looks like the one shown in the figure below. It consists of several lines (in millions) depending upon the size of the project.

```

File Edit Format View Help
rac_basic_sample_test project - Notepad
#21= IFCDIRECTION(0,0,-1.0);
#23= IFCDIRECTION(1,0,0);
#25= IFCDIRECTION(-1,0,0);
#27= IFCDIRECTION(0,1,0);
#29= IFCDIRECTION(0,-1,0);
#31= IFCAXIS2PLACEMENT3D(#6,$,$);
#32= IFCLOCALPLACEMENT(#37,#5,$);
#35= IFCPERSON($,'Macalister','Samuel',$,$,$,$,$);
#37= IFCORPORATION($,'Autodesk','','$,$);
#38= IFCPERSONANDORGANIZATION(#35,#37,$);
#41= IFCOMERISORY(#38,#5,$,'HOCHANGE',$,$,$,1398448497);
#42= IFCSIUNIT(*,LENGTHUNIT,'MILLI',METRE.);
#43= IFCSIUNIT(*,LENGTHUNIT,$,METRE.);
#44= IFCSIUNIT(*,AREAUNIT,$,SQUARE_METRE.);
#45= IFCSIUNIT(*,VOLUMEUNIT,$,CUBIC_METRE.);
#46= IFCSIUNIT(*,PLANEANGLEUNIT,$,RADIAN.);
#47= IFCDIMENSIONALEXPONENTS(0,0,0,0,0,0);
#48= IFCMEASUREMENTUNIT(IFCRATIONEASURE(0.0174532925199433),#46);
#49= IFCCONVERSIONBASEUNIT(#47,'PLANEANGLEUNIT','DEGREE',#48);
#50= IFCSIUNIT(*,MASSUNIT,'KILLO',GRAM.);
#51= IFCSIUNIT(*,TIMEUNIT,$,SECOND.);
#52= IFCSIUNIT(*,THERMODYNAMICTEMPERATUREUNIT,$,KELVIN.);
#53= IFCDERIVEDUNITELEMENT(#50,1);
#54= IFCDERIVEDUNITELEMENT(#52,-1);
#55= IFCDERIVEDUNITELEMENT(#51,-3);
#56= IFCDERIVEDUNITELEMENT(#53,#54,#55),THERMALTRANSMITTANCEUNIT,$);
#58= IFCDERIVEDUNITELEMENT(#43,3);
#59= IFCDERIVEDUNITELEMENT(#51,-1);
#60= IFCDERIVEDUNITELEMENT(#58,#59),VOLUMETRICFLOWRATEUNIT,$);
#62= IFCSIUNIT(*,POWERUNIT,$,WATT.);
#63= IFCUNITASSIGNMENT(#42,#44,#45,#50,#51,#52,#56,#60,#62));
#65= IFCAXIS2PLACEMENT3D(#6,$,$);
#66= IFCVECTOR(2,0,0.001815023152052,0.79863551004729);
#68= IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,1,0.000000000000E-5,#65,#66);
#71= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Axis','Model',*,*,*,#68,$,GRAPH_VIEW,$);
#73= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Body','Model',*,*,*,#68,$,MODEL_VIEW,$);
#74= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Box','Model',*,*,*,#68,$,MODEL_VIEW,$);
#75= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('FootPrint','Model',*,*,*,#68,$,MODEL_VIEW,$);
#76= IFCGEOMETRICREPRESENTATIONCONTEXT($,'Annotation',*,*,*,#76,0.01,PLAN_VIEW,$);
#77= IFCGEOMETRICREPRESENTATIONSUBCONTEXT($,'Annotation',*,*,*,#76,0.01,PLAN_VIEW,$);
#79= IFCPROJECT(2jqsICF9aV90LExyVUG0',#41,001-00',$,$,'Sample House','Project Status',(#68,#76),#63);
#85= IFCPOSTALADDRESS($,$,$,('Enter address here'),$,,'Boston','MA');
#89= IFCBUILDING(2jqsICF9aV90LExyVUG1',#41,'Samuel Macalister sample house design',$,$,#32,$,'Samuel Macalister sample house design',.ELEMENT,$,$,#85);
#95= IFCARTESIANPOINT(0,-0,-800.);
#97= IFCAXIS2PLACEMENT3D(#95,$,$);
#98= IFCLOCALPLACEMENT(#32,#97);
#100= IFCBUILDINGSTOREY(2jqsICF9aV90LExX7XTBY',#41,'Foundation',$,$,#98,$,'Foundation',.ELEMENT,-800.);
#102= IFCARTESIANPOINT(0,0,-550.);
#104= IFCAXIS2PLACEMENT3D(#102,$,$);
#105= IFCLOCALPLACEMENT(#32,#104);
#106= IFCBUILDINGSTOREY(2jqsICF9aV90LExX7XSAs',#41,'Level 1 Living Rm',$,$,#105,$,'Level 1 Living Rm',.ELEMENT,-550.);
#108= IFCAXIS2PLACEMENT3D(#6,$,$);
#109= IFCLOCALPLACEMENT(#32,#108);
  
```

Figure 5.8 A typical ifc format text file

From this text file, the lessons that are added to the model can be extracted using external software like “ifc file analyzer” which separates the lessons learned from the text file and organizes them in excel format. This process can be useful when

- The team does not have the software in which the model is built. It can be because the model is built using a different software platform or the model is created in a later version of the software which is not available for the concerned team.
- The size of the file is an issue. The ifc file is very less in size when compared to the size of the model in the software format.
- This process can be useful irrespective of the software used to build the BIM model. The process explained in the previous section is specific to Revit Platform.

Chapter 6 The Validation Process

6.1 Overview

The validation process consisted of focus groups and person-to-person interactions mainly in a BIM consultancy firm in California, U.S. The firm consisted of members whose experience ranged from intermediate to expert level in the use of BIM. The firm has a knowledge management program in place. The management conducted review and training sessions for its employees with the help of industry experts. The knowledge base of the organization consisted of ftp, where all the documents related to the firm's projects are stored. The developed methodology has been tested in the organization for three months till date and is proving to be useful.

Also the validation phase helped in improving the knowledge extraction part of the process. The members have been active from the start and have been very co-operative in testing and improving the process throughout the three month period. During the three month span, a total of three interviews with the top management of the firm and two focus group meetings with the project members on the usefulness/effectiveness of the methodology have been conducted and the recommendations/comments from the process have been taken into account to improve the methodology. The full potential of the methodology, the challenges that can be faced during the implementation can be known if tested in a full range projects.

This chapter explains how the methodology was validated, the process carried out for the validation, the results and some of the changes that have been made to the initial methodology and comments on how to improve the process in the future to be even more useful.

The validation process was first started with a presentation explaining the developed methodology, potential uses associated with the knowledge management process and roles of different project team members to successfully implement the knowledge management process.

6.2 Roles of Different Project Members

6.2.1 Project Engineer/ Site Engineer/ BIM engineer/ Project Team Member

At the lowest level, the project engineer/site engineer/BIM engineer or any project team member, when faced with a learning situation simply captures the knowledge, notes it down in the created “lessons learned” parameter as explained in previous chapters. If the team member finds it necessary to refer to any knowledge pertaining to the particular subject he/she can refer to the knowledge database of the organization using the location address that is provided in the “knowledge base” parameter created in the BIM model. The project team member can refer to the knowledge either to reuse any of the knowledge captured previously to address the situation at hand or to simply increase his understanding of the subject. Proper use of this process can reduce the amount of possible mistakes that can otherwise be made.

This role is best suited at the lowest level, because all the project member has to do is enter the knowledge from the learning situation in the model. He/she doesn't have to worry about the authenticity/correctness of the information because in the later stages of the process when the knowledge is extracted from the model, an expert on the subject reviews the lessons captured, verify and validate them based on the correctness of the data. Another advantage of this is that the project manager or the person responsible to conduct post project reviews/knowledge review sessions can clarify the concept about the particular topic to the project team members so that they are knowledgeable about the topic and would carry forward the knowledge into the future

projects. Without such understanding, the project member might possibly commit a mistake with the misconception he/she has about the topic.

6.2.2 Knowledge Manager

Knowledge Manager has a role to play during two stages of the methodology. The first one is to extract the captured knowledge from the BIM model, organize the knowledge based on the *family* it is associated to and send them to relevant subject experts. In the second stage, the knowledge manager receives the validated knowledge along with the classification (if it is a code requirement, lesson learned or best practice followed) from the subject experts and posts it in the knowledge base of the organization according to its classification. This knowledge is now made available to all the members of the organization from the knowledge base.

6.2.3 Subject Expert/Trade Expert

The responsibility of the subject/trade expert is to go through all the lessons that are captured within the model and verify the authenticity and correctness of the lesson captured. The expert after going through all the lessons in the model, decides which knowledge is relevant, useful and reusable based on his/her discretion. The expert then classifies the knowledge based on how the knowledge base of the organization is set up. Once the expert classifies all the useful knowledge, he/she then sends the document containing the knowledge that is to be shared to the knowledge manager who adds it to the knowledge base of the organization.

An additional responsibility of the expert would be to go through the knowledge in the database once in a while, review them and update it (based on any changes to the code requirement, any new identified best practice) accordingly. This is important because if the

knowledge base is up-to-date, then even if the project members access the knowledge using the links from the previous model, they get up-to-date information.

6.2.4 Management

The main responsibility of the management is to provide the resources (necessary software and machines) to carry out the process without any difficulty. Additional responsibility would be to train the employees about the methodology and motivate the project members to capture the knowledge as soon as it is created. The successful implementation depends on how well the management instills this culture into its employees and how well they encourage their employees to use the resources to increase its knowledge base and receive the benefits of the knowledge.

6.3 Focus Group Meetings

The focus group consisted of all the BIM engineers/ Project Engineers in the firm. The group consisted of a total of 10 members off whom 6 engineers have an experience of more than 5 years in the area of BIM. Firstly, the methodology was demonstrated to the group explaining the whole process, ideas behind it and the main purpose of the methodology. Immediately after the presentation a discussion was held about the methodology presented. The views from the discussions included

- All the members from the group felt that the process of capturing lessons learned using shared parameters was simple, easy to implement and can be very effective. The firm has decided to create the lesson learned shared parameter in its projects and capture any lessons learned using the parameter.

- All the members felt that the knowledge sharing process works effectively if the organization has an extensive knowledge base. The firm has decided to first create the knowledge base with the help of all the resources available and then make it available to members of the organization. Once the database is mature enough, the firm has decided to start using the *type* shared parameters in the models to share the knowledge base for its members.
- Most of the members felt that the Knowledge extraction part using ifcs and using separate software to extract the lessons learned from the ifc files as a time consuming process. Most of them were also not in favor of switching software and go through the extra effort of extracting knowledge already present in the model. They felt that a simple and easy process would be more helpful.
- Overall, everyone felt that the approach is very useful for the organization to capture lessons learned from the projects.

After the first focus group meeting, further research was conducted to improve the knowledge extraction process and alternate method of using schedules within Revit was developed as discussed in the previous chapter. Instead of exporting the Revit model to ifc and then extracting lessons learned from the model using another software, “lessons learned schedule” was created within Revit and all the knowledge captured within the model was presented in that schedule.

After this development, another session of focus group meeting was organized in the firm and the newly developed knowledge extraction process was discussed. All the members felt that this approach is much simpler and more efficient. All the members also liked the idea of viewing the exact location as to where the lesson is created in the model using the schedule. They also

expressed that this method would be very helpful during the PPRs and knowledge meetings carried out in the firm.

After the second focus group meeting, a final face to face discussion was conducted with the head of the firm who has an experience of more than 8 years in the area of BIM. The entire methodology was explained with the potential uses of an extensive knowledge database. He felt that the process can be very useful for the organization and permitted to test the methodology in the organization. He understood the importance of knowledge maintenance and decided to populate and update the knowledge blog of the organization. Few suggestions concerning the software development side of BIM to increase the usefulness of the process were also made during the discussion. They are included in the future research chapter of this book.

6.4 Implementation

The methodology was implemented mainly to test the potential of the developed methodology and how well it can assist the knowledge management program of the organization. The firm has a knowledge management program where the company has brought in experts from the trade to conduct training sessions once in a month. The sessions included general lessons concerning the trade, efficient ways in which BIM can be used in modeling and during the coordination meetings, real life examples of the situations faced during the design and during installation on the field, mistakes committed in the previous projects and how they could have been avoided and the approach to be followed for the project set up etc. The project team members would take notes individually during the sessions and the company has the presentations saved on the local server. The problem with it was there is no 'single place' where all the knowledge is stored, the company has a knowledge blog but it is not updated frequently because of the time-constraint and because no one was particularly assigned to do it.

The methodology was implemented by first creating the “lessons learned” shared parameter and attaching it to all the elements in the BIM models of the firm, the team members were asked to note down any lessons learned during the execution of the projects and the project manager has decided to validate all the extracted lessons from the model and classify the lessons based on how the knowledge blog was classified. The IT manager has been asked to update the knowledge blog and add the validated lessons.

There had been no issues so far in implementing the methodology in the firm and during the span of three months during which it is implemented there have been two training sessions which included a presentation from a trade expert and a knowledge review session. During the end of the knowledge review session, the lessons learned have been extracted from all the models and the trade expert is in the process of validating the lessons. The lessons are collected by project wise and the trade expert goes through all the lessons project wise using the model and updates the excel sheet and classifies the category to which the lesson can be associated in the blog.

Also a discussion was held on the usefulness of the method and the team felt that the method has been helpful and thought that the firm will benefit if the firm continued implementing the methodology. The only drawback identified was the extra time the trade expert (in this case the project manager) has to put in to validate the lessons. But keeping in mind the long term use of an efficient KM process, the firm has decided to continue implementing the methodology. Some of the lessons captured were also discussed with the trade experts during the training sessions. The methodology has not only been helpful in capturing and updating the knowledge in the model and on the knowledge blog but also it has been very helpful in the training sessions.

Chapter 7 Illustrative Example

As discussed in the previous chapter, the methodology was utilized in a BIM consulting firm located in California. The example used for explanation in this chapter is the construction of a hospital project in California. During the execution of the project, the project members came across several situations where something new was learned. Using the methodology discussed in this study, the knowledge generated was captured, extracted, validated and stored in the knowledge database of the organization. The rest of the chapter explains about the project and the procedure carried out.

The model used in this example is a medical center building project located in California. The total area of the building is just above 60,000 square feet. The building has three levels, 300 parking spaces and the total cost is estimated to be \$35 million. The project was started in September 2012 and is estimated to be completed by August 2015.

BIM is extensively used in the project for clash detection between different trades, for initial estimation and for the production of shop drawings. Every project team was responsible for building their own BIM model, i.e. architect was responsible for modeling the core, shell and all other architectural components; structural consultant was responsible for modeling the structural component of the building and it is same with electrical, mechanical, plumbing and fire protection sub-contractors. Everyone used Revit software for modeling; co-ordination and clash detection was carried by the BIM consulting firm using Autodesk Navisworks. The model used in the example below is electrical model of the project (shown in figure 7.3).



Figure 7.1 Rendered model of the example (hospital project)

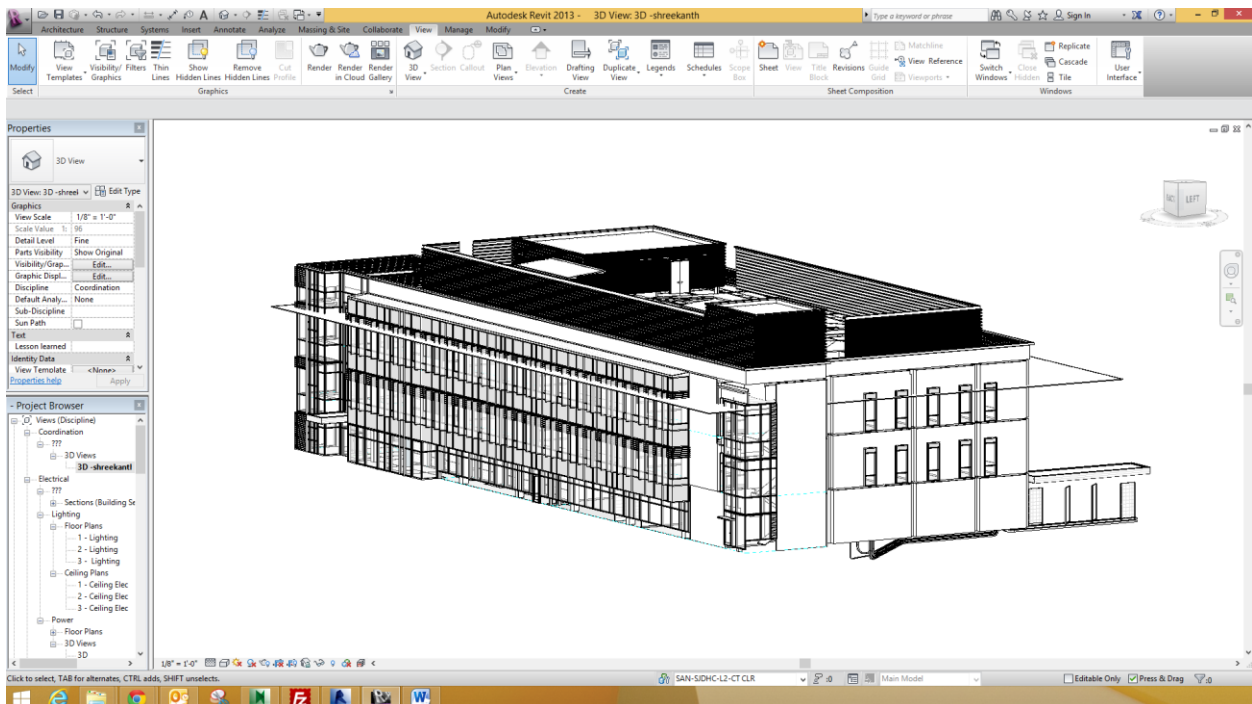


Figure 7.2 Architectural model of the project

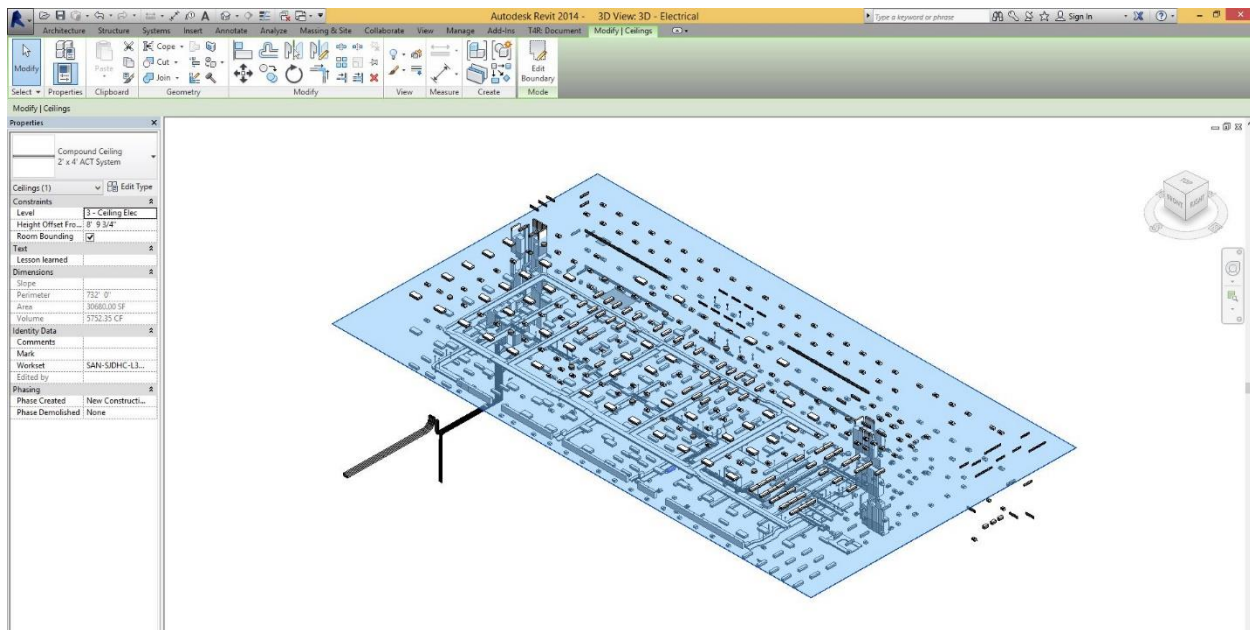


Figure 7.3 Electrical model of the project

The KM Process

As explained in the earlier chapters, the concept of *shared parameters* is used to carry out the KM process. The process consisted of following steps:

Knowledge Capture

When a project member is faced with a learning situation/opportunity, the lesson learned can be attached to the BIM model using the “lessons learned” shared parameter as shown in the figure below. In the example presented below, the project member learned that when a conduit is connected from Panel A to Panel B, the total number of degrees of the bend along its whole path should not exceed greater than 360°. This is something new learned by the project member, therefore he/she can attach this lesson to the “lessons learned” parameter that is present under the “text” section in the properties palette as shown in figure. 7.4

Lessons can be attached to the model using the 3D view or in a floor plan or they can also be added directly to the lessons learned schedule that is created during the knowledge extraction (explained in the next section of this chapter). Fig. 7.4 shows a lesson attached using the 3D view of the conduits; fig. 7.5 shows lesson attached using a floor plan of the model. Fig 7.5 contains lesson about the supports during the routing of conduit. In this situation it is learned during the modeling by the project engineer that when there is a offset in the conduit run (change in direction of change in elevation), a support must be provided at a distance not greater than 3ft and it should be followed by the regular spacing of supports of 8ft.

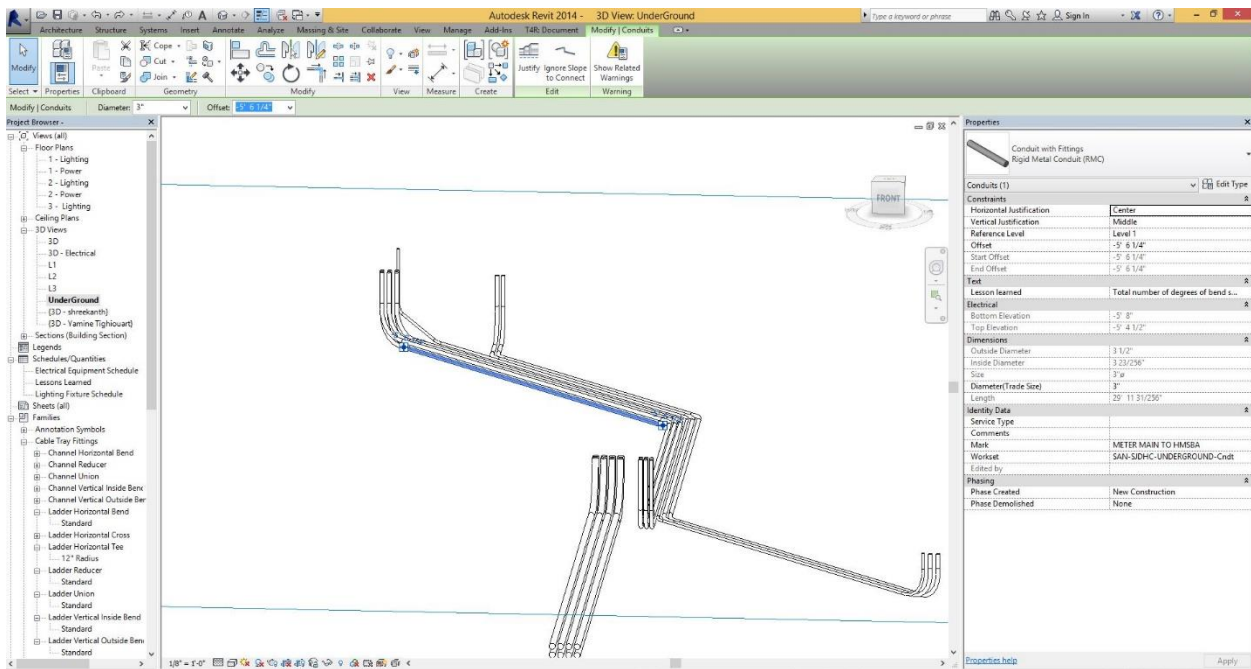


Figure 7.4 Knowledge capture process in 3D view

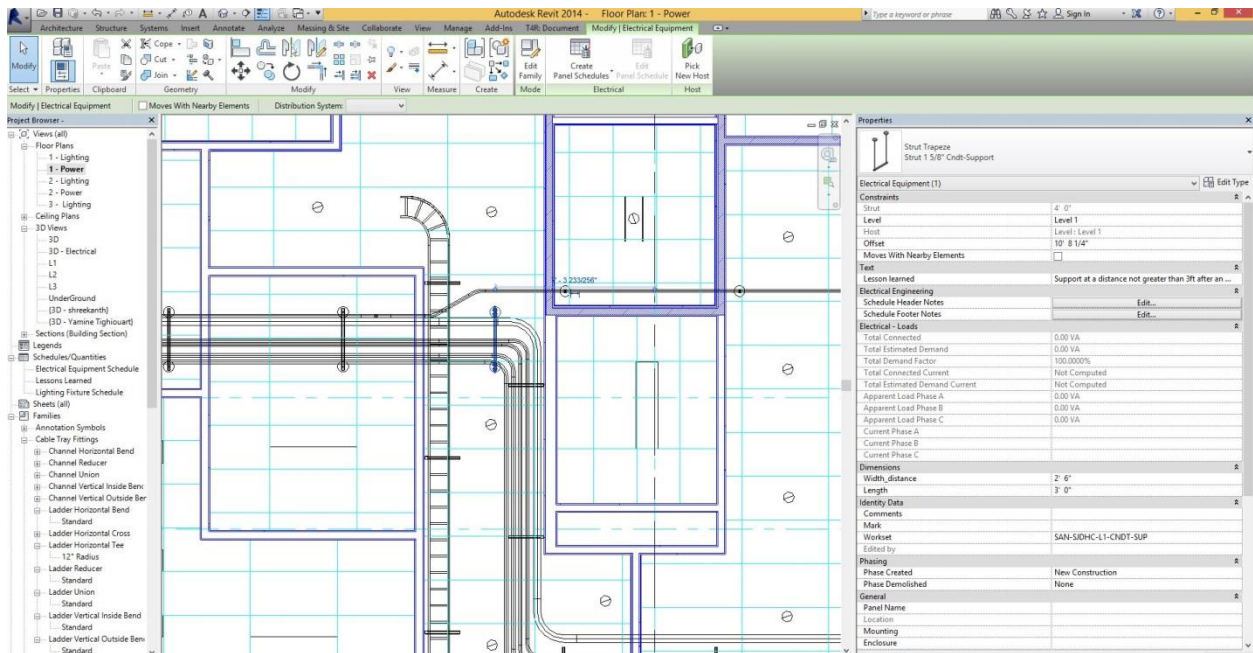


Figure 7.5 Knowledge capture process in a plan view

Similarly lessons learned during the course of the project are attached at the respective locations.

Knowledge Extraction

After the end of the project or the completion of a milestone, all the lessons attached to the model can be extracted by creating the “Lessons Learned” schedule using the software and extracting them to a Microsoft Excel file as explained in the previous chapter.

In this example, the lessons are extracted during a monthly review meeting for the validation by experts. The “lessons learned schedule” extracted is shown in the figure 7.6 below

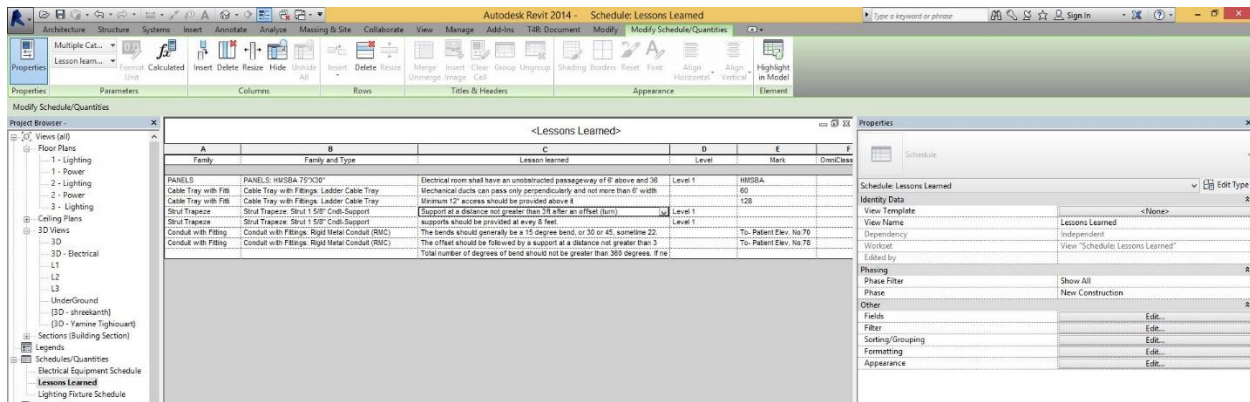


Figure 7.6 Lessons Learned Schedule in the Revit model

Once the schedule is created in revit, it can be converted to Microsoft excel sheet as shown below.

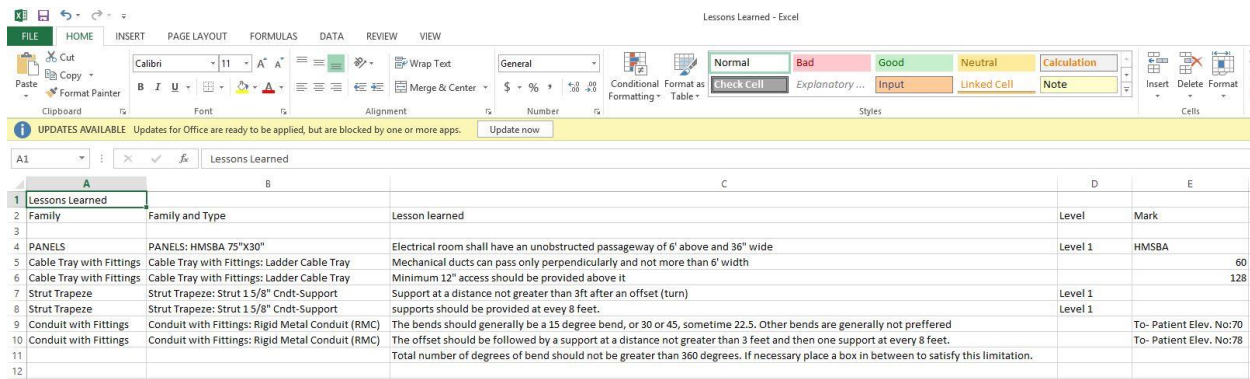


Figure 7.7 Lessons Learned schedule in the Microsoft excel format

Knowledge Validation

The Excel sheet along with the Revit model is sent to the subject experts within the organizations. The experts go through all the lessons in the schedule of the Revit model or the excel sheet, they are expected to add any additional relevant information about the lesson, other situations where the problem can be expected, if the lesson can be reusable and any examples for his/her experience from previous projects. The reviewed lessons can be updated either in the

excel sheet or the Revit model. After the validation of the extracted lessons, they are stored in the knowledge base of the organization.

Knowledge Maintenance

As explained in the previous chapter, knowledge maintenance varies from organization to organization. In this example, the organization used online blog to explain the lessons and FTP (file transfer protocol) for storing the Revit files. The updated lessons are stored within the model at proper locations and they are also stored in the knowledge blog of the organization. The BIM model with the stored knowledge is also stored in the knowledge base of the organization. In this case, the BIM models are stored on ftp and the lessons are updated in the knowledge blog of the organization as shown below. Only the members of the organization have access to both the blog and ftp files. The following section contains the screenshots of the site on how the organization structured it to store the lessons.

1. The Home page contains information about the blog and how the blog is structured. Since the firm is a MEP BIM consultant firm, the sections in the menu include lessons pertaining to Electrical, Mechanical and Plumbing sections in particular. Rest of the lessons which concern the firm is included in the other section of the menu. The site also contains Contact option to send a message to the admin about any issues relating to the site or the lessons posted.

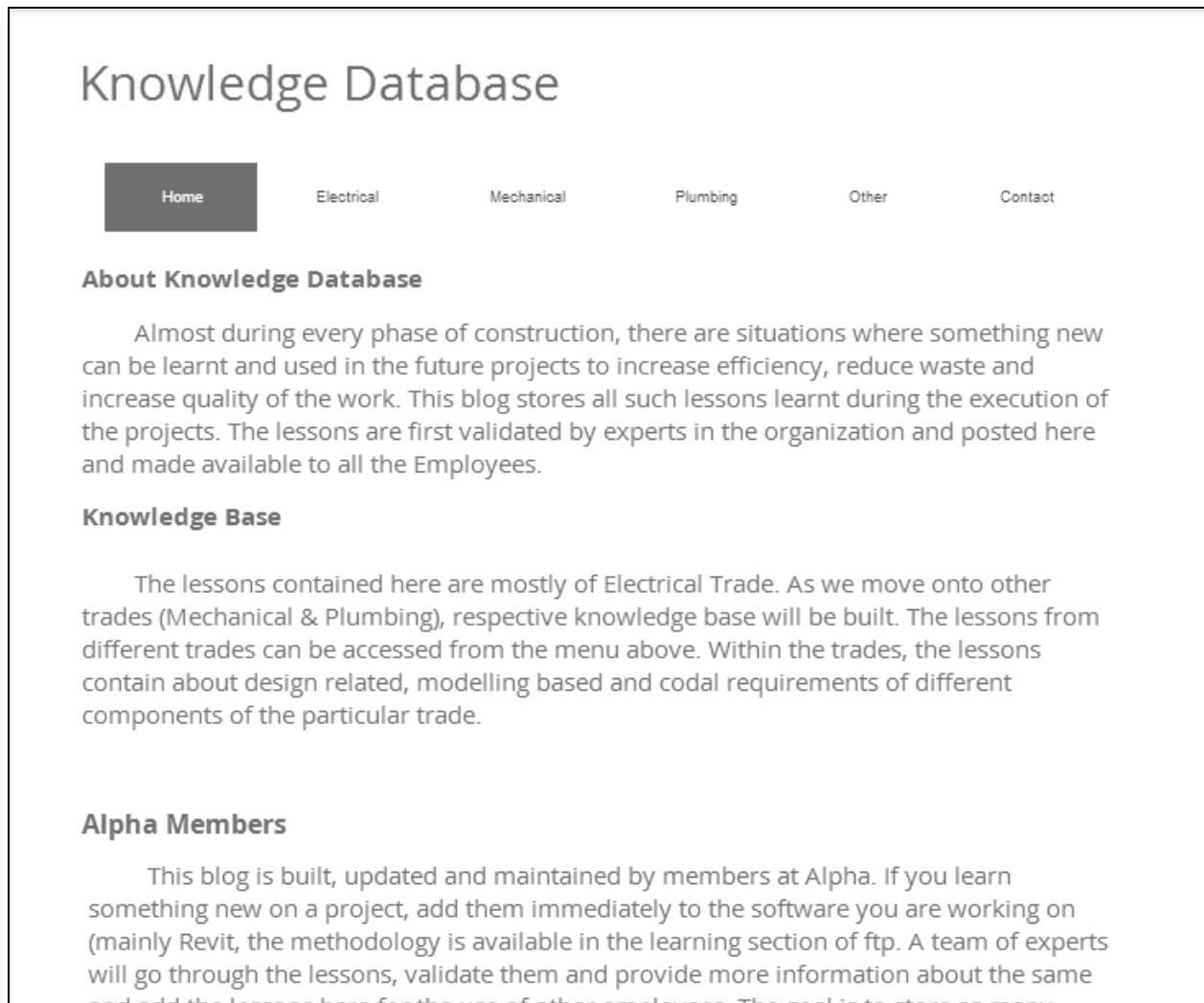


Figure 7.8 Home page of the Knowledge Maintenance blog

2. When you click on the particular trade, lessons associated to that trade are accessible. For example, if you go to the Electrical section of the menu, it has lessons containing to various components related to the electrical trade of construction, all these components are present on the left hand side of the site. Within these components, the lessons are further classified based on the discipline, modeling related software, code requirements during the design/installation, best practices followed industry wide when installing the particular component, OSHA requirements and any unique situation related lessons. For example, on clicking the conduit option, lessons associated with the conduit component

are available with further classification of the lessons as explained and shown in the figure below.

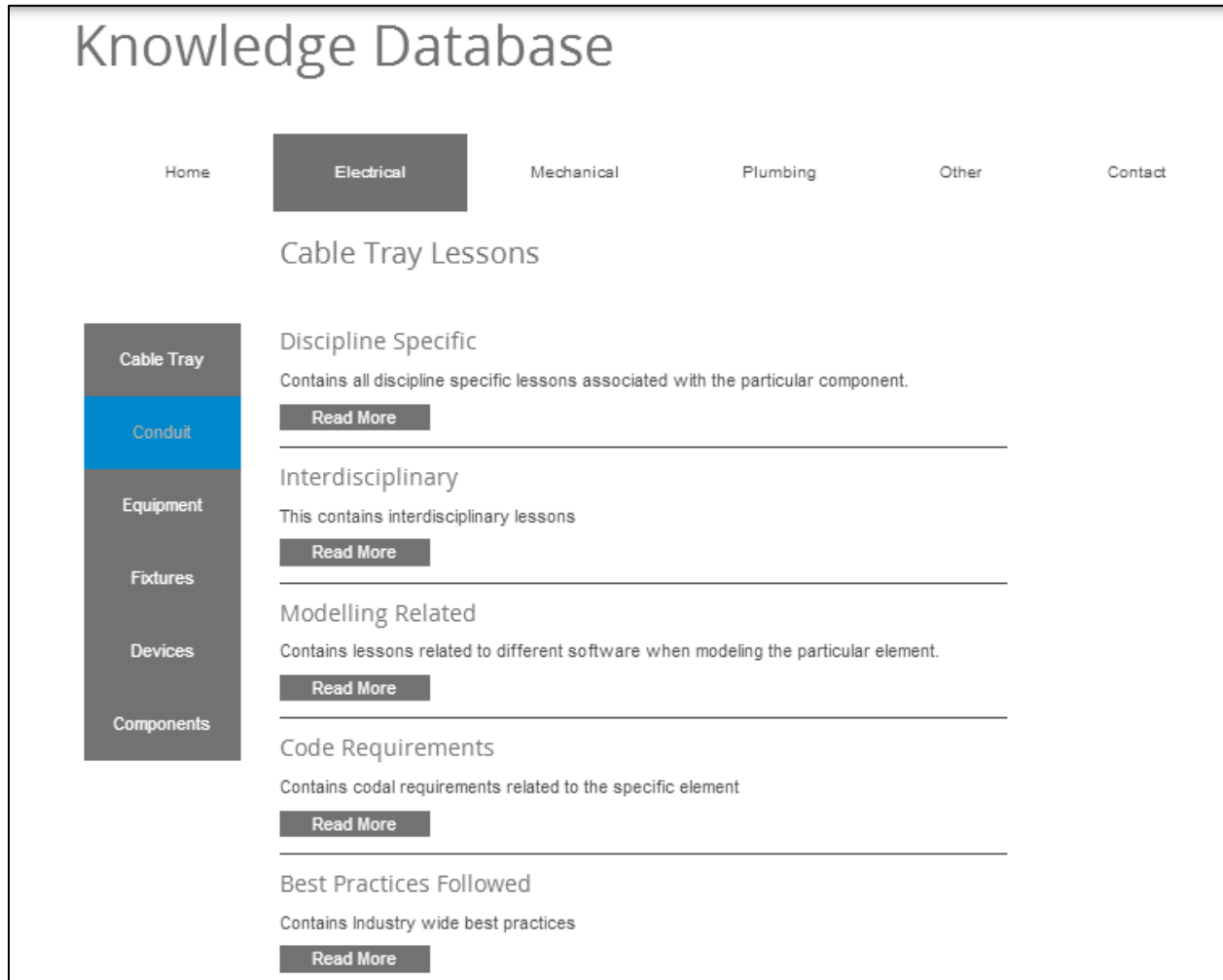


Figure 7.9 Electrical section of the blog containing conduit lessons

3. This part of the site contains the actual lessons associated with that element in that particular classification (eg. disciplinary lessons, OSHA lessons etc.) that the organization has included. In this particular section, lessons are separated based on different concepts associated with that particular component. In the figure below (and on the site), the electrical conduit, discipline specific lessons are further classified based on the concepts like the offsetting a conduit, installation of conduit, support of the conduits,

etc. Lessons contained on this page are put in the form of small statements and the detailed explanation is provided in the link (read more, best practice etc.) attached towards the end of the particular lesson. In this particular example, lesson 2 is about the generally used bends of the conduits, if a person is interested to learn about the angles of the bends, he/she can simply click on “read more” button and learn about it. Similarly lesson 3 is about the installation and there is actually a lesson learned on site. Therefore, if the “lessons learned” button is clicked, it will take you to the page containing the lesson learned on the site with detailed explanation and all the information about the project etc.

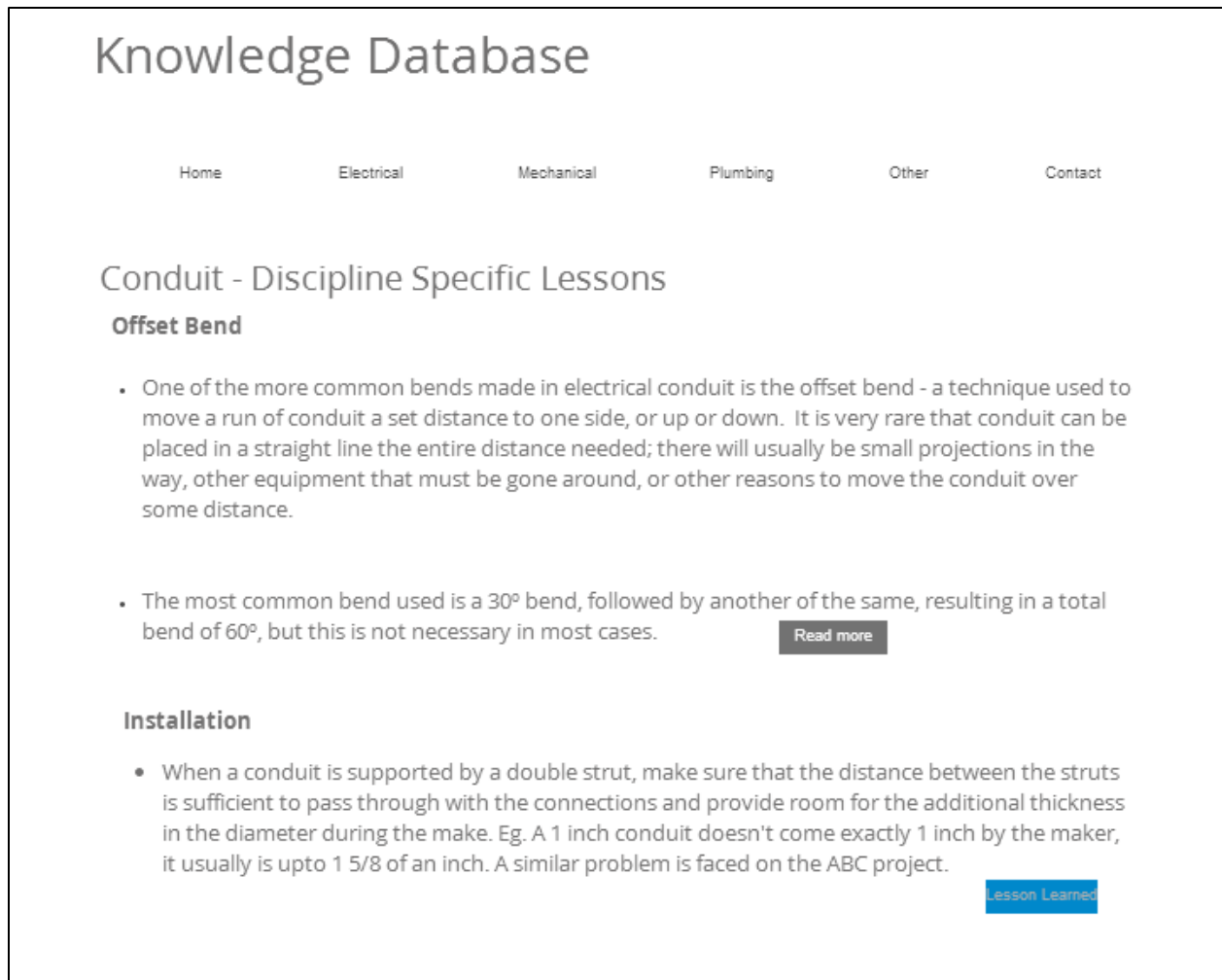


Figure 7.10 Discipline specific conduit lessons learned page of the blog

4. This page contains the lesson learned with complete details. The lesson is explained with the images in this example. The lessons can also contain explaining the situation and showing the actual site conditions. It can contain a link to another site where a full detailed explanation is present. The second section of this page contains the complete details of the project, where this situation has occurred, the project details, the location of the REVIT file, the location of the project, project id etc. The last section of the page on the website contains information about who created this lesson and the person who validated the lesson before posting it on the site.

Knowledge Database

Home

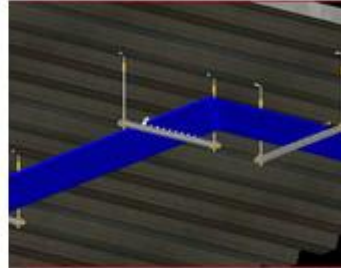
Electrical

Mechanical

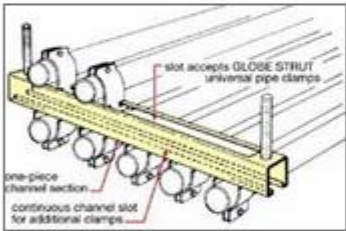
Plumbing

Other

Contact



Spacing when using a double strut



When a double strut is used, the conduits pass from between the struts. In this case the conduits were of 1 inch size and the a space of 1.5 inches was provided between the top and bottom struts. Routing of the conduits was not possible on site because the size of the conduits were 1 5/8 of an inch. Even if the conduits were one inch, space would not have been sufficient to make the connections.

Project Details

Name of the project: Project Airport Control Tower

Project id : REI-ACT

Mark: 1103

Location: Control Tower - Level 3 - San Francisco, CA.

Revit File Location: ftp://01.Internal_Folders/REI-ATCT/Central_File_03.03.2014.

Creator: Shreekanth Amireddy

Designation: Project Engineer

Email: shreekanth@alpha.com

Phone: 334-339-8877

Date: 02.15.2014

Validated by: Vinay Kumar

Designation: Project Manager

Email: vinay@alpha.com

Phone: 510-329-6432

Date: 03.01.2014

Figure 7.11 Description page of a lesson learned

Chapter 8 Conclusions and Scope for Future Research

The 2014 McGraw Hill SmartMarket Report shows that the construction industry worldwide has been advocating the use of Building Information Modeling. The report states that the stakeholders recognize the potential uses of BIM to minimize errors, increase profits and perform more efficient work. The report also shows that the construction industry has significantly increased the usage of BIM in the past decade with BIM adoption in North America rising to 72% in 2012 from 28% in 2007. The report also predicts that the contractor's usage of BIM will increase by 50% on average over the next two years.

With the growing awareness of the potential of BIM and its increased usage among various stakeholders, it seems logical that a knowledge management process developed with the use of BIM is likely to succeed. The methodology proposed in this study makes use of BIM as a tool to capture the knowledge generated in the projects, store them within the models at the locations where it is created and then extract it from the model, validate and store them in the knowledge base of the organization, where all the employees can access and reuse the knowledge to avoid repetition of mistakes.

The methodology has been applied in a BIM consultancy firm for a period of four months and has found to be a useful tool to assist the knowledge management program of the organization. The developed methodology served as a very helpful tool to capture and store the lessons in the BIM model. Some of the other advantages/applications included:

- 1. Elimination of Knowledge Loss due to time lapse:*

The proposed methodology advocates and rather facilitates storing the knowledge as soon as it is created. Many construction projects use BIM during all project phases and it is most

likely that a project engineer has to refer to the BIM model during the design phase and during the construction phase as it is being built. This is a very advantageous phenomenon to store any new learning in the model as the learning situation is created. Also, as discussed in the earlier chapters, the lesson entered into the BIM model can be informal and the project engineer can enter his/her understanding of the situation because all the lessons undergo validation process, where incorrect lessons are corrected and any missing information can be provided in detail by the subject experts.

2. *All knowledge created in a project is located in one model*

The literature review shows that knowledge is scattered across the project in various formats. For a user to find the required information he/she might have to refer to various sources (construction documents, RFIs, CAD files, emails etc.). The use of BIM helps in avoiding the problem as the BIM model contains all the necessary information about the project. And with the use of proposed methodology, the BIM model also contains all the knowledge learned/related to the project. In addition, the model may also contain a link to the necessary location in the knowledge base. An added advantage of the methodology is that the exact location of the lesson stored can be viewed in the 3D model. This helps in better understanding of the context of the situation. It can be a very important feature during the Post Project Reviews.

3. *Lessons can be grouped together based on users preference*

With the proposed methodology, the lessons added to the model can be viewed in the Revit Schedules. The schedules can be manipulated based on the user preference. The user can group together all the lessons about a particular element or lessons learned in a particular area of

the project or lessons about a particular concept/discipline etc. Also multiple schedules can be created based on the necessity/usefulness. The user can create a schedule containing lessons of a particular concept or a schedule containing all the validated lessons of the project so far can be created and viewed as the project is progressed. Or the user can create multiple schedules each containing lessons grouped on one particular thing/concept etc.

4. The Advantage of validation process

The project engineer, when entering a learning situation into the model, he/she doesn't have to worry about any research on the same because all the lessons are validated before entered into the database. Another advantage of the process include, if any learning entered into a model is a misconception or an incorrect information, the project manager/trade expert has an idea that a particular project member has a misconception about a particular topic. With that in mind, the particular concept can be discussed and explained in a Post Project Review or a knowledge session review. Also a schedule to discuss any topics or address any questions during a PPR can be created so that no learning opportunity is missed because of forgetting something due to time lapse.

5. No additional software is needed to implement the methodology. The organizations can use the same BIM model they built to store the lessons learned and they can use the same knowledge base they have to store/update the lessons.
6. This process requires no additional training or the training required is very minimal.
7. The project members can refer to the lessons at their convenience and increase their learning/knowledge about the subject from the BIM models.

The methodology can potentially overcome some of the drawbacks of current knowledge management tools, but for the successful implementation of the methodology, the organization has to:

1. Create a learning culture within the company. Any model can fail if the members of the organization do not use it on a regular basis. The management has to encourage its employees to use the methodology and create a culture within the company to make learning an exciting process.
2. The management should plan the expert's time properly. The experts should continue working on their projects as well as spend sufficient time in validating the lessons and adding additional content related to the topic as they review the lessons. The management should use the expert's time intelligently so that both the projects and the validation process do not get hindered.
3. Knowledge maintenance should also be given priority and should be done on a regular basis. And it is more beneficial if all the reviewed lessons are discussed in a post project review or a knowledge review session.
4. New employees should have an orientation program explaining the methodology and the management should encourage them to use the methodology for their learning of the subject.

Scope for Future Research:

The methodology developed as a part of this research is based on Autodesk Revit® platform, which is considered to be the most widely used BIM software in the construction industry. However, there are other BIM software like Bentley, ArchiCAD, Tekla etc., which are

widely used in the construction industry. Based on this study, similar methodology to capture, store and extract knowledge from the BIM model can be developed for other BIM software.

The successful implementation of the methodology in other AEC firms can be conducted as a part of future research. This study was tested in only one BIM consultancy firm. How successful the methodology can be in other design firms, with general contractors and sub-contractors etc., can be tested as a part of further case studies.

Studies may be conducted to see if one model for each type of construction (hospital, residential, schools, airport etc.) containing all the lessons from various similar projects is more useful versus one model for each construction project.

Software extensions which warn the user when a best identified practice is not followed or when a mistake is repeated during the design can be developed as a part of future research. These extensions can make use of the knowledge base of the organization. Extensions such as help guides which pop up on the screen when the user is working with a particular component in the software can also be developed. These help guides can contain all the lessons learned so far, best identified practices of construction, safety lessons etc., which the user can refer to during the design or construction of the facility.

Further studies can be conducted to develop to more organized knowledge bases which suit all type of AEC firms.

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