A New Business Process Model for Enhancing BIM Implementation in Architectural Design

Ibrahim A.I. Abdelhady

Dissertation submitted to the faculty of
Virginia Polytechnic Institute and State
University In partial fulfillment of the
requirements for the degree of Doctor of
Philosophy
In
Architecture Design and Research

Approved by

James R. Jones (Chair)

Elizabeth Grant | Kevin D. Carlson

Robert Schubert | Sean McGinnis

Sept 11, 2013 Blacksburg, VA, USA

BIM, Business Process Modeling, Information Workflow, Schematic Design, Design Development, Mid-Size Architectural Firms
IRB# 10-143

A New Business Process Model for Enhancing BIM Implementation in Architectural Design

Ibrahim Abdelhady

ABSTRACT

During the past few years, Building Information Modeling (BIM) started to gain acceptance within the AEC industry. But, as with many software products for project management, BIM currently faces significant issues and obstacles that hinder its widespread use. The broad goal of this study is to improve BIM implementation in mid-size firms during the Schematic Design (SD) and Design Development (DD) phases. The study has four main objectives. First, mapping the existing "As-is" BIM related process model in mid-size firms, and modeling the flow of information between BIM users inside these firms. Second, identifying the challenges that are currently facing BIM users during the Schematic Design (SD) and Design Development (DD) phases, because of the importance of these phases in making critical decisions that directly affect the building life cycle. Then, linking these challenges to a BIM related business process model in order to identify when and how these issues occur. Third, exploring the structural conditions that may change or affect the "As-is" BIM workflow. Fourth, the study proposes a new business process model that can enhance BIM implementation in mid-size firms.

The study is qualitative in nature, and based on interviews with a sample of BIM users involved in mid-size firms in the USA. The researcher attempted to capture BIM issues and the flow of information between BIM users through case studies and interviews inside their firms. Also, the researcher involved a new group of BIM users in the research to seek their feedback, in order to generalize the research results.

Dedications

to Mom, Mai, Omar and the Little Adham

Acknowledgments

I would like to express my deepest appreciation to Dr. Jim Jones, my advisor for the continuous support of my research, also for his patience, motivation, enthusiasm, and immense knowledge. His thoughtfulness, patience and guidance helped me in all the time of research and writing of this thesis. I also have to thanks him for being a brother and a friend to me. I don't know how I would have made it without him in many difficult and incomprehensible times. On a personal level, Jim taught me a lot of things that reformed my personality, changed my way of thinking and made me look in a different way to my life.

Besides my advisor, I would like to thank my committee members; Dr. Elisabeth Grant, Dr. Kevin D. Carlson, Dr. Sean McGinnis and Mr. Robert Schubert for all their encouragement, insightful comments, and contributions during my experience as a doctoral student. Their help, support, guidance, and advice throughout the research meant a lot towards establishing this goal.

My gratitude to my parents and my little family for their unconditional support, both financially and emotionally throughout my degree. In particular, the patience and understanding shown by my wife, she was always there cheering me up and stood by me through the good and bad times.

Last but not least, I would like to thank everyone who helped me in this research. Special thanks to Matt Davis, Raya Al-jadir, Mr. Dennis Jones, and Dr. Sedki Riad, for their continuous support and thoughtfulness.

Index

Chapter 1: Introduction

Chapter 2: Literature Overview: BIM Benefits and Challenges

Chapter 3 Business Process Modeling

Chapter 4: Method of Inquiry

Chapter 5: Data Collection and Analysis

Chapter 6: BIM "As-is" Model

Chapter 7: Workflow Structural Conditions

Chapter 8: BIM "To-Be" Related Mode

Chapter 9: Developing Technology Domain

Chapter 10: Conclusion

Appendices

Index of Figures:

Index of Tables:

Chapter 1

Introduction

1.1 Introduction

Today, there is little doubt that Building Information Modeling (BIM) is a new technology that is reshaping the building industry. BIM has emerged as a useful tool for architects, engineers, and contractors in the delivery of new constructions. BIM is an innovative tool that most design and construction professionals do not currently use on a regular basis. According to the Smart Market report, in 2008, architects were the most frequent BIM users with 54% usage (McGraw-Hill 2008). However, as those professionals increase their understanding of BIM and its capabilities, BIM will likely become a part of common design and construction practices. For example, in the past BIM has mainly been utilized by architects and structural engineers, but recently it has been used by plumbing system designers, mechanical and electrical engineers. BIM can be used to support integration between team members as well as collaboration in the early phases of design, therefore it has the potential to reduce the number and severity of problems associated with traditional construction delivery practices.

According to the Smart Market Report, BIM has various advantages over the current CAD drafting systems. These include conflict resolution (clash detection), better collaboration, more accurate cost estimation, etc. However, full implementation of BIM will likely require significant changes in the management structure of architectural offices and relationships between BIM players (Eastman 2008). On the other hand, BIM, like many other products in the project management software industry, currently faces significant issues and obstacles that prevent its widespread use. These issues include inappropriate adaptation strategies, old management and organizational structures, and slow software development. There arises the need for businesses to assess and rethink their existing processes, communication mechanisms and information flow strategies in order to fully avail themselves of the opportunities that

BIM has to offer. This may involve the means to smoothly shift from existing CAD platforms, and how to find the precise changes that can prompt architectural offices to improve their existing business processes, and develop strategies that are flexible enough to incorporate BIM as it evolves.

Based on these requirements, there is a need for new business process models that supports Business Process Re-engineering (BPR) for BIM. The need has emerged for a new business process model, which is able to illustrate how, with the use of BIM, different members of a mid-sized architectural firm could derive benefits and overcome traditional process inefficiencies. In order to effectively adopt BIM in such firms, a redefinition of their current business model is required, one that could lead to a significant change in the work practices.

To facilitate this change, first it is important to map the BIM implementation challenges that are currently present in mid-sized architectural firms as they relate to how information flows, BIM related activities and the subsequent mapping of the existing business processes model. For this, two case studies and several interviews were conducted. The case study findings helped to develop the existing business model and to identify challenges associated with BIM implementation, and the potential areas for improvement, especially those ineffective processes at the departmental boundaries. Then, based on the business process modeling criteria, the researcher developed a new business model that will support better BIM implementation and help to overcome current problems while providing a new coordinated flow of activities performed by firm members that can traverse functional or departmental boundaries while at the same time, ensure flexibility. Next, the researcher sought feedback from the case study participants, and the model was subsequently redeveloped based on this feedback. Finally, the research conclusions, recommendations, and outcomes are presented.

Before summarizing these steps, this chapter first introduces Building Information Modeling (BIM) and Business Process Modeling (BPM) definitions. It also explores the need for change within the architectural industry. Furthermore it defines the problem statement addressed in this dissertation and explores the scope of the research in the context of its architectural design relevance. The chapter represents the overall structure of this dissertation. The next section defines BIM in the context of this research.

1.2 BIM Definition

Building Information Modeling (BIM) is a confusing term that is not familiar to most people (Eastman, 2008). Few are aware that BIM is a virtual representation tool sold by vendors, which enables data for manufacturer's details to be imported directly into project design, and presents 3D models of products in place in the building (Jernigan, 2008). Additionally, it provides the ability to add and access detailed imagery and information to everyone involved in the design and construction processes. At the same time, it is known that BIM is not limited to 3D applications but it is a compatible process for achieving real-time collaboration between the different project parties (Jernigan, 2008).

Thus, according to the first view, BIM is an object-oriented approach to computer-aided architectural design, the Associated General Contractors of America defined BIM as "*a data-rich, object-oriented, intelligent and parametric digital representation of the facility that allows views and data appropriate to various users' needs to be extracted and analyzed to generate information, which can be helpful in making decisions and to improve the process of delivering the facility*" (AGC, 2005). Furthermore, some researchers define BIM as a tool that simulates the project construction in a virtual environment. Chuck Eastman, in his BIM handbook, supported this concept by defining BIM as "an accurate virtual model of a building that is digitally constructed, that model contains precise geometry and relevant data needed to support the construction, fabrication and procurement activities required to realize the building" (Eastman *et al.*, 2008, p.8).

A BIM model is a multi-purpose tool that can be used in different types of analysis and simulation purposes, which makes it very powerful, intelligent, and functional for most AEC users. Due to this, some government clients and different organizations currently have begun to define BIM and set up "National Standards" to support the BIM approach. According to NBIMS (National Building Information Model Standard) *"BIM is a computable representation of all the physical and functional characteristics of a building and its related project/life-cycle information, which is intended to be a repository of information for the building owner/operator to use and maintain throughout the lifecycle of a building"* (NIBS December, 2007, p.7). Furthermore, the Associated General Contractors Guide defines BIM as *"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, 2007, p.3).

The American Institute of Architects has defined BIM as *"a model-based technology linked with a database of project information".* This reflects the general reliance on database technology as a foundation. In the future, it may be possible to search structured text documents, such as specifications, and link them to regional, national, and international standards (AIA, 2009). The US General Services Administration also defines BIM as *"the development and use of a multi-faceted computer software data model that not only documents a building design, but simulates the construction and operation of a new capital facility or a recapitalized facility. The resulting Building Information Model is data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback on and improvement to the facility design"* (GSA, 2007).

Underwood and Isikdag identified the main objective of BIM as to have an easily accessible set of information about a product. This information has to be formal, consistent, non-ambiguous and non-redundant to enable the smooth exchange of this information among all model parties throughout the entire building project life-cycle. (Underwood and Isikdag, 2010,, p.36). This requires a state of stability and clear identification of functions and participants' roles to minimize conflicts, redundancy and loss of information.

1.3 Importance of BIM to the AEC industry

Recently, BIM systems have replaced CAD 2D symbols with building elements (objects) that can be presented in multiple views and at the same time have non-graphical attributes assigned to them. According to Howell and Batcheler this adds intelligence to the model itself:

> *"The inclusion of parametric 3D geometry, with variable dimensions and assigned rules, adds "intelligence" to these objects, permitting the representation of complex geometric and functional relationships between building elements…"*

So, BIM includes all its physical, functional characteristics and project life cycle information in one model; we can simply call it a *"Smart model"* (Howell, 2006, p: 1).

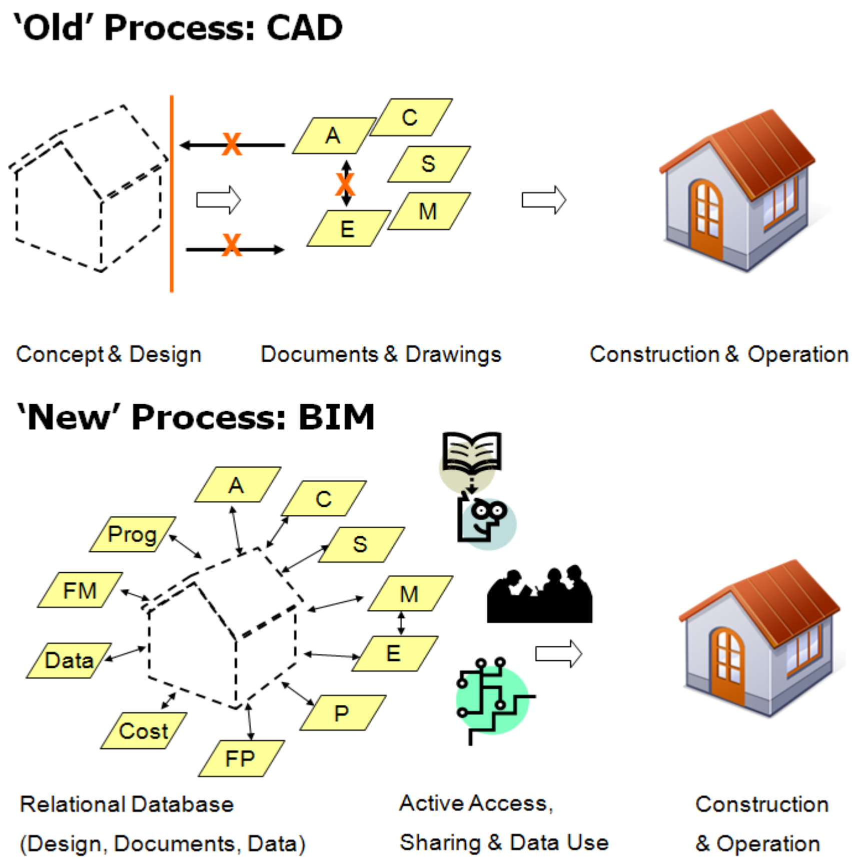


Figure 1.1 Comparison between Conventional CAD and new BIM Approach.
Source: (Howell, 2006)

Because BIM usually offers advantages over CAD, BIM is being broadly adopted across the construction industry. In 2008 the majority of BIM users were architects with 43% supporting more than 60% of their projects, while contractors represented a minority with nearly half (45%) using it on less than 15% of their projects and a quarter (23%) using it on more than 60% of their projects.

According to the Smart Market Report, BIM usage grew rapidly in 2009. Nearly half of all 2008 adopters (45%) became heavy users of BIM in 2009, using it for at least 60% of their projects. This is a 10 percent increase over the previous year. (McGraw-Hill, 2008)

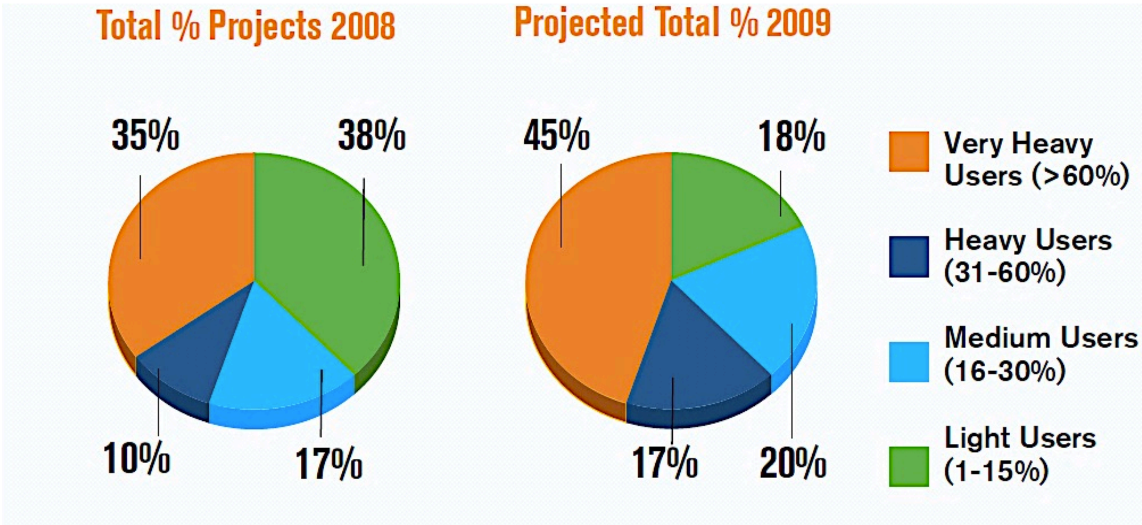


Figure 1.2 Growth of BIM in 2008 and Growth Expectations in 2009

Source: (McGraw-Hill, 2008)

BIM has started to become mandatory for the construction industry, while some US governmental divisions require the submission of the IFCs that include exchanges between the different BIM platforms (energy analysis, collision checking, etc.) attached to the construction documentations. Yet other divisions have moved forward and mandate BIM for specific types of projects. For example, the Division of State Facilities in Wisconsin announced the Guidelines and Standards for BIM implementation on July 1, 2009, which requires that all constructions (new and addition/alteration) with total project funding of at least $5M must apply BIM. In addition, it is required on all new construction with total project funding of at least $2.5M. Furthermore, BIM usage is encouraged but not required on all other projects (The State of Wisconsin June 17, 2009).

The State of Texas has also put forth similar requirements. The Texas Facilities Commission (TFC) announced that a BIM model is required for all state design and construction projects after September 2009. The TFC oversees the state's real estate development as owners and operators of its facilities, providing extensive real estate master planning and development strategy for the State. At the time of this writing, the

Facilities Design and Construction division was managing 125 projects valued at a total of over $500 million (Yoders August 13, 2009).

In addition to the governmental divisions' BIM mandate, BIM can also be applied to support solutions for sustainability/LEED, which is another mandate of the federal government's General Services Administration (GSA). The agency requires that all submitted projects meet specific energy performance goals and all new construction projects and substantial renovations to be LEED-certified (GSA, 2009). Here, helpful in analyzing the evolving design, BIM can document sustainable characteristics of the project during any design phase to help achieve the specific credits sought for LEED certification.

1.4 The Need for Change in the AEC Industry

It has been mentioned that the AEC industry is an intensive information exchange environment which involves cross functional and inter-organizational activities (Anumba, 1999, p. 37-44) (Lottaz, 2000, pp. 1-24), where the information is being rapidly exchanged between the different project entities, such as; client, architect, structural designer, cost engineer, facility management engineer, LEED engineer, fabricators, subcontractors, contractor and material suppliers. Thus, the BIM user has to manage all those types of information exchange. Figure 1.3 illustrates the communication network and exchange of information between architectural/construction project entities.

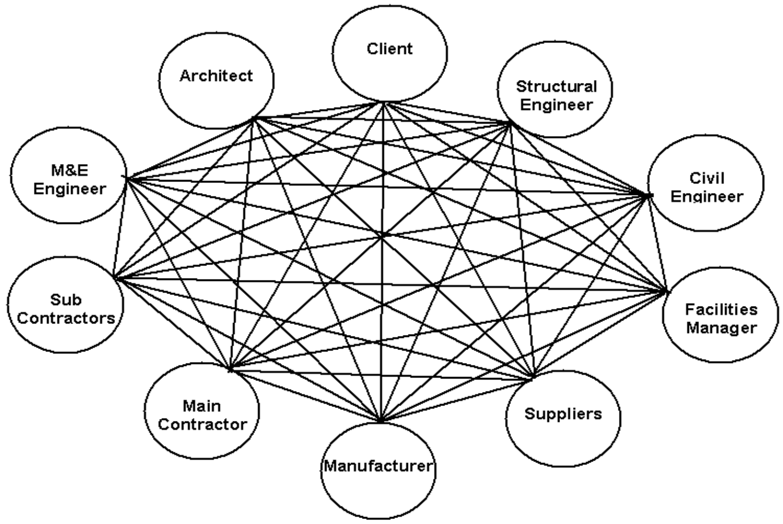


Figure 1.3 Complex Communication Network between Architectural/Construction Project Members. Source: (Jernigan, 2008, p. 197 – 212.)

Thomas et al States *"as a project grows larger in size and budget, the exchange of information gets more complicated and the possibility of communication failure also increases"* (Thomas Ng, 2001, p. 3). Smith similarly indicates that it is important for the architectural/construction industry to formulate new efficient and effective business processes in order to improve co-ordination between various project partners, while BIM as a process is supposed to help overcome these fragmentation issues and communication barriers, it has not reached the state of full implementation (Smith and Tardif 2009). Thus, it was important for this research to develop a new process model to improve BIM implementation, and to find some new effective ways to enhance methods of communication between BIM entities, which should help to increase efficiency and productivity of construction projects from the early stages of the architectural/construction project.

1.5 Business Process Modeling (BPM)

Business Process Modeling is an organizational mapping method and a core enabler for any new initiative that helps to improve both organizational efficiency and quality. Its beginnings were in capital/profit-led business, but the methodology is applicable to any other organized activity. Business Process Modeling has specific techniques that are usually concerned with mapping the organizational structure and the information flow to enable understanding, analysis and positive change.

According to Smith and Fingar, a Business Process Model (BPM) can be defined as "a flow diagram that shows events, actions and links or connection points, in the sequence from end to end. Resources are featured within BPM in terms of how they are processed. People (teams, departments, etc.) are featured in a BPM in terms of what they do, to what, and usually when and for what reasons, especially when different possibilities or options exist, it is across functional flow diagrams that usually combines the work and documentation of more than one department in the organization" (Smith and Fingar, 2003, p. 13). Thus, business modeling is first concerned with the actions or the events that occur to start a process, then the processes that gets performed, and the end results of the process flow. Most of the time the process flow is branching to other events, which makes sequencing in the process modeling a significant and essential factor to most aspects of a model, that helps to draw a big picture of the firm work flow and see how all the model elements work together.

1.6 Benefits of Business Process Modeling

The business process-modeling diagram has various benefits, such as:

1. Supports better and quicker understanding of the workflow by non-stakeholders.
2. The business process modeling diagram bridges the gap between how the work flows inside a firm and the complexity of the various business languages (Raj 2003).
3. Helps to achieve quality discussions among teams based on defining workflow, roles and responsibilities among employees.
4. Reflects the organizational limitations and errors in the workflow in a more structured way that helps to come up with sustainable competitive advantages (Raj, 2003).

Although the process model can be presented in a simple way in order to help non-stakeholders understand the workflow, it is also important to mention that sometimes the model flow can be complex and contain sub-processes, which can be shown by another Business Process Diagram linked via a hyperlink to the main model. In some models, the process may have the mark "+" which denotes the decomposition of this process into sub-processes, but if it doesn't have a '+' mark, it can be considered as a simple task.

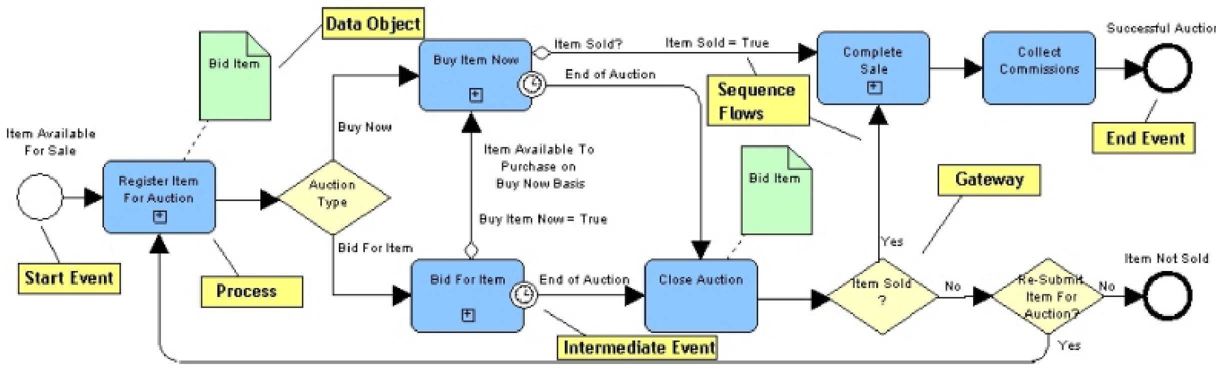


Figure 1.4 Simple BPMN Business Process Diagram for an on-line auction system. Source: (Patrick C. Suermann, 2007)

BIM business process models have not been introduced for the architectural field. Even though, business process modeling is not significantly different than preparing a construction schedule for an architectural project, such a model has not been developed for BIM use in mid-sized architectural firms. Each architectural firm typically has its own activities, which are predefined, and these have a critical path of workflow during the project timeline. This is similar to Dana Smith's argument that "Business leaders who are accustomed to using construction scheduling software may find it very easy to use business process modeling software. These programs allow detailed business processes to be conveniently presented as higher-level business summaries. Whichever tools are used, it is important to track the time and cost of the building process modeling effort, so that eventually the return on investment can be measured."." (Smith and Tardif, 2009)

1.7 Problem Statement

Although BIM has various implementation and management issues, companies across the AEC industries are increasingly leveraging BIM to achieve competitive advantage (Eastman 2008). On the other hand, Business Process Modeling is being used to manage architectural /construction projects, to monitor activities, and to map the information flow. Thus, this research seeks to identify BIM management and communication structural constraints during the Schematic Design (S.D) and Design Development (D.D) phases. The objective of this work is to identify these challenges and constraints, map the existing workflow as it relates to BIM use, identify the variables which could change or influence the existing workflow, and then develop a proposition for a new Business Process Model (BPM) to overcome BIM barriers related to BIM implementation. The proposal is grounded in the proposition that these barriers currently limit full BIM implementation.

1.8 Research questions

To develop an explicit and flexible business process framework that aims to improve BIM implementation in the mid-size architectural firms, the researcher sought answers to at least four main research questions. These questions are presented here.

- What factors associated with this model become barriers and constraints to full BIM implementation? (Identifying the different BIM challenges)
- What is the structure of an As-is Business Process Model (BPM) that is used in architectural offices? (Mapping of "As-is" model)
- What factors associated with the As-is model would impact/change the As-is model (Identifying the model structural conditions)
- What would be the new process model to support the enhanced implementation of BIM? (Developing new "To-be" model)

1.9 Research Objectives

The goal of this research is to answer the four above-mentioned research questions with regard to helping mid-sized architectural firms to enhance BIM implementation. Therefore, this dissertation has four specific research objectives:

1. Mapping the existing challenges that limit BIM implementation during S.D and D.D. phases in mid-size architectural firms.
2. Mapping the existing workflow as it relates to BIM implementation (as-is model) for mid-size architectural firms.
3. Identifying the variables and structural conditions that would impact or change the existing workflow.
4. Developing a new model that supports BIM implementation in mid-size architectural firms.

These objectives are elaborated on in the following section.

1. To map the existing challenges that limit BIM implementation.

The researcher conducted two case studies and several interviews in an attempt to map those challenges for mid-size firms. Whereas, the researcher observed the day-to-day operations, team interactions and communication exchanges as they relate to project design development and construction management using BIM. Moreover, a survey was conducted to request additional information from participants concerning their point-of-view concerning the challenges for BIM implementation.

2. To map the As-is business process model for mid-size architectural firms

The process model presented here is believed to be the first such model, and could be used in the future as a reference for further research for different business processes in the architectural/construction filed.

3. Identify the model structural conditions: Although the generated "As-is" model should be generic to reflect BIM-related workflow in a broad number of mid-size

firms, the researcher found that it is also important to identify the model structural conditions, where these conditions may influence the As-is model and change the workflow. Thus, a qualitative approach has been used to identify these structural conditions (the different business contexts).

4. To develop a new model that supports communication improvement in mid-size architectural firms: Feedback from stakeholders and BIM managers on the developed model was gathered. The model was updated and redeveloped based on this feedback. The final conclusions related to this to-be model is presented in the last chapter of the dissertation.

1.10 Research Methodology

Based on the goals of this research the methodology evolved as the dissertation progressed. The main goal of this dissertation is to evaluate and map the business process as it relates to adopting BIM in mid-size architectural firms in the USA. A set of objectives was defined to meet this goal, and to give a clearer perspective on how the dissertation would be approached and to define the project scope.

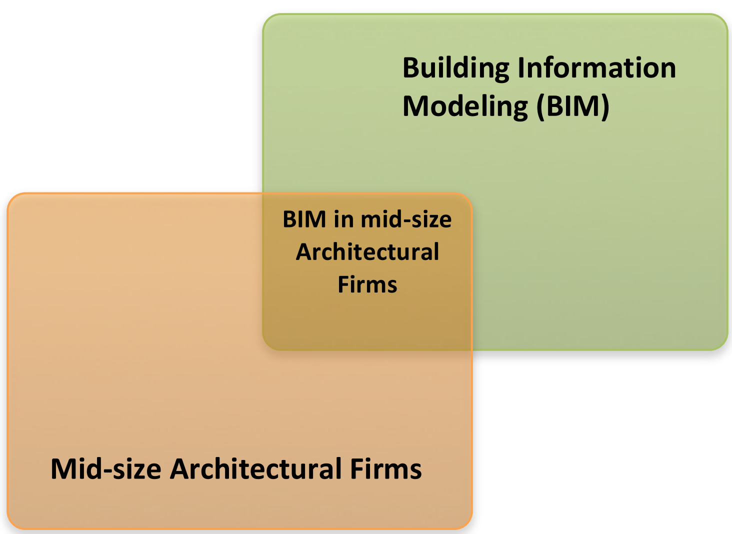


Figure 1.5 Venn diagram and Areas of Interest for the first objective.

Source: Researcher

The first research objective was focused on exploring the implementation of BIM in general and its particular opportunities and challenges in the AEC industry. The areas of interest for this objective and the overlap between these areas are illustrated using a Venn diagram (see Figure 1.5). A Venn diagram identifies the major methodological and topical components that were explored and studied in the dissertation. Each Venn square represents a specific area of study (Schooley 1995). Whereas the research subject matter is the shared common areas that is located at the intersection of these two areas, forming a new topic of interest.

To meet the first objective, a comprehensive review of the relevant literature with information drawn from different sources including research and industry publications was conducted to determine the general challenges and advantages of using BIM. Based on this information, the researcher started the data collection phase by conducting a survey to explore the influence of these constraints on BIM quality within a sample of several BIM users inside the US in 2010. The survey was prepared using a qualitative approach based on the information derived from the literature review. The survey was distributed using personal and phone interviews.

1.11 BIM and Business Processes Modeling (BPM)

The second objective for this research was to map the existing business process model in mid-size architectural firms as it relates to BIM implementation (Figure 1-6). This objective was met using a qualitative approach. The work carried out was done concurrently and iteratively as deemed necessary as the research evolved. The research comprised of two detailed case studies of mid-sized architectural firms trying to implement BIM. These case studies focused on the current methods of document exchange and communication related to BIM use between members in two mid-size firms. The analysis of the data collected from these sources helped identify the shortcomings in the current business processes and the complexity of the existing communication and document exchange models within architectural offices, but they were not sufficient to model the whole BIM related workflow in both the S.D and D.D phases. Thus, the researcher conducted another series of interviews to complete the layout of the as-is model and to gather more information about information exchange between members.

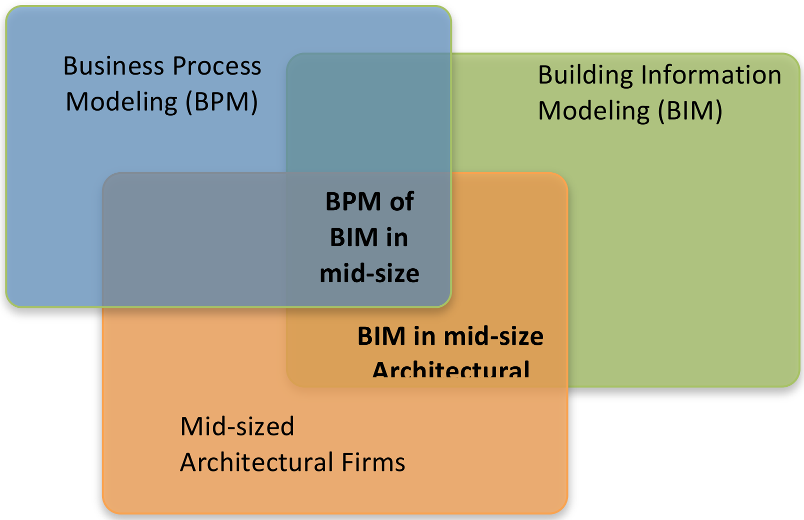


Figure 1.6 Areas of Interest and overlaps between these areas for the research second objective Source: Researcher

1.12 Research Scope

This study is qualitative in nature and it will focus on the following parameters:

1.12.1 Design Phases: Schematic Design and Design Development phase:

> *"All the big mistakes are made in the first day"* Paul Adams, A.I.A, (Jernigan, 2008, p.28)

Both the Schematic design phase (S.D) and Design Development phase (D.D) are critically important in making decisions that could directly influence the final design of the building and its quality. Thus, if efforts were focused to minimize or eliminate early stage mistakes, this possibly would help in gaining significant benefits. Moreover, no doubt that during the Schematic Design and Design

Development phases, while information is rapidly being exchanged between team members, the team members are under enormous pressure to make decisions in a limited time frame; these decisions are critical and could affect the performance of the facility throughout its life cycle. Also, while there is a high probability of frequent design changes, timing is critical to improving design quality. By improving BIM implementation during these two phases, it is expected that the team members will be able to avoid redundant efforts, minimize the time for preparing project documents and subsequently allowing more time for making design decisions.

1.12.2 Project types

This study focuses on mid-size to large scale projects (commercial buildings, educational, etc.). These projects were chosen as a limit for this research for two reasons.

a) Due to the complex nature of mid-size and large-scale construction projects, the number of communication issues that might typically emerge is more than for small-scale projects. BIM is substantially used in large projects and many stakeholders are typically involved during the design phase. Each stakeholder brings expertise in a specific decision-making area. Thus, it is expected that for these projects the vast majority of communications occur within the architectural firm and with other functional parties and this will reveal issues related to BIM implementation.

b) Adapting BIM in today's architectural firms adds cost to the overall project budget, consequently the design firm typically will try to pass this increase in cost on to the clients who will pay more, only when they perceive value for the added cost. But for now, it can be difficult to demonstrate the future benefits of BIM for small projects. For example, one potential advantage of using BIM is that it may help minimize the cost of operating the facility after occupancy. Yet for commercial or residential projects, the owner usually has no direct incentive to increase the energy efficiency of their buildings because he/she usually can pass the cost of operating their buildings to their tenants.

1.12.3 Firm size

According to Demkin, small-size firms in the US usually contain 5 people or less, and typically they have no formal organizational structure, while medium-sized firms usually operate with 5 to 50 employees organized structurally in different departments such as design, production, business development, and construction administration. Then, large architectural firms contain over 50 people structured in studios specializing in project types, and they may be distributed in satellite offices (Demkin and American Institute of Architects. 2008).

The scope of this study was limited to the medium-size architectural firms (5 to 50 members) for the following reasons.

a) Given the research time constraints, the number of communication exchanges and BIM implementation issues that might typically emerge between large-size firm members (+50 members) may consume more time than what is available for this research.

b) According to DesignIntelligence.com, the number of small firms in the US is 16 firms out of a total of 895 architectural firms (less than 2%). Thus, focusing on BIM implementation issues and BIM workflow in these firms may be less important for BIM experts and users in the US market (DesignIntelligence, 2012).

1.12.4 Research Sample

The research sample was limited to two case studies from purposefully selected architectural offices. In addition, the research included multiple-type interviews with different BIM users within two rounds of structured and semi-structured interviews.

1.12.5 Geographic Area

The focus of the study is limited to the North American continent.

1.13 Approach

This research employed a qualitative method based on the grounded theory approach, in which a setting of interest was entered without preconceived notions. Through observations, the researcher documented and interpreted the challenges of BIM relating to communication during the Schematic Design and Design Development phases. Also, a new proposed workflow was drawn based on the interpretation of the findings. One important feature of the grounded theory is that it is open ended. Moreover, it has a sequence of three phases; data gathering, coding and theory building. The researcher proceeded back and forth between data gathering and coding to examine the data and sort it, before reaching the final research output.

This research proposes a new process model for the full implementation of BIM. The study included the following phases (Fig 1.8)

1. Literature Review: literature review helped identify the main advantages and barriers to the full implementation of BIM within the mid-size architectural firms, which is important for informing the data collection phase.

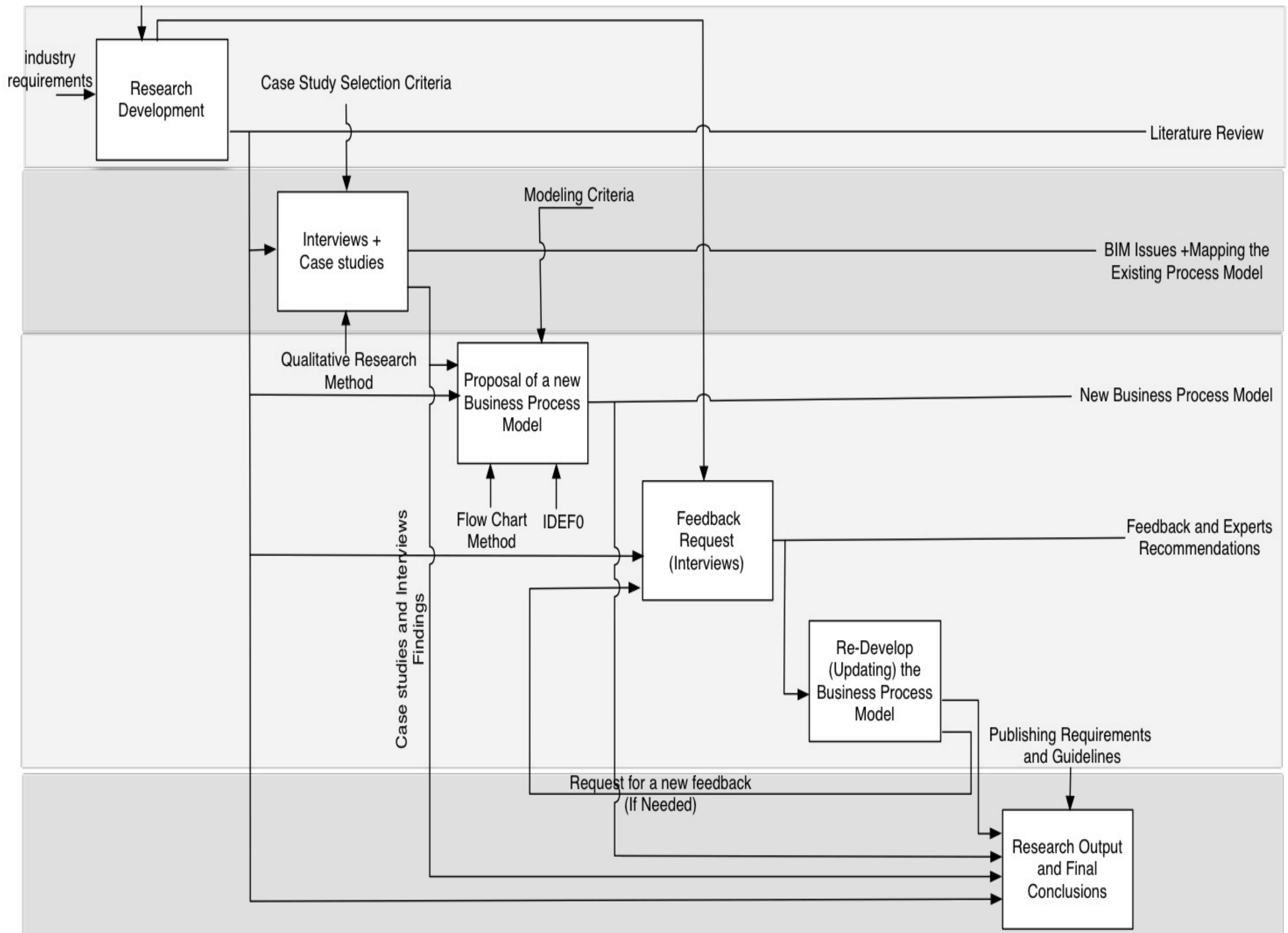


Figure 1.7 Layout and the Purposed Process Model For This Dissertation Source: Researcher

2. Data Collection: Although the literature review was not one of the formal data collection methods, it helped formulate the interview questions and the criteria for the case studies, this is in order to map challenges and build on the existing process model for these firms.

3. Data interpretation and data analysis: Using a qualitative approach, the researcher generated the As-is BIM workflow that highlights challenges of communication and the current limitations for the use of BIM during the Schematic Design (S.D) and Design Development (D.D) phases.

4. Developing the To-be model: Using an interpretative approach to develop a new process model that assesses the chances of enhancing BIM implementation.

5. Research Feedback: The last phase of this research was a survey that sought feedback for convergence of opinion for the proposed model. The model was redeveloped based on the feedback received.

1.14 Summary

This dissertation focuses on revealing the operating challenges that limit getting the best use out of BIM. Then, a new business process model is purposed that helps architectural firms to better adapt BIM. BIM is a new collaborative environment that requires architectural firms to change their structure and information flow. Thus, this research seeks to identify the BIM issues that limit implementation, mainly during the Schematic Design and Design Development phases.

While focusing in the Schematic Design and Design Development phases, BIM helps to identify mistakes very early. Moreover, BIM has a broader scope and is believed to have the capabilities to automate the entire building lifecycle. Such capabilities are paramount especially in these early stages, which is the earliest and the most determinant phases in the basic services for the building design process. From these phases onwards, the decision-making is formed and the remaining phases are based.

Chapter 2

Literature Overview: BIM Benefits and Challenges

2.1 Introduction

Usually, any construction project reflects the needs of different parties; the owner has his/her own goals and business plans, the architectural firm seeks to improve the architectural quality, reduce construction risks and improve the construction cost/time efficiency, while the contractor is trying to obtain the highest profit out of the construction process. Those goals need to be managed and harmonized. BIM is a tool, with the potential to achieve those goals.

BIM has been defined in various ways, and has a range of features, which can make the architectural/construction process clearer for all of the project parties. By using a 3D model in any phase of the construction, we can notice what has been achieved in any section of the building, how the construction process will go, and what the expected challenges are. Thus, a key benefit that comes out of using BIM for all the team members is that errors can be easily detected. However, at the same time, BIM can become a big challenge for team members who do not understand how to get the most out of BIM.

This chapter defines BIM, documents how important BIM is to the construction industry, and what are the benefits of using it. Also it discusses various BIM domains and states the overall challenges associated with three domains of BIM.

2.2 BIM features

Who will benefit by enhancing BIM implementation during the Schematic design and Design Development phases, and subsequently who might apply the results of this study? Smart Market Report shows that architectural, structural, mechanical and plumbing system designers' .in that order. are the most likely to use BIM. In 2008, architects were the most frequent BIM users with 54% usage. Engineers are slightly behind with 43% of all engineering disciplines using BIM. Electrical engineers lag behind mechanical and structural users (Figure 2.1), because typically electrical design elements are relatively small when compared to bulky structural systems, as well as that electrical coordination or modeling issues are often less critical than other systems (McGraw.Hill 2008).

As shown in figure 2.1, the expectation for 2009 was that two-thirds of architects would be either heavy or very heavy users, and that engineering was expected to see a 37% increase in usage.

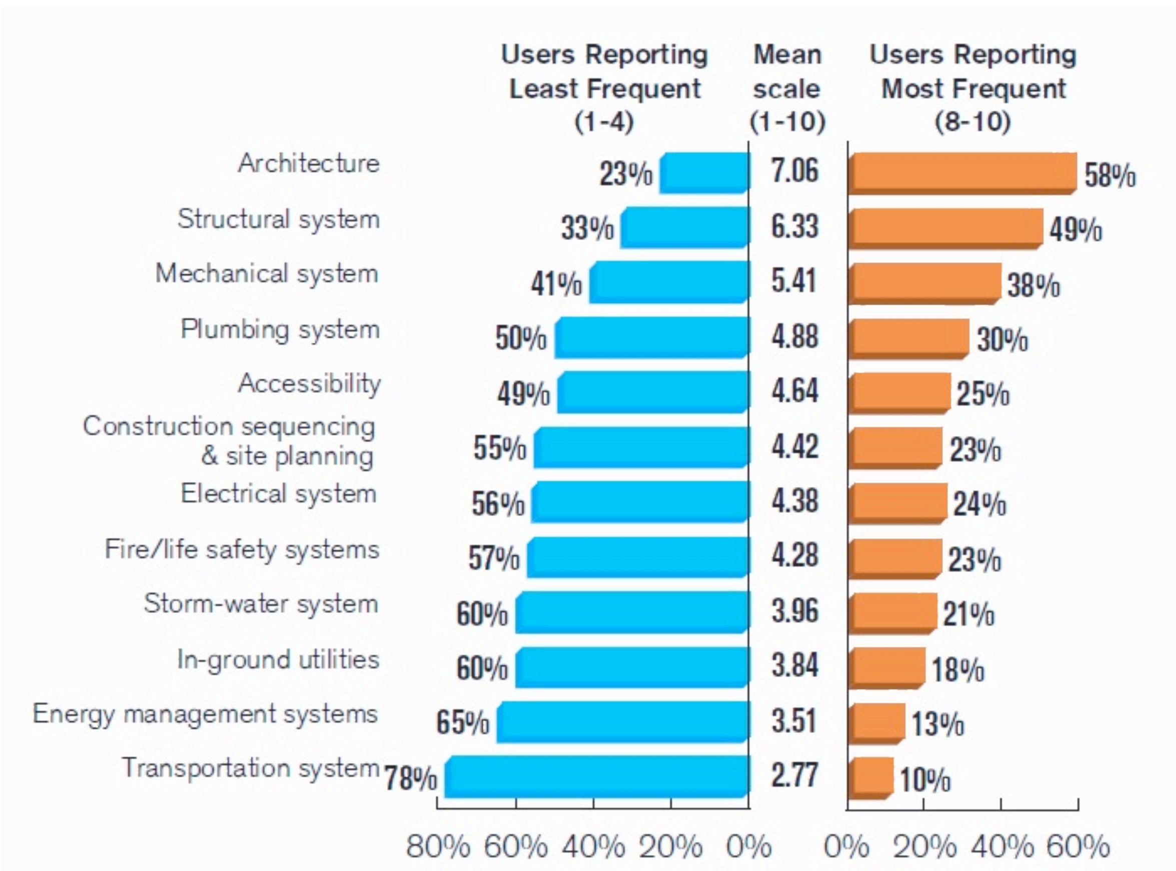


Figure 2.1 BIM Users and Frequency of Modeling Elements with BIM.

Sources (McGraw.Hill, 2008)

2.3 BIM Advantages

After more than ten years of BIM use, it is clear that BIM has started to reach a certain level of maturity. Several BIM products are now available to serve various fields such as architecture, structural engineering, MEP engineering, and construction. On the other hand, an increasing number of developers are working on supporting technologies to extend BIM capabilities to cover different aspects of design, planning, and construction. Here, we will classify the major advantages of BIM (Figure 2.2); these advantages will be outlined and classified throughout the S.D and D.D. project phases.

2.3.1 BIM Advantages during the Schematic Design Phase

Compared to the other project design phases, the advantages of using BIM in the Schematic Design phase are relatively limited. Some advantages of BIM in the Schematic Design Phase are reviewed.

1) Model Visualization (2D and 3D)

BIM is a design technology that has replaced CAD drawings with an intelligent 3D computer model that contains structured information for both quantitative information (length, area, volume, and etc.) and qualitative information (material, contents). This may comprise all the design elements such as architectural, structural, electrical, mechanical, and construction process management. Blueprints and 2D information (plans, sections, elevations, etc.) as well as all other construction documentations (list of materials, specifications, reports, and estimates) can be easily generated from the same BIM model.

2) BIM and Cost estimation

Although cost estimation typically falls within the scope of work of the cost estimator, and includes material takeoffs, cost estimation is an important feature that helps architects making critical decisions in the early stages of the project. BIM has replaced manual takeoffs, counts, and measurements by generating cost estimates and materials quantification directly from the underlying model, which saves time spent by the estimator on digitizing the architect's paper drawings, or importing their CAD drawings into a cost estimating package (Autodesk 2007).

2.3.2 BIM Advantages during the Design Development Phase

According to the state of Wisconsin, department of Administration Division of State Facilities (DADS) report on the current state of BIM technologies and recommendations for implementation, the Design Development phase is one of the most critical phases in the building life cycle. When compared to non-BIM projects, BIM projects are developed to a significantly higher level of details in the Design Development phase, which adds more value and confidence to the design solutions, in addition to less revisions later in the construction documentation phases (The State of Wisconsin June 17 , 2009). In the next section, we will summarize some of the major advantages of BIM during the Design Development Phase.

1) **BIM for Sustainability (BIM and LEED)**

Although the intense analysis of a sustainable design proposition usually takes place in the Design Development phase (D.D), the foundation for sustainable design starts from the Schematic Design phase (S.D.) As a collection of software, BIM can support sustainable design through performance analysis. For example, linking BIM to energy analysis applications helps to evaluate the projected use of energy throughout the building life cycle. This integrated approach was not possible when using traditional CAD tools.

Another important feature of BIM applications is their ability to convert the model into non-proprietary formats that contain important design information. Formats such as Green Building XML (gbXML) are supported by various BIM products to enhance the design for LEED compliance and other sustainability goals. Krygiel and Nies indicated that BIM can aid in the following aspects of sustainable design (Krygiel and Nies 2008).

a. **Building Orientation** (to select the best building orientation that results in minimum energy costs)

b. **Building Massing** (to analyze building shape and optimize the building envelope)

c. **Day-lighting analysis** (Data analyses of daylight and shades that result in energy saving)

d. **Water harvesting** (to reduce water needs in a building)

e. **Sustainable materials** (to reduce material needs and to use recycled materials)

2) Energy modeling and HVAC design

To reduce energy needs and analyze renewable energy options such as solar energy, air conditioning/air ventilation, heating, etc. Preparation for these energy performance analyses usually starts after architectural and HVAC design have progressed sufficiently to provide the required information to simulate the building, or at least have the required information or the fundamental design decisions that will be employed to start modeling. HVAC design tools have to import the original building geometry from BIM to create the thermal analysis of the building, and then identify building zones that have one or more spaces, which behave thermodynamically similar. The purpose of this is to adapt the designed HVAC systems to the geometries of the thermal zones, which they serve (Krygiel and Nies 2008).

According to the Smart Market Report, most green project designers (57%) find BIM provides a high level of assistance with their sustainable projects (Figure 2.2). Moreover, as BIM continues to develop, software developers and technology providers are working to enhance BIM to track LEED credits, and to address the sustainable design and construction demands (McGraw-Hill, 2008).

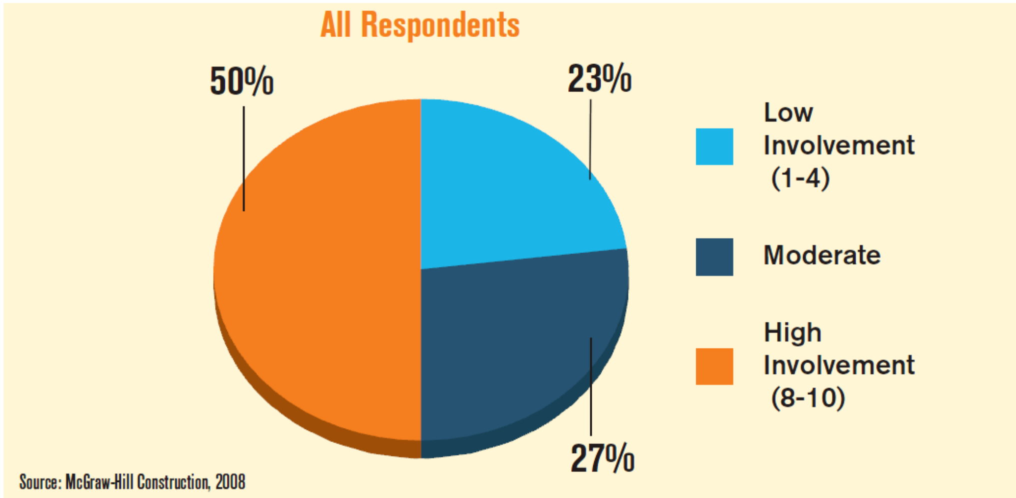


Figure 2.2 BIM involvements in Green projects. Source (McGraw-Hill, 2008)

3) BIM for Mechanical/Plumping Design

BIM offers a collaborative environment for MEP engineering in which they can work and extract drawings and documents directly from the model. BIM also helps engineers to design and simply modify their design by moving, editing, or dragging design elements directly on the screen. Subsequently all model views, drawing sheets and MEP documents are automatically updated whenever a change is made on the model. This is an important BIM feature, which is known as the "Parametric Change Engine" (Autodesk, 2008).

BIM displays the layout of the mechanical system, so that users can get instant feedback on their designs and also can perform many engineering calculations directly in the model. For example, ducts and branch calculations, sizing main and fan sizing are analyzed using American Society of Heating, Refrigerating and Air.conditioning Engineers standards (ASHRAE.) Furthermore, a BIM analysis can automatically suggest a suitable modification for enhancing the design, such as, providing duct and pipe routing solutions between any two points. The software can help the designer find multiple suggested routing paths . allowing him to choose the best solution that improves the design, enabling it to reach its maximum performance and efficiency (Autodesk, 2008).

4) BIM for Electrical Design

The electrical power and lighting circuits of whole buildings and individual spaces can be easily modeled using BIM. Similar to the mechanical design, the electrical designer can create whole circuits that contain light fixtures, or power devices or equipment in the model, while defining wire types, voltage ranges, distribution systems, and finally connection to a distribution panel. By using the "Built.in electrical calculations engine", "BIM gives the designer instant feedback and calculates the estimated demand loads directly on the model so it helps to prevent overloads and mismatched voltages. BIM also validates the electrical model to make sure that circuit elements/equipment are connected and contribute properly. Then it automatically "wires" those elements and places abbreviations/indications explaining the electrical flow to the main panel (Autodesk, 2008).

5) BIM for Structural Design

The Structural design process has been improved by using BIM for structural analysis and simulation. The BIM model includes all structural elements of the projects such as beams, girders, columns, panels, etc. Thus, some advanced BIM applications make it possible to simulate the construction process before excavation begins at the job site whilst simultaneously preparing whole project documents. Another important feature of BIM is that it is used as a conflict-resolution tool between the structural and MEP elements (Kymmell 2008).

a. **Driving Model Analysis:** The structural analysis model can be derived directly from BIM, which helps save time for analysis preparation.

b. **Driving Data Analysis:** Because data and design results are stored in the BIM model, quantity takeoffs can be easily and fully automated. Also, analysis models may be derived automatically.

c. **Design changes and time saving:** In 2D practice, the issue with design changes is that they are often individually in various places, and in diverse documents, which requires significant time and effort. Design changes in BIM are automatically updated through all documents at once. The 3D model maintains the major benefit of requiring only one local change, which is then automatically applied throughout. This means better design flexibility and less time and money.

d. **Clash detection:** In addition to project coordination and construction simulation, BIM offers an important feature called "clash detection" in which conflicts between the structural elements and the MEP components are revealed. The importance of the clash detection feature is that it can discover these conflicts virtually, prior to construction, so they don't affect the bottom line or the project completion date. Obviously, this saves re-work time and construction budget revisions.

6) BIM and Constructability Analysis

Constructability analysis is a valuable part of the pre-construction phase, and refers to the assessment of requirements and circumstances pertaining to the construction process, in order to achieve the desired result (i.e., how can the materials be best assembled?). The BIM process in the construction phase applies both to project team management (people-related) and to process management. BIM also continues to be useful for planning purposes that carry over into the construction phase. Some of the key benefits and advantages of BIM are shown in figure 2.3

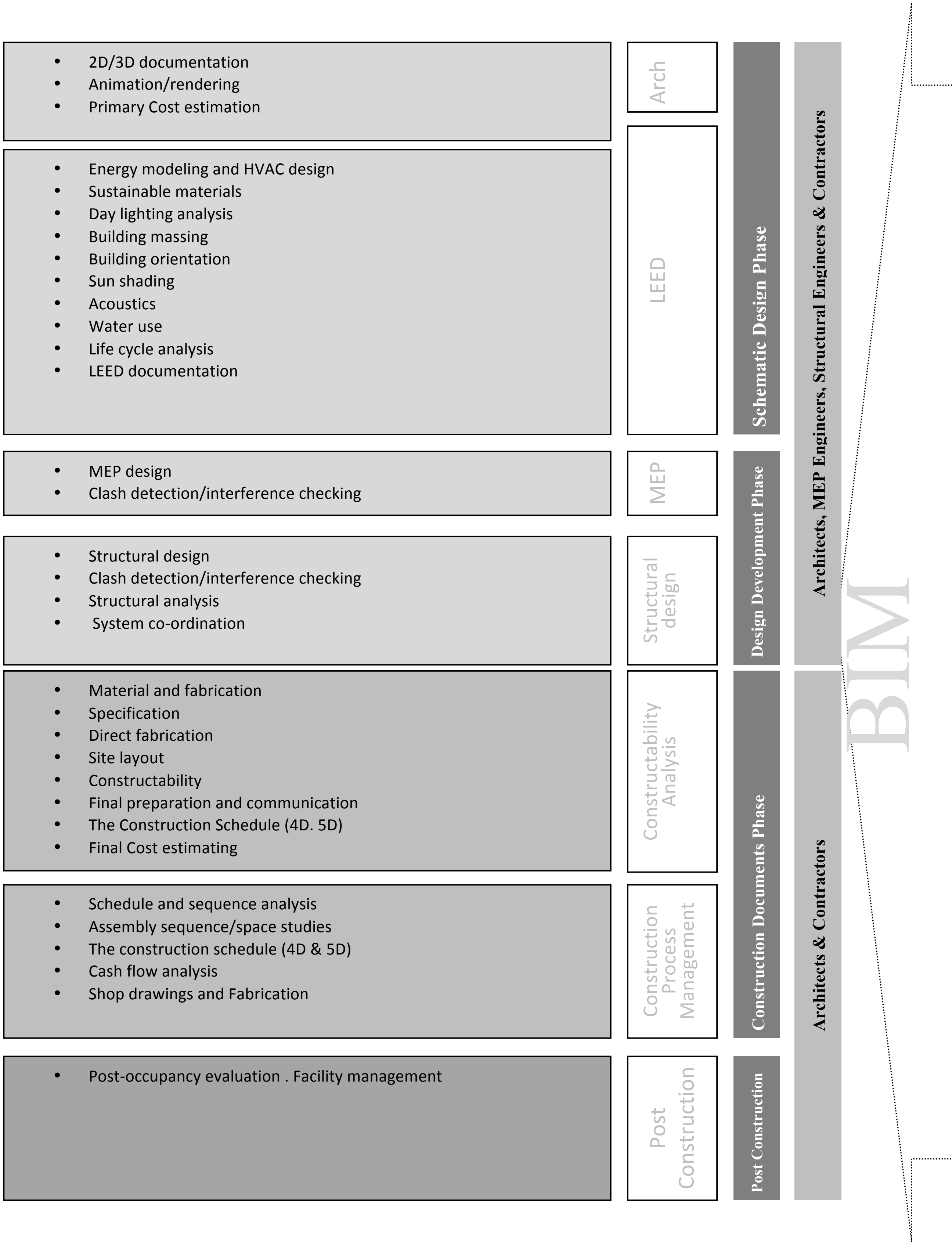


Figure 2.3 BIM features over the different project phases. Source researcher

2.4 BIM Domains

Based on the previously introduced BIM definitions, we can see that although BIM is considered one of the best visualization tools, it is not limited to 3D applications, nor is it a single piece of software. BIM has evolved into much more than a visualization tool; it is a new management process and a collaborative environment. From the researcher's point of view, the best way to describe BIM for this dissertation is as "a process of collaboration and interactive environment between the different project parties." McGraw-Hill Smart 2008 Market Report supported this definition by asserting that BIM is "The process of creating and using digital models for design, construction and/or operations of projects." (McGraw.Hill 2008, pp.17)

In addition, according to the US National Building Information Modeling Standard (US NBIMS), BIM can be defined as; "Building Information Modeling (BIM) is a data based digital representation of functional and physical characteristics of a building from earliest conception to demolition…. BIM, most importantly, is a collaboration of different stakeholders at various phases of the building life cycle to explore, insert, extract, update or modify building information in the BIM database to support and reflect the roles of that stakeholder."(NBIMS-Committee, 2010)

This dissertation does not focus on BIM applications or how to better use the software. It discusses the major changes to the existing process model of the traditional architectural project phases and the new methods of data sharing than most CAD architects and engineers are used to. The dissertation also concerns the actions, systems, integrated practice and management processes that are often integral to this change.

BIM is the core management of information and the complex relationships between the social and technical resources that represent the complexity, collaboration, and interrelationships of today's organizations and environments. The focus is on managing projects to get the right information to the right place in the proper time frame. The scope of this research is not to cover every option and all of the currently available or emerging tools and systems, but its main goal is to resolve problems that are caused by inconsistent information, which can be interpreted differently by each BIM player.

By using the 'conceptual clustering' of observable activities and the discovering of roles and interactions in the AEC industry, Michalski has identified three main domains for BIM where information is being exchanged rapidly between these domains: Technology, Process and Policy (Underwood and Isikdag 2010) (Michalski, 1987). Each of these domains has its players, requirements and deliverables. Those players can be individuals, teams, organizations or other groupings (Figure 2.4) (Underwood and Isikdag, 2010, p.66). A complete BIM process model is when these three BIM domains interact within the AECO industry, this forms the whole BIM process model. It is important to understand that failure of the process can be caused by inconsistent and ambiguous information that is being transferred either between the players of the same domain, or between the players of two or three of these domains.

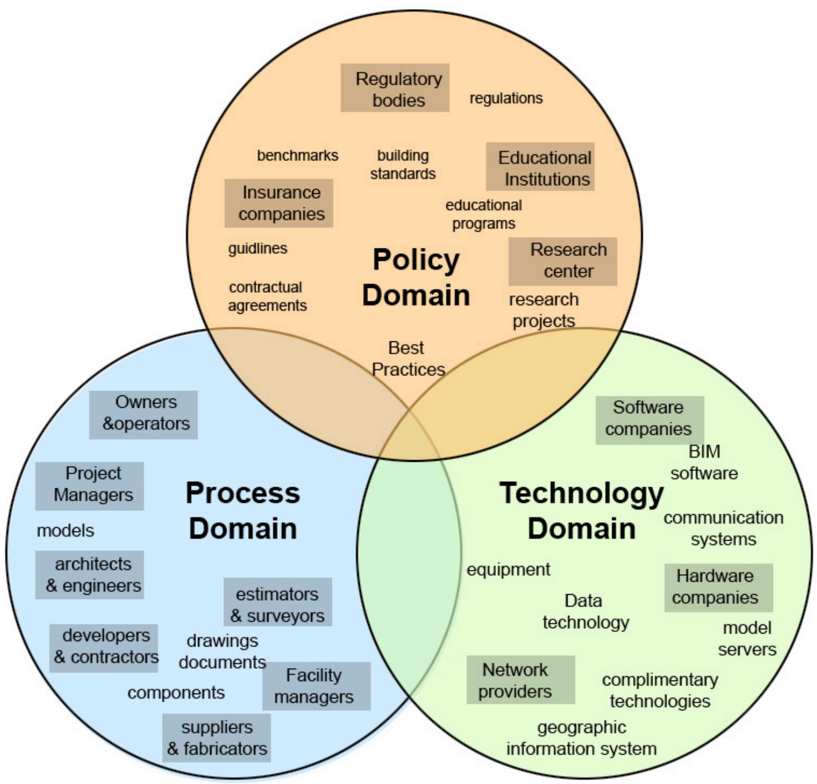


Figure 2.4 The three main domains of Building Information Modeling (BIM)
Source (Underwood and Isikdag 2010)(pp.66).

2.4.1 Technology Domain

The BIM "Technology" domain includes organizations, and software and hardware vendors that focus on the technical aspects of BIM use; the players of this domain could help to directly and indirectly enhance efficiency and profitability of BIM related procedures by developing software, hardware, equipment and networking systems.

2.4.2 Policy Domain

The "Policy" domain contains a group of players from insurance companies, universities and research centers, etc. who focus on preparing practitioners, delivering research, distributing benefits, allocating risks and minimizing conflicts within the AEC industry (Underwood and Isikdag 2010, p.66). Although the roles of this group don't appear to be clearly articulated in the current BIM modeling procedures, these roles are vitally important because they lead to changes in the AEC industry.

2.4.3 Process Domain

The last domain, which is the main focus of this dissertation, is the "Process" domain. This domain includes BIM members who handle BIM documents and information. This group includes facility managers, owners, engineers, contractors, architects, etc. This information can be used for ownership and operations of buildings or construction operations (Underwood and Isikdag, 2010, p.66).

2.5 Expected Challenges related to the BIM Domains

In the early stages of this research, the researcher attempted to classify BIM challenges inside mid-size architectural firms into two types, exogenous and indigenous. The exogenous challenges are mainly the issues that oppose BIM implementation between internal/external entities, such as the communication and contractual issues between architectural team and the contractor. While indigenous challenges are the issues that are to a given firm, for example the communication between the architectural team and BIM manager, or interoperability of files between the different BIM players but within the same organization. It was later found that it is difficult to use this type of classification because of the regular exchange of information; team dynamics and contractual relationships usually occur between- or within- two BIM domains. Thus, it became important to understand that BIM issues cannot be classified within a single domain, but interactions and transfer of knowledge between the players of separate domains are most critical.

Underwood and Isikdag give two cases in which BIM issues could occur between two BIM domains, they state “Case 1: when a BIM deliverable requires input from two or more players or fields. For example, the development and implementation of non-proprietary interoperable schema (like Industry Foundation Classes) necessitates the joint effort of Policy players (researchers) as well as Technology players (software developers). Case 2: when players pertaining to one field generate deliverables classified in another. For example, the Australian Institute of Architects is an industry body'- whose members are Process players (architects)- generating Policy deliverables (guidelines and best practices). (Underwood and Isikdag 2010, p.72).

In this dissertation, the researcher tried to map most of the BIM challenges from different literature resources before starting the “on site” data collection phase. Although these challenges may or may not be found in mid-size firms, and need to be uncovered and verified through other verification methods, mapping of these challenges helped formulate the interview questions, and to identify some important aspects for consideration during the case studies. In the following section we will classify these challenges in relation to the three BIM domains.

2.5.1 Expected Challenges of the Technology Domain

Expected challenges within the technology domain are represented by BIM software and hardware issues. In this section we will shed light on the most important of these issues:

a) **Interoperability:** The current lack of interoperability between the different BIM applications is one of the biggest issues for BIM implementation. Research conducted by Newforma suggests that instead of depending on a single building model, typically some project team members depend on a number of purpose-built models including (Howell 2006):

- Conceptual 3D design model (for example, using SketchUp)
- Geometric design detailed model (for example, using Bentley Architecture, Structural, and HVAC products)
- Finite element analysis structural model (for example, using STAAD)
- Steel fabrication Structural model (for example, using Tekla's Xsteel)
- Design coordination model (for example, assembled from multiple sources of design information via NavisWorks)
- Construction sequencing and planning model (for example, using Graphisoft's Virtual Construction solutions)
- Hospital Equipment inventory model (for example, using Codebook)
- Energy analysis model (for example, using DOE.2 or Energy Plus)
- Fire/life safety and egress model (for example, using IES "virtual building environment")
- Cost model (for example, using Timberline)
- Resource planning model (for example, using Primavera)

As a result, it seems that for a central BIM model it is unlikely that all project members will share a common model; Project teams deal with a collection of different software companies, each of which has their own trusted and preferred software applications for design and analysis. Throughout the different phases of a project life cycle and between different companies, it is very rare that a single product is being used on any one building project.

b) Forms of visualization: How does one properly view a BIM model? Using a 3.screens projection system by the Immersive Construction Lab while interviewing the project parties (Otto, Messner et al. 2005). If the project parties are to view the model on a single desktop computer, they may miss identifying some of the geometric elements as clearly and quickly as they can when using a large projection display. A feedback of the differences of using information through the desktop/flat screen and the 3.screens projection system could be presented and how it was obtained.

c) **Information exchange:** How is BIM information shared? BIM is a set of interactive software exchanging information with various formats. To effectively transfer between different BIM applications, a management strategy must be in place to support those different modeling tools, while not losing the embedded data and important features. This strategy can add complexity to the process.

d) **File size:** is one of the main issues and problems of the Technology Domain, and it also affects the Process Domain of BIM. BIM is considered a very specified set of details and large quantities of data that are included for each object in the 3D model, and that is why it generates huge file sizes for the whole construction that limits the navigation, rendering, managing, and sharing of the model. In addition, typically one computer can't manage all of these details, attributes, 3D models and information and be able to share it, and then go one step further and generate a 3D simulation and analysis via high end up-to-date machines (the architect must have a good understanding of the capabilities of BIM applications to be able to handle those simulations).

e) **Transferring from an old version to a new version:** some BIM systems cannot access a newer file version, which arguably is a profit motive for some software vendors. This is a challenge when the firm is using different BIM applications.

2.5.2 Expected Challenges for the Policy Domain

Although the importance of this domain is not explicitly clear in an office workflow, its role is important because it is a catalyst for change in the AEC industry. Here we will discuss some issues related to this domain.

a) **AIA policy Issues:** An important issue that impacts BIM implementation is concerned with who will be responsible for any inaccuracies in the BIM model. Based on current AIA policies, the architect is only responsible for the design, while the contractor is only responsible for the construction process, while the integrated approach supported by BIM blurs the boundaries of responsibility between the project parties, as a result, risk and liability will become more of a concern (A.I.A 2008).

In September 2008, the AIA tried to foster the adoption of BIM within the design-building industry and at the same time it addressed a new cross-platform solution by announcing the new BIM document E202-2008. This document is not a stand-alone agreement document but must be attached to the AIA agreement of design, construction or services. This document eliminated some of the current limitations in managing the BIM environment inside the office, but still needs to be updated to more specifically address the duties of each party. The document identifies the model ownership, assigns the responsibility for creating or modifying each element of the model at each project phase, controls users downstream of the model, and promotes the interoperability between the users by establishing a standard file format (A.I.A 2008).

b) **Model Copyrights and Legal Changes to BIM Documentation:** It is normal for the team members to use proprietary information while creating BIM objects but they have to consider the copyrights of the data and the proprietary nature of the information, which are being used in the BIM model. In order to avoid inhibitions that discourage participants from fully realizing the model potential, this information should be protected.

2.5.3 Expected Challenges for the Process Domain

The challenges associated with the Process domain can be described briefly as the following.

a) Communication Difficulties: From the literature review, one of the expected issues that the researcher may find in mid size firms is the lack of early stage of collaboration during the early stages between the different BIM stakeholders. Another aspect of this problem is that the early stage of collaboration between these stakeholders may be initiated through BIM but, as previously mentioned, there may be interoperability and formatting issues. This is because data and information exchange challenges have to be driven by the good understanding of the construction strategy and the methods of transferring this information on time and in the proper format.

b) Method of collaboration: collaboration between leaders of each team (MEP, Structural, Architectural, etc.) and their members is another significant challenge in mid.size firms. Since information often flows back and forth many times throughout a project, an important issue is to be able to manage the hierarchy between those users inside the firm.

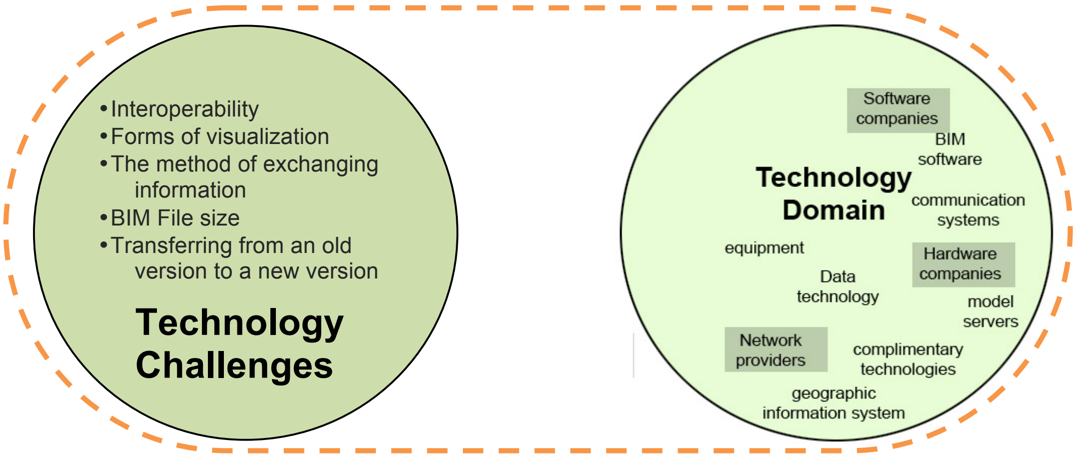
c) Frequent design changes: ideas might become unrecognizable because of the back and forth interactions between different individuals. Currently, there is no better alternative then to accept this iterative process (Kymmell 2008). Some sources indicate that frequent design changes may consume much of BIM users' efforts when the workflow is not well planned (Kymmell 2008) (Borzage 2006).

d) Controlling Data Feed: To be able to know and define who will control the data feed and updating of the model, is very important. It is typically the team leader's responsibility to manage risk due to wrong data feed and missing information. Accordingly, the AIA document E202.2008 considers a scenario of splitting the responsibility of data feeding between the different architectural office team members. Also, the office team will typically try to identify who is responsible for any errors. This suggests that, there should be only one person responsible for data updating and feeding, which could slow the process and can add more time and cost to the project (A.I.A 2008).

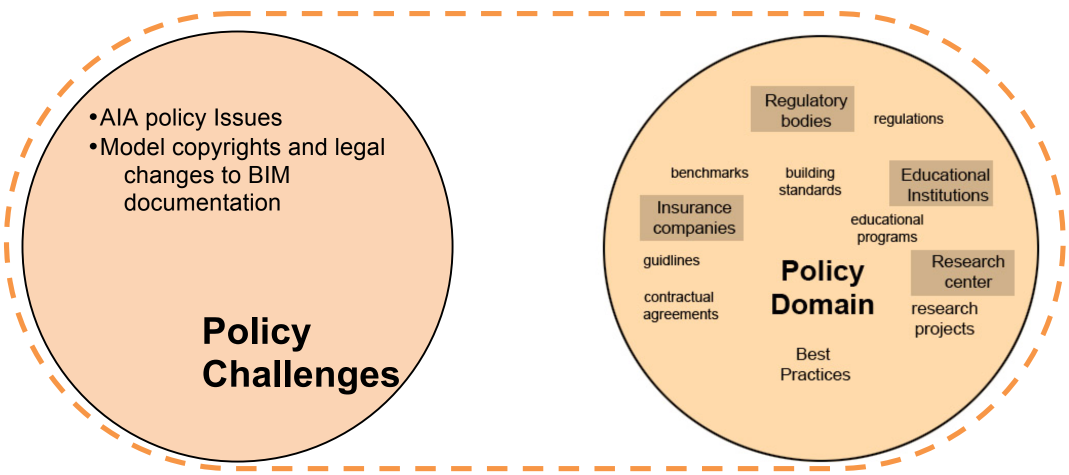
e) Contractual responsibilities: A "Cooperation mechanism" in the form of defined contact responsibilities between BIM members is often missing. This mechanism should identify the relationships between all the BIM members. It should also encourage the cooperation between the project parties rather than create obstacles and challenges to collaboration. Michael Borzage, professor of construction management at CSU Chico, explains that the weakness of the design-bid-build project delivery approach within the workshops that Construction Simulation Lab offers to the industry, as follows.

> *“In the traditional design-bid-build project delivery approach, the design and construction portions are deliberately segregated by means of specific contracts with the Owner, the Architect and the Builder. While the reasons for employing this approach may be debated, there can be little disagreement that the owner loses opportunities for added value, and takes on additional risk in at least three important areas. First, the project budget is established early in the process, and serves as an important constraint in the project program."(*Borzage 2006*)*

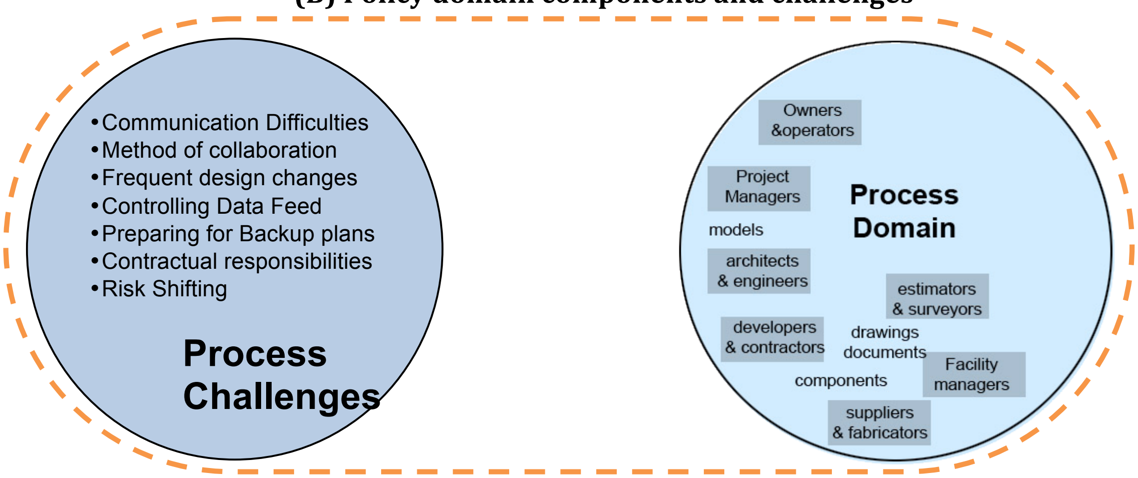
At the time of bidding, one of the shortcomings with respect to the owner is the “sticker shock" if the bid far exceed the proposed budget. It will be difficult to consider change at this point by identifying and reducing the areas of the project that are generating excessive costs, and the result is typically damage control. The Design-bid-build contractual method is a linear process, which does not support the implementation of BIM.



(A) Technology domain components and challenges



(B) Policy domain components and challenges



(C) Process domain components and challenges

Figure 2.5 Components and Challenges of BIM domains

As previously mentioned, the challenges for BIM implementation usually occur through interactions between the three BIM domains, some of these challenges can impact one or more of the BIM domains simultaneously. Although the research started with mapping these challenges through the literature review, further on-site investigation was needed to determine the impact of these challenges on the BIM related workflow. Figure 2.5 summarizes the challenges associated with the three BIM domains.

2.6 Summary

This chapter discussed BIM definitions and also describes some of the important features of BIM as categorized through the different project phases. The Chapter discusses the three BIM domains; Technology, Policy and Process as proposed by Underwood and Isikdag. Based on these domains, the researcher elaborates the challenges that are currently being faced under each domain. The chapter introduces a general scope of all these issues that will be the foundation for the next phases of the research, but this literature overview will work as a reference for the remainder of the dissertation particularly during the phases of data collection and feedback gathering.

Chapter 3

Business Process Modeling

3.1 Introduction

Mapping the existing (As-is) Business Process Model (BPM), and developing a new flexible model that will help to better adapt BIM in mid-sized architectural offices are two objectives of this research. It is expected that by achieving both objectives the improvement of the core of this new model would help enhance BIM implementation in architectural firms.

This chapter generally focuses on the modeling process of any business workflow, the definition of the Business Process Modeling (BPM), review of the existing methods of mapping a process model, and finally explores the steps that should be taken to map and develop the proposed to-be model. However, it is important to note that mapping the business process for architectural design is a new field of study, and pre-studied models have not been introduced before for BIM implementation. It should further be noted that any business process model for architectural design would be incomplete. The design process is both tangible and intangible. This work focuses only on those tangible dimensions of the process.

Thus, this chapter will first review the literature concerning the definition of the process modeling. Then, it will discuss the concept of Business Process Reengineering and the modeling languages that are currently being used in the construction industry. Finally, the chapter explores two of the most popular modeling theories and compares between their advantages and disadvantages to help chose one mapping approach for this research. It is important to mention that analysis of the problem and goal-driven frameworks are the expected outcomes of this research.

3.2 Relationship between BPM and research goals

Chapter one in this study identifies the research objectives as the following:

1. Mapping the existing challenges that limit BIM implementation during the S.D and D.D. phases in mid-size architectural firms.
2. Mapping the existing BIM related workflow (BIM as-is model) for mid-size architectural firms.
3. Identifying the variables and structural conditions that would impact or change the existing workflow.
4. Develop a new model that supports BIM implementation in mid-size architectural firms. (Chapter 1 - p.40)

The second and fourth objectives of the research focuses on modeling the existing BIM work flow, then developing a new model that helps improve BIM implementation in mid-size firms. Thus, Business Process Modeling (BPM) and the way modeling is approached may well be considered as the foundations for this dissertation.

To initiate the modeling process, first we need to map the existing model and identify how it functions. This will be reflected as the “As-is" model. This involves the modeling of the required levels, associated with specific areas in the workflow that are detailed enough to explain how the process flows. It would not be unusual that these areas not all be developed to the same level of detail. Once we develop the "As-is" model then the next step is to create the "to be" model, which is considered an improvement in the way that BIM related business process works. This step requires the leaders describe and discuss the required changes, which is challenging, due to the required level of understanding of the whole process as it exists. At this point, the new "to be" model becomes the road map for the changes in this firm.

To summarize, it is expected that the research would result in two main models that reflect the BIM related business processes inside mid-size architectural firms:

- 'As is' or the existing model (the current situation)
- 'To be' model (the intended new situation) which would be used to analyze, test, implement and improve the process.

3.3 Relationship between BPM and BIM Domains

As explained earlier in the Venn diagram, (chapter 1 p. 12) the areas of interest for this research overlap between Building Information Modeling (BIM) and Business Process Modeling (BPM). As previously introduced, BIM includes three domains, Policy, Technology and Process. While the Business process modeling (BPM) includes different approaches, the most important ones for the AEC industry are the IDEF and BPMN. Thus, a combined approach that includes both modeling methods will be used in this research (Smith and Tardif 2009).

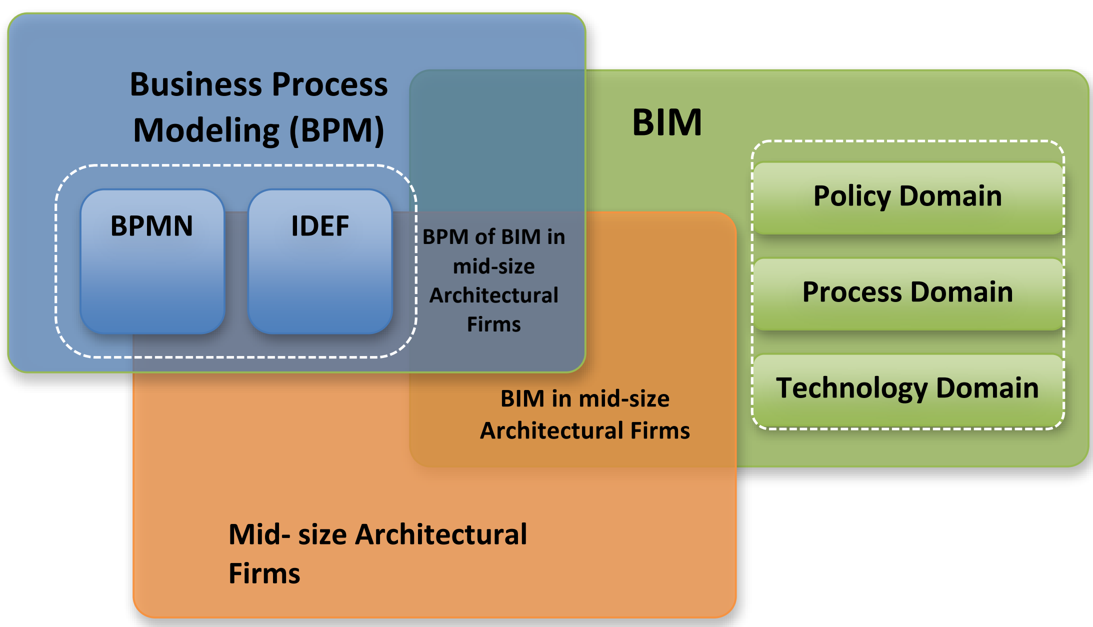


Figure 3.1 Detailed Venn diagram

Although the Policy domain has a major impact on the workflow, making changes to this domain requires involvement of stakeholders outside of the project team, which is not a focus for this research. Thus, the research will focus on the other two domains, Process and Technology, and the relation between the business process modeling/reengineering and these two BIM domains (figure 3-2). This can be considered a new limitation for the research but necessary given the research scope and timeframe. Based on these two domains and the modeling approaches, the interviews questions and case studies criteria will be formulated, as it will be explained later in chapter 5 of this dissertation. Figure 3-2 explores and discusses the focus of the study.

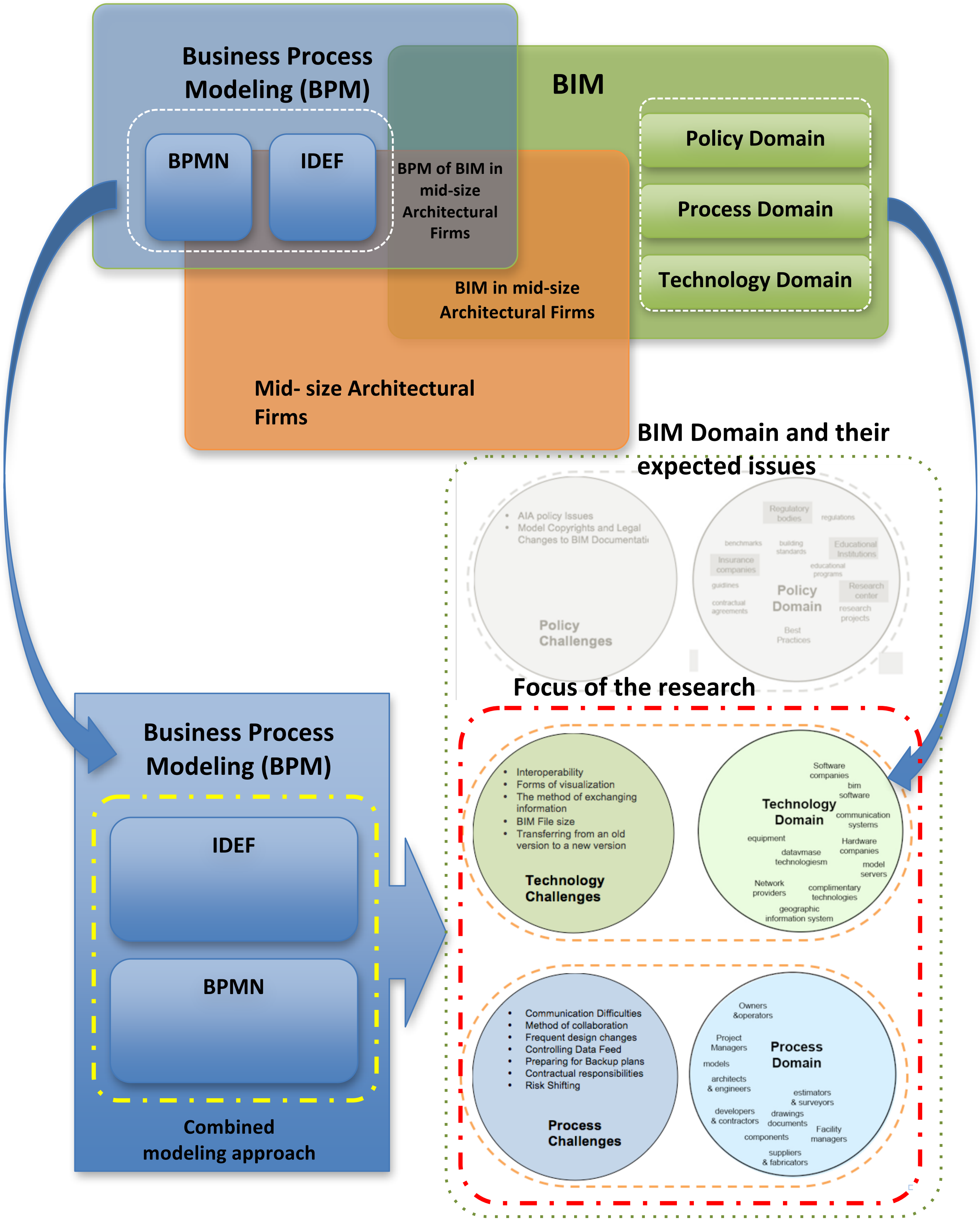


Figure 3.2 Focus of the study

3.4 Overview of Business Process Mapping

As previously introduced, Business Process Modeling (BPM) is commonly a diagram representing a sequence of activities that shows sequential events, actions and links or connection points. The term 'process' can be defined based on the subjected field of interest. For example Harrington (1991) defines the term "process" as "any activity or group of activities that takes an input, adds value to it and provides output to an internal or external customer. Processes use an organization's resources to provide definitive results". Davenport (1993) states that "a process is simply a structured, measured sets of activities designed to produce a specified output for a particular customer or market". Talwar (1993) defines the "process" as "a sequence of pre-defined activities executed to achieve a pre-specified type or range of outcomes".

3.5 BPM Theory

Reengineering Business Process (BPR) focuses on a specific change at any level of organizational structure of the whole management system. This term has been simultaneously introduced by two groups of initiators, the first group is Michael Hammer and James Champy who in 1993 published their book "Reengineering the corporation: A Manifesto for business revolution". The book explained that the Reengineering process is "the fundamental rethinking and radical redesign of business processes to bring about dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed." On the other hand, with more emphasis on information technology, Davenport & Short (1990) have also suggested that the BPR is "the analysis and design of work flows and processes within and between organizations".

Reengineering the business process can be better described as a "change mechanism", which fundamentally focuses on defining confrontations and conflicts in BIM organizational and functional tasks. This change is expected to solve workflow conflicts and organizational interrelations, and subsequently improve BIM implementation, meet customer requirements and enhance overall performance.

3.6 Evolution of BPM approaches

Although the Business Process Modeling has different approaches, the main approaches are the Business Process Model and Notation (BPMN), the Unified Modeling Language (UML) and Integrated Definition (IDEF) modeling. According to Dana Smith, the most common approaches that are being used in the AEC industry are the BPMN and IDEF. For a better more elaborative definition of these approaches the next section will provide a detailed discussion (Smith and Tardif, 2009).

3.6.1 Business Process Model and Notation (BPMN)

Business Process Model and Notation (BPMN) is a graphical representation approach and modeling method for mapping business procedures. It is also known as Business Process Modeling Notation. This approach was first introduced by Business Process Management Initiative (BPMI), but currently it is being developed by the Object Management Group after the two organizations merged in 2005. The latest version of BPMN is 2.0, as of March 2011. This version works based on a flowcharting technique, which is very similar to activity diagrams from the Unified Modeling Language (UML). The BPMN approach is one of the most powerful languages used in representing information flow, interdependencies of roles, and sequence of activities, which helps many organizations in the building industry.

The BPMN approach aims to support business process and to provide a standard notation for both professional and non-professional users (technicians/business analysts and firm stakeholders) by providing a way to simply represent any management process. A BPMN is presented in common graphical languages that bridges communication gaps and unifies graphic notation while considering the complexity of business execution languages, and particularly Business Process Execution Language (White, 2006).

Moreover, the widespread adoption of the BPMN and the variety of competing standards help to unify both basic and advanced business process concepts in one diagram. Thus, many architectural/construction organizations are giving more attention to the BPMN approach (Smith and Tardif 2009).

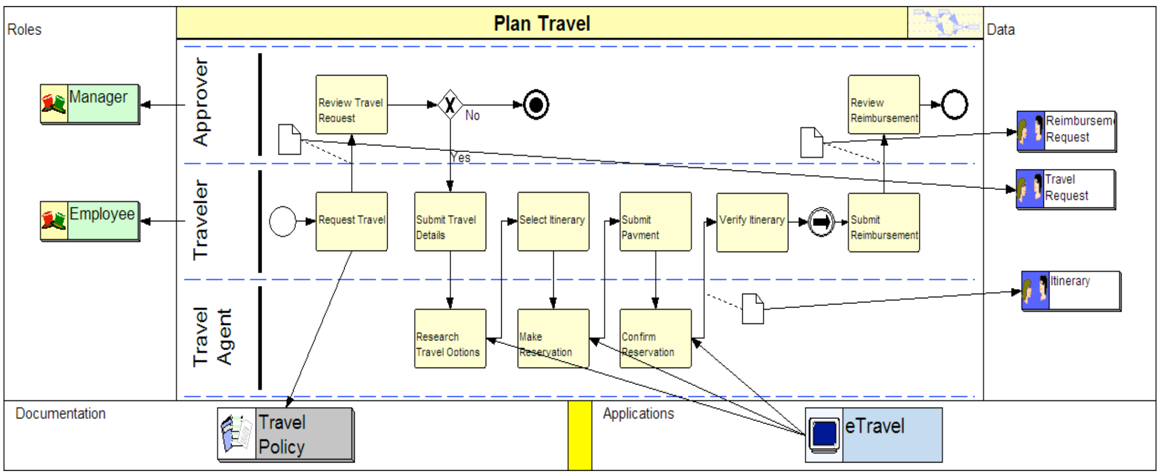


Figure 3-3 Business Process Model and Notation for a process with a normal flow. Source: (Sowell 2009)

As shown in figure 3-3 in the Business Process Diagram, there are a number of graphical elements with which we represent a business process. In the above example we can see different types of elements that describe how the process works. Within these elements are the activities that represent the work that was carried out, the beginning and end events, which indicate the starting point and completion of the process, plus the decision elements known in BPMN as Gateways, which indicate alternatives along the way. These elements are connected by means of Sequence Lines that show the process flow.

At the beginning of the Process there is the figure “Start Event”, which indicates the beginning of the process. Processes can begin in different ways and BPMN provides for different types of Start Events (simple, message, signal, etc.). At the end of this process we find the figure "End event", indicating termination of the process. As the graph shows, the process ends when the applicant is rejected, the credit application is not approved or the loan is granted and disbursed.

The gateway used in the above example is the Exclusive Gateway. As a decision element, this gateway behaves like an "XOR"; in other words, only one of several given alternatives can be taken. In the Credit Application Process we can see two examples of the use of an exclusive gateway. The first one depends on the result of verifying the applicant's information: the line may run in one of two directions; if the result was "Applicant Rejected", the process ends there, and if the applicant was accepted, the process can continue. In the second example, the decision is based on the result of the credit study: if the application is rejected, the client is notified, if it is approved the credit is disbursed.
The BPMN modeling approach has some advantages and disadvantages when compared to the other modeling approaches, here we will summarize some of them.

3.6.1.1 Advantages of the BPMN

1) Having more details than the IDEF model, which helps to instantly identify problems in the sequencing or assignment of activities to performers.
2) BPMN uses a swim-lane notation, showing the activities within swim-lanes that indicate each performer's activity, which gives a clear vision about the workflow and "what's going on? And who does what?" to model analysts.
3) When compared to IDEF, BPM is a more structured, composed, coherent and consistent way of executing and continuously changing end-to-end business processes. BPM usually shows the composed sequence of activities in one diagram and involves all the workflow resources and components in light of their contribution to business performance in the same model.
4) BPMN activities require a strict structure and composed sequence; BPMN combines the Activity Model with the Scenario Sequence Model at the same

time.

3.6.1.2 Disadvantages of the BPMN

1) Because the BPMN is quite complicated, and usually combines activities, tasks, processes, sub-processes and other workflow details in one model, model readers' usually get confused and get lost in the diagrams.
2) Because the model usually contains unlabeled arrows and symbols that connect and present BPMN activities, the relationships between these activities may be less apparent and difficult to read by nonprofessionals.

3.6.2 IDEF Modeling Approach

The Integrated Definition (IDEF) is a business process modeling approach that was first initiated and developed by the U.S. Air Force in the 1970s to cover a wide range of uses, from functional modeling to data simulation, object-oriented analysis-design and knowledge acquisition. As a widely used functional modeling approach for engineering purposes, this approach is being used in the architecture/construction industry as a modeling approach to map and analyze the functions and activities for the design/construction process (Savage 1996, p: 84).

The Integrated Definition (IDEF) has at least fourteen versions but the most-well known and widely used of the IDEF family are IDEF0 (a functional modeling language building on SADT) and IDEF1X, which address information models and database design issues. The IDEF0 was derived from the graphic modeling language Structured Analysis and Design Technique (SADT) as developed by Douglas T. Ross and SofTech, Inc. (Ward 2009) to model the decisions, actions, and activities of an organization or system. In the architecture/construction industry, IDEF0 represents functional modeling by tracing the Inputs, Controls, Outputs and Mechanisms (ICOMs), which captures the important data flow for each activity, resulting in a hierarchical series of diagrams, and text cross-referenced to each other. Usually, the primary modeling components (activities) are represented on a diagram by boxes, and the data (inputs/outputs) that interrelate those functions is represented by arrows. The diagrammatic representation of IDEF0 methodology can be seen in Figure 3.4.

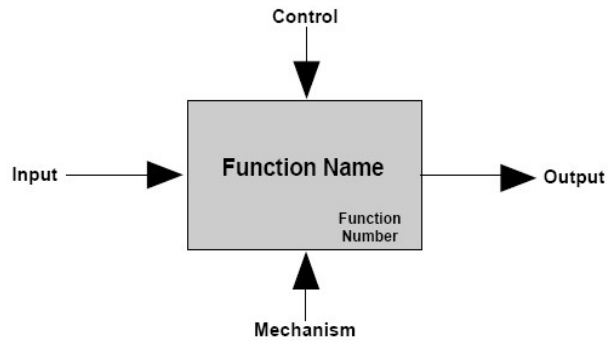


Figure 3.4 IDEF0 Notation

Source: (Defense.Acquisition.University 2001)

There are five elements to the IDEF0 functional model (see Figure 3.4): the activity (or process) is represented by boxes; inputs are represented by the arrows flowing into the left hand side of an activity box; outputs are represented by arrows flowing out the right hand side of an activity box; the arrows flowing into the top portion of the box represent constraints or controls on the activities; and the final element represented by arrows flowing into the bottom of the activity box are the mechanisms that carries out the activity. As shown in Figure 3.4, the diagram of IDEF0 shows the function as a box and the Inputs, Control, Output and Mechanism (ICOM's) activity as arrows leading to the box or leaving it, as shown in Figure 3.5. The box is an important activity that connects other units in the same functional model. By adding more details to this activity box, the model becomes more descriptive, enough to qualify for decision-making.

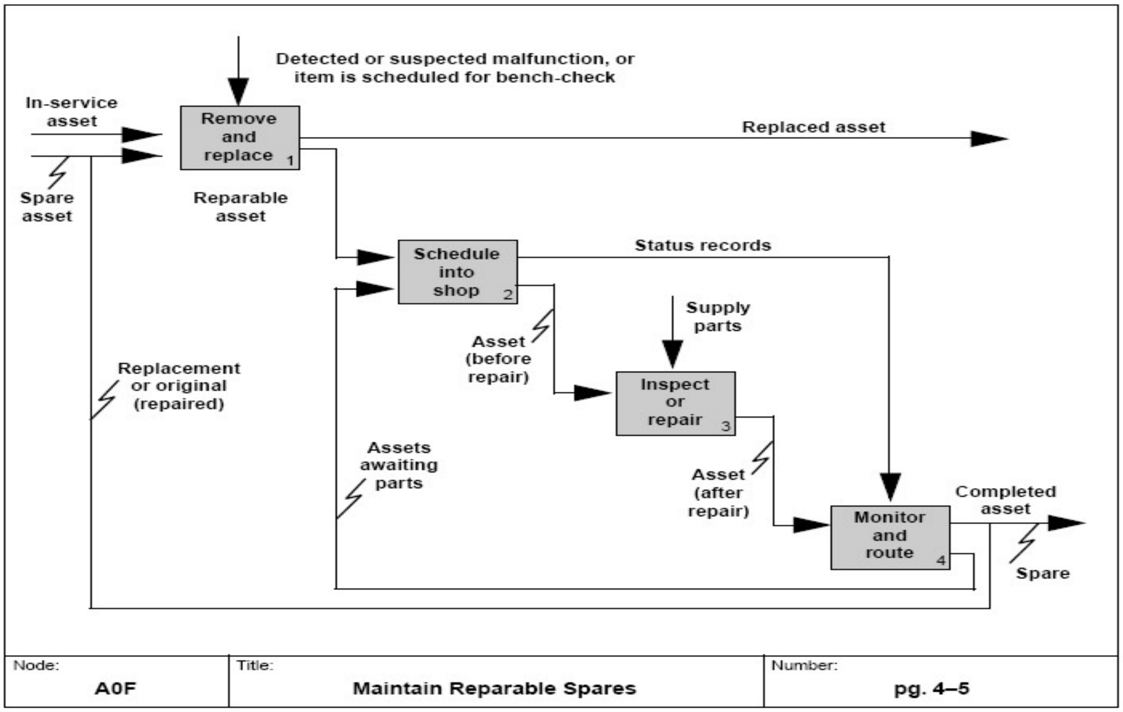


Figure 3.5 IDEF Diagram Source: (Defense.Acquisition.University 2001)

3.6.2.1 Advantages of IDEF Modeling Approach

1) The major advantage with using IDEF0 is that it is composed of consistent models, whereas the parts of the models can be partitioned and produced independently. Then, it can be integrated into the larger model.

2) The IDEF0 model consists of a decomposed system, which is found to work according to this dissertation methodology. Later, with the help of feedback and the suggested changes, this method helps to include all the necessary activities in the developed model.

3) The easily understood and instantly read IDEF0 model saves time that would be spent on the explanation and training of reviewers. Also, this allows the inclusion of a large number of comments from BIM players at one time. The direct contact between the researcher and BIM players allows an efficient

development and fluent integration of comments and suggested changes from a large number of reviewers.

4) The arrangement of boxes (activities) does not require a strict sequence, which gives the possibility to manage feedbacks between activities. Also, several activities can occur in parallel to each other, or in sequence depending on a specific activity accomplishment.

3.6.2.2 Disadvantages of IDEF Modeling Approach

1) Because of the simplicity and readability of the IDEF0 model for non-professionals, this typically doesn't present details for more complicated processes. For example, one of the rules in IDEF0 is that each diagram should consist of between 3 to 6 boxes, which makes it difficult to describe more than 6 activities for each diagram without becoming trivial.

2) Usually, IDEF0 diagrams have to be presented to interviewees followed by an explanation of the modeling syntax from the researcher. Without this explanation, it is expected to initially get un-precise, confused or wrong feedback from model readers', which subsequently might cause many users to reject the model at the beginning.

3.7 Combined Modeling Approach:

The recommended approach that was used in this dissertation is the combined approach, where the researcher found that it may be advantageous to perform the basic analysis in IDEF0, uninfluenced by any thoughts of who performs the activities or in what sequence they are performed so the model can be discussed with non-professionals. Then, we can move gradually to a more detailed level of mapping using BPMN for final presentation.

3.7.1 Criteria of Using the Combined Approach

This approach combines the advantages of both methods and avoids the weakness of each approach as explained earlier; the methodology of the combined approach will be as follows.

1) **Using the IDEF0 – As-is model:** the researcher initially performed the basic analysis and described the overall BIM activities using the IDEF0 model. In the beginning, this model helped capture the interrelations and the sequencing of the activities, without consideration of who or what decisions are being made to perform each activity. In this phase, the generated model is generic and referred to as the "Logical Activity Model". This was important for understanding the "As-is" model, inputs and output of each phase and how BIM is being implemented in architectural firms.

2) **Using the BPMN approach – As-is model:** In the next phase, the researcher went into each business component to add annotations with more details, such as; activities, performed by whom, decisions, communication types and the flow of information. This model identified the problems that limit BIM implementation at each node and the subsequent errors.

3) **Using the IDEF0 – To-be model:** The researcher developed the "to be" model using IDEF0, this model was generic while discussing the goals for this dissertation. The model presents the required changes and the proposed framework for implementing BIM. It also presents the sequencing and the suggested methods of communication among different BIM players.

4) **Using the BPMN approach – To-be model:** Finally, the researcher added more detail into each business node using BPMN, while describing more specifically the sequences of activities, inputs, outputs and events that occur at each node. This level of Activity Model is sometimes called the "Physical Activity Model."

3.7.2 Advantages of Using the Combined Approach

In addition to achieving the advantages of both the IDEF0 and BPMN methods, this combined approach also is adapted for the following reasons:

1) **Gradual building of the BIM related workflow:** It is preferable to start by outlining the general activities of the "As is" and "To be" models. This is best achieved by a modeling method that generally describes the overall activities and decomposes them (IDEF0), and relates them via the inputs and outputs that they provide each other.

2) **Quicker understanding of BIM related workflows:** By starting the discussions and interviews with the IDEF0 model followed by the BPMN model, which can be of value to the research, as this approach makes sure that all BIM members have a quicker understanding of the existing BIM related activities, and then the researcher went into more details by presenting the BPMN model.

3) **Identifying BIM issues:** Once the researcher identified the problems with the "As is" model, changes were assigned to each specific business node with input from the team members.

3.8 Summary:

This chapter provides the background information regarding the business process modeling in this study. The chapter discusses two models that will be presented in this research, As-is model and To-be model. On the other hand, it gives reasons for the rise of process modeling in the AEC industry and discusses the criteria for using two modeling approaches, and then presents a comparison between the advantages and disadvantages of each approach.

The chapter also points to the modeling method that was used in developing the business process models in this research. Due to some limitations on both modeling approaches, the researcher suggests a combined approach to generate the existing model (As-is model), and then to develop a new business process model (To-be model). The chapter also focuses on the criteria of using the combined approach and the criteria that was used in this research. In the next chapter, the research methodology will be reviewed and discussed.

Chapter 4

Method of Inquiry

4.1 Introduction

An important objective of this research is to expand on the current state of knowledge of BIM communities, by gathering and analyzing data provided by different BIM users and stakeholders, and then interpret the findings to form patterns that would define the new business process model. To achieve this objective, this study is qualitative in nature and relies on gathering information from multiple resources, such as case studies and interviews that have been conducted with participants and BIM stakeholders from the AEC industry. Thus, this chapter examines the research methodology via the qualitative research method, with its definitions, features, data collection strategies, data analysis, interpretation tactics, and finally the strengths and the weaknesses of the qualitative method.

4.2 Research Methods

The previous chapter outlined that this research focuses on both the “BIM Process Domain” and the “BIM Technology Domain” to identify communication and information constraints during the Schematic Design (S.D) and Design Development (D.D) phases. The objective of this work is to map the business process in terms of BIM related communication and information exchange, identify the issues these two domains, and then to develop a proposition for a new Business Process Model (BPM) that helps to overcome these constraints, which would then, be intended to develop and to improve BIM related process flow in the realm of mid-size architectural firms.

Thus, this dissertation will first attempt to provide an overview of the existing (As-is) process model, which presents the communication mechanisms and data flow related to BIM inside the subjected firms. After interpreting this information, the researcher proposes a new model (To-be model) to support BIM implementation and improve collaboration among its stakeholders. Although the model suggested in this research can be considered generic and represents BIM related workflow in most mid-size firms in the US, the structural conditions that could impact or change this model will also be identified.

To achieve these objectives, the researcher adopts a qualitative method, as it is suitable for the subject matter, which does not lend itself to quantification. Moreover, qualitative research is the method to provide a complex textual and coherent description of how people experience a given situation such as BIM-related workflow. It gives a detailed description of the "human" side on these situations, which includes description and logical explanation of human interactions, behaviors, opinions, emotions, and relationships between individuals, which subsequently produces a wealth of detailed information about a specific event.

4.3 Overview of the qualitative research method

The qualitative method can be defined as a scientific research method that does not depend on comparing quantities, but is concerned with words rather than numbers. It is a non-numerical data collection method that can be used for policy and program evaluation research (Marshall and Rossman, 2011, p. 11). Strauss and Corbin define the qualitative method as "any type of research that produces findings not arrived at by statistical procedures or other means of quantification" (Strauss and Corbin

,1998, p: 12). For example, the qualitative method has been applied in many cases to monitor in depth the human behavior and the reasons or the decisions that govern that behavior. Furthermore, the qualitative method aims to understand how and why certain outputs were reached, and the process that resulted in those outputs. It can also be applied to answer questions such as; were participants able to handle their tasks? Or did the software cause any unintended effects? (Denzin and Lincoln 2011). Norman Denzin and Yvonne Lincoln, offer the following "generic" definition for qualitative research describing it as “multi method in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them. Qualitative research involves the studied use and collection of a variety of empirical materials.” (Denzin and Lincoln, 2011, p. 2)

Therefore, a qualitative method can help investigate the why and how of decision-making situations. It has been employed in different academic disciplines, especially in those of the social sciences, education, psychology and others. Hence it is regarded as a multi-method approach that is interpretive and naturalistic. Groat states that qualitative research “ is characterized by being holistic, conducted through prolonged, open-ended contact, relying on human subjects as measuring devices due to the relatively little use of standardized measures, and the principle mode of analysis in this case is through words, sketches and observations” [(Groat and Wang, 2002, p: 176-212) (quoted in Elmasry, 2008, p: 45)].

Thus, in this research, challenges and information exchange, workflow and business process model as they relate to BIM implementation are observed using a qualitative approach in their natural and existing settings, from which the researcher attempts to interpret the collected data, in order to fulfill the research objectives.

4.4 General characteristics of the qualitative research

Although qualitative research can take various forms, yet they all have common characteristics that can be identified using examples from different types of research. In the next section we will illustrate these characteristics.

4.4.1 An Emphasis on Natural Settings

An emphasis on Natural Settings means that qualitative research emphasizes the importance of looking at different variables as they are found in their natural setting, while the objects of inquiry are not removed from the venues that surrounds them in everyday life. In Cuffs and Groat/Ahrentzen studies, they claim that "In both these cases, the researchers used a variety of tactics that placed themselves or their data collection tactics into the context being studied; the context did not have to be altered for the study to be conducted." (Groat and Wang, 2002, p: 179)

4.4.2 A Focus on Interpretation and Meaning

In qualitative research, the researcher should not only develop his/her theory based on the empirical realities of the collected data, but also he/she has to play a vital role in interpreting and making sense of these data. For example, Cuffs and Groat/Ahrentzen usually employed some methodological practices (memos, notes, etc.) in their research that embrace interpretation and guides the development of the remaining interviews (Groat and Wang 2002, p: 179).

4.4.3 A Focus on How the Respondents Make Sense of Their Own Circumstances

When conducting qualitative research, the researcher should present a holistic portrayal of the setting or the phenomenon understudy as understood by the respondents themselves. It is important that the researcher supports the research by using a range of quotations from the respondents' feedback; these quotations are selected to support the strength of the researcher's opinion or belief; similarities between respondents; differences between respondents; and the breadth of ideas.

4.4.4 The Use of Multiple Tactics

These multiple tactics are referred by Denzin and Lincoln as a "pieced-together, close-knit", which can be defined as a set of practices that provide solutions to a problem in a concrete situation (Groat and Wang 2002). It does not necessarily mean that the qualitative study employs multiple tactics. However, the multi-tactic qualitative study presents an excellent illustration of the bricolage approach.

4.4.5 Other Aspects of a Qualitative Research Strategy

Qualitative research is characterized by a holistic overview of the context under the studied phenomenon, this can be achieved through intense and/or prolonged contact with a 'field' or 'life' situation, and the study of how people real-world situations "make sense" of their environment and themselves. Thus, qualitative research has a broad number of additional attributes and a variety of other tactics; these attributes have been summarized by Groat and Wang in the following table;

Table 4.1 Summary of additional attributes of the qualitative research design. From J. Creswell, Research Design: Qualitative & Quantitative Approaches (Sage Publications, 1994); and Miles & Huberman, Qualitative Data Analysis (Sage Publications, 1994).

Holistic. "The goal of qualitative research is to "gain a 'holistic' (systematic, encompassing, integrated) overview of the context under study." (Miles and Huberman, 1994, p. 6).
Prolonged Contact. "Qualitative research is conducted through an intense and/or prolonged contact with a 'field' or life situation." Hence, the emphasis in many studies on "fieldwork." (Miles and Huberman, 1994, p. 6).
Open Ended. Qualitative research tends to be more open-ended in both theoretical conception and research design than other research strategies (e.g. experimental or correlational) because it typically eschews the notion of a knowable, objective reality (Creswell, 1994, p. 44).
Researcher as Measurement Device. Since there is relatively little use of standardized measures—such as survey questionnaires, the researcher is "essentially the main 'measurement device' in the study." (Miles & Huberman, 1994, p. 7).
Analysis Through Words. Since an emphasis on descriptive numerical measures and inferential statistics is typically eschewed, the principal mode of analysis is through words, whether represented in visual displays or through narrative devices. (Miles and Huberman, 1994, p. 7).
Personal Informal Writing Stance. In contrast to the typical journal format of experimental or correlational studies, the writing style of qualitative work is typically offered in a "personal informal writing stance that lessens the distance between the writer and the reader." (Creswell, 1994, p. 43).

4.5 Comparing Quantitative and Qualitative Methods

The major difference between quantitative and qualitative method is that qualitative research is most likely to focus on contemporary phenomena, while quantitative studies are primarily concerned with data collection and numerical inputs that rely on documents and other material artifacts (Groat and Wang, 2002). Natasha Mack and Cynthia Woodsong present some major differences between the qualitative and quantitative methods. One of the main differences is that the level of interaction between the researcher and participants in the qualitative methods is much higher than what could be found in the quantitative method. This is because the responses from participants in the qualitative method allow meaningful comparisons even if participants are asked identical questions in the same order (Natasha Mack, 2005, p: 11). It is a strong reason to make the qualitative method the most appropriate for this research, due to the greater spontaneity and adaptation of a high level of interaction between the researcher and BIM users. Whereas the responses from quantitative methods are usually "closed-ended" or fixed, which requires the researcher to have a more in depth understanding of the questions related to the subject matter. Thus, for qualitative research it is best to ask questions and be prepared for a range of possible responses (Natasha Mack, 2005, p: 11).

Moreover, the qualitative method allows for a less formal relationship between researcher and participants, with more interactivity in both directions, which gives the participants the opportunity to respond more freely, paving the way for more details and answers than what are typically required by the quantitative method.

On the other hand, Natasha Mack and Cynthia Woodsong argue that both methods differentiate in a few aspects, such as; their analytical objectives, types of questions they pose, types of data collection instruments they use, and forms of data they produce. To summarize, Natasha Mack and Cynthia Woodsong briefly outlines these major differences in the table below.

Table: 4-2 Comparison of quantitative and qualitative research approaches.

Source: (Natasha Mack, 2005, p.147)

Comparison of quantitative and qualitative research approaches

	Quantitative	Qualitative
General framework	Seek to confirm hypotheses about phenomena	Seek to explore phenomena
	Instruments use more rigid style of eliciting and categorizing responses to questions	Instruments use more flexible, iterative style of eliciting and categorizing responses to questions
	Use highly structured methods such as questionnaires, surveys, and structured observation	Use semi-structured methods such as in-depth interviews, focus groups, and participant observation
Analytical objectives	To quantify variation	To describe variation
	To predict causal relationships	To describe and explain relationships
	To describe characteristics of a population	To describe individual experiences
		To describe group norms
Question format	Closed-ended	Open-ended
Data format	Numerical (obtained by assigning numerical values to responses)	Textual (obtained from audiotapes, videotapes, and field notes)
Flexibility in study design	Study design is stable from beginning to end	Some aspects of the study are flexible (for example, the addition, exclusion, or wording of particular interview questions)
	Participant responses do not influence or determine how and which questions researchers ask next	Participant responses affect how and which questions researchers ask next
	Study design is subject to statistical assumptions and conditions	Study design is iterative, that is, data collection and research questions are adjusted according to what is learned

Despite these differences, qualitative and quantitative methods can be combined so that aspects of one can augment the characteristics of the other. Groat and Wang states, “Historical research may advantageously incorporate a focus on the social impact of particular buildings, styles, or city forms. Likewise, studies of contemporary environments may profit from analyses of historical archives and physical artifacts.” (Groat and Wang, 2002, p: 187)

4.6 Reasons for Adapting The Qualitative Approach In This Dissertation

According to Bryman and as adopted by the author, the qualitative research method can be adopted in this research for the following reasons (Bryman, 2001, p: 265-266).

1- **The research is an outcome of investigations conducted on the AEC market that don’t include numerical data:** This research typically involves data in a form of words, interviews, and opinions of BIM users (largely text-based data). Numerical data does not have a place in qualitative studies. Subsequently, findings do not result from statistical procedures, correlations, and similar mathematical calculations; instead, they come from an interpretation of these non-numerical data.

2- **The research Links between reality (BIM activities) and theory:** According to Bryman, the qualitative approach is not a theoretical phenomenon that is separated from reality, but deals with an existing real case. The social outlines are the normal outcomes of mapping the existing interactivity between different BIM disciplines. According to Natasha Mack and Cynthia Woodsong, the qualitative method is more effective than quantitative in identifying intangible factors, such as social norms, socioeconomic status, gender roles, and their input in the research, which is the main focus of this research (Natasha Mack, 2005, p: 7).

3- **Data collection methods of the qualitative approach allows more interaction between the researcher and BIM users:** The qualitative research approach allows greater spontaneity and adaptation of the interaction between the researcher and the research participants, which provides more accurate information about existing BIM issues and data flow. Natasha Mack and Cynthia Woodsong state “ qualitative methods ask mostly “open-ended” questions that are not necessarily worded in exactly the same way with each participant. With open-ended questions, participants are free to respond in their own words, and these responses tend to be more complex than simply 'yes' or 'no' ” (Natasha Mack, 2005) Thus, using the qualitative method helps the researcher to measure the reactions of BIM stakeholders to a limited set of questions, and subsequently it facilitates comparison and aggregation of data.

4- **Qualitative method allows the change in research design according to the collected data:** In opposition to the scientific model of the quantitative method, whereas theoretical issues raise the research questions, and subsequently drives data collection and interpretation, in the qualitative method, the former in this research is being generated from the latter, since the former is being tested through the latter (deductive view). The former strengthens the relation between theory and research. For example, in this research, a literature review has been conducted to explore the expected challenges of BIM in mid size firms(chapter 2), this review guided the research questions and objectives that later led to the research findings and data interpretation.

For example, this study started with a focus on BIM implementation issues and data workflow in the Schematic Design phase, but later, the research has been expanded to include the Design Development phase. This change in the research design came about as a result of the collected data, which showed that the amount of the communication and information exchange in the Schematic Design phase is less than what could be found in the Design Development phase, as more BIM stakeholders are involved.

Another example of study change would be that, the research started with an objective of mapping and classifying BIM issues, and then these issues would be linked to BIM domains, but based on the data collected, one domain (Policy Domain) has been excluded from the study because of the anticipated difficulty of making any changes to this domain (Policy Domain). Therefore, the study proceeded with a focus on two domains, Process and Technology domains.

Thus, if the existing case for process flow was found to be different than that from the data collected during the literature review, the research design could be changed according to the study situation.

4.7 Types of Qualitative research methods

In this section, we will summarize the basic characteristics of the three main approaches to qualitative research: Grounded Theory, ethnography, and interpretivism.

4.7.1 Grounded Theory

Grounded Theory emerges from the data without preset opinions or notions, which subsequently develop the theory from these data. Once theory development begins, other similar settings can be studied to see if the emergent theory has explanatory power. Strauss has described Grounded Theory as "the development of theory, without any particular commitment to specific kinds of data, lines of research, or theoretical interests." More recently, Strauss and Corbin offered this definition:

> *"In this method, data collection, analysis, and eventual theory stand in close relationship to one another. A researcher does not begin a project with a preconceived theory in mind (unless his or her purpose is to elaborate and extend existing theory). Rather, the researcher begins with an area of study and allows the theory to emerge from the data. ... Grounded theories, because they are drawn from data, are likely to offer insight, enhance understanding, and provide a meaningful guide to*

action." (Strauss and Corbin, 1998, p.18) quoted in (Groat and Wang 2002, p.181)

The main feature of Grounded Theory is its use of an open-ended, intensive, and iterative process that simultaneously involves and reexamines all data throughout the life of the research and doubles back-and-forth between collecting data and coding them. Another important feature is the practice of "memoing", which is described by Strauss as the following,

> *"Theoretical ideas are kept track of, and continuously linked and built up by means of theoretical memos [author's emphasis]. From time to time they are taken out of the file and examined and sorted, which results in new ideas, thus new memos.... Sorting [author's emphasis] of memos (and codes) may occur at any phase of the research. Both examination and sorting produces memos of greater scope and conceptual density."* [(Strauss and Corbin, 1998, p.18) quoted in (Groat and Wang 2002, p.181)]

4.7.2 Ethnography

Although Ethnography has been broadened to a number of different disciplines, such as sociology, human geography, organization studies, educational research, and cultural studies, this approach was originally adopted from the field of anthropology. Ethnography emphasis the studying of a particular culture tied to its notion of ethnicity, customs, beliefs, behavior, and/or geographic location based on information collected through fieldwork. Ethnography has been expanded later to include virtually any group or organization.

The main difference between an ethnographic approach and the Grounded Theory is that Grounded Theory aims to create a theoretical explanation that can be applied to other settings, while the ethnographic approach gives a full delineation of a particular setting that focuses on a wide audience of its human validity (Groat and Wang, 2002).

The most widely used approach of ethnographic fieldwork is the participant observation, whereas the researcher becomes an active member of a culture or a group to record extensive field notes. On the other hand, the ethnographic approach is similar to the Grounded Theory since there is no preset limiting of what will be observed and no real ending point in the ethnographic study.

4.7.3. Interpretivism

As mentioned earlier, Interpretivism seeks to resolve the proverbial Cartesian split between subject and object, mind and matter. In this approach, the researcher provides a full description of the context under study (Denzin and Lincoln, 1994, p: 18), or as Schwandt puts it: The interpretivist researcher must struggle with “the paradox of how to develop an objective interpretive science of subjective human experience."

Interpretivism has been developed from the phenomenological tradition of the philosophers Edmund Husserl and Martin Heidegger and the work of scholars who have tried to adapt this tradition to the human movement sciences (Denzin and Lincoln, 1994, p: 118). Thomas Schwandt describes interpretivism as "Proponents of these persuasions share the goal of understanding the complex world of lived experience from the point of view of those who live it. This goal is variously spoken of as an abiding concern for the life world, for understanding meaning, for grasping the actor's definition of a situation, for Verstehen. The world of lived reality and situation-specific meanings that constitute the general object of investigation is thought to be constructed by social actors." (Denzin and Lincoln, 1994, p. 118)

4.8 Basic approach of qualitative method adopted in this research

The qualitative approach that was adopted in this research is the Grounded Theory, which depends upon the induction method to generate theories or models from empirical data. Because there are very few existing business process models for mid-size architectural firms, the necessity of using Grounded Theory combined with different data collection methods seemed appropriate for this research, in order to generate the desired models and framework. Moreover, the research findings could be gradually refined during the data collection and analysis process and finally to ground the model on the empirical data. There were a few other reasons that suggested the adaption of the Grounded Theory in this dissertation that will be explained in the following section.

1. Better guidelines for a sufficient collection of pertinent data

Essentially, Grounded Theory provides guidelines for the collection of required data for the research without pre-knowledge of these data, concepts, ideas, model or theory concerning the studied phenomena. Also, it can guide towards when to stop data collection. It does so in a highly data-oriented and objective way that is helpful for researchers.

The data collection guidelines are well suited for this dissertation. As mentioned in the third chapter, there is very little information about the business process model of BIM in mid-sized architectural firms in the USA. Subsequently, there are no guidelines that could be found for data collection related to this subject. Thus, personal interpretation by the researcher is involved in the different phases, such as data collection, data analysis, and data verification.

2. Grounded Theory provides guidelines for developing the required BIM related business process model

As previously presented the main objective of this research is to develop a new business process model for BIM implementation. This can be understood as developing a new model rather than testing an existing one. Such is the main features of Grounded Theory, where the research starts without a theory and then develops a new one. Charmaz argues that Grounded Theory could "develop an integrated set of theoretical concepts from their empirical materials that not only synthesize and interpret them but also show processual relationships" (Charmaz, 2005, p: 508). Strauss and Corbin state “studying the routinization of action/interaction, especially in organizations, and discovering what conditions make it possible to stay routine in the face of contingencies (unanticipated happenings) can be just as important a contribution to knowledge development as is studying the novel and problematic action/interaction”. (Strauss and Corbin, 1998, p: 168)

It is believed that data analysis methods used in Grounded Theory can help establish a new process model by modeling the common actions/interactions in the business process and subsequently revealing the routine process of the activities. An important objective of this dissertation: is modeling the common actions/interactions in the business process.

3. Coding of Grounded Theory provides a better mechanism for developing the business process models

Another reason to adopt Grounded theory as a method is that the coding mechanism seems able to help develop a new business process model, through its use for data analysis, developing concepts and the subsequent grouping approach into categories according to similar characteristics. Moreover, the Grounded Theory helps to break the information workflow into bits and pieces (process components), while documenting the business contexts (activities/tasks) for these pieces. Thus, the new business process model was developed through the open coding, the axial coding, the categorization of key activities/tasks into groups and then the rearrangement of these key activities/tasks. Grounded Theory coding succeeded in categorizing these activities into groups at the company level according to the identified structural conditions.

To conclude, Grounded Theory has been adopted and adapted for this dissertation because it is a data oriented qualitative method that is capable of developing a new business process model by using mechanisms of data collection and coding.

4.9 Qualitative Data Collection Tactics

Qualitative tactics of data collection usually involve direct interaction with individuals on either a one-to-one basis or in a group setting. Usually, the process of data collection is time consuming, and sometimes the collected data cannot present the general case in the field of the study. Thus, combining two or more of these tactics enriches the research data and gives a deeper insight into the phenomena under study.

The qualitative research method includes the use of qualitative data collection tactics, and then these data are categorized into patterns for the purpose of organizing and reporting the research findings. Qualitative researchers typically depend on various methods for gathering information such as, participants' observation, case studies, interviews, field notes, and obtaining any other required documents to further understand and explain the studied phenomena (Myers, 2004). Hancock also mentions varying methods of collecting and obtaining a specific type of data; qualitative data cannot be analyzed statistically. Data collection tactics vary between case studies, face-to-face interviews, focus groups, participants' observation and as such tends to be time consuming to collect (Hancock, 1998).

4.9.1 Case Studies

This strategy excels at bringing us to an understanding of a complex issue or object and emphasizes detailed technical and contextual analysis of the studied phenomenon. Case Studies have been used for years as a qualitative research method to examine a variety of disciplines and to provide the basis for ideas and extension of methods through individuals, groups, firms, institutions or other social units. Researcher Robert K. Yin defines the case study research method as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used” (Yin, 1984, p: 23). Thomas offers the following definition of case study: "Case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods. The case that is the subject of the inquiry will be an instance of a class of phenomena that provides an analytical frame — an object — within which the study is conducted and which the case illuminates and explicates." (Thomas, 2011, p: 512)

The main difference between the case studies strategy and other qualitative research strategies is that a single case may not present the whole population of the studied phenomenon. Thus, it is important to set good criteria for selecting the case study in order to make sure that it will present particular facets of the studied phenomenon and what is common and pervasive (Beatham, 2003). As the case study is one of the strategies that have been used in this research, these selectivity criteria will be discussed in more detail in the next chapter.

4.9.1.1 Types of Case Studies

A. **Exploratory case studies:** This type of case study is often performed before implementing a large-scale investigation, and it is mostly considered with certain conditions as generalization and/or validation of the studied phenomenon (Yin, 2003). According to Yin, this type of case study is used to explore those situations in which the intervention being evaluated has no clear, single set of outcomes (Yin, 2003). Exploratory case studies are used to develop a new theory in a field where "not much is known", or to validate, confirm, falsify or adapt a given theory (Eisenhardt, 1989). The basic purpose of exploratory case studies is to help select types of measurement and to identify questions before the main investigation. The major disadvantage of this type is that the initial findings may seem convincing enough to be released prematurely as conclusions (Yin, 2003).

B. Explanatory (Inductive) case studies: This type of case study is often performed if there is a need to answer questions that may explain "the presumed causal links in real-life interventions that are too complex for the survey or experimental strategies" (Yin, 2003, p: 15). Siggelkow states "this type of case study is used to illustrate a research field with little theoretical knowledge" (Siggelkow, 2007). Exploratory cases aim to develop a new theory in a field where "not much is known" (Eisenhardt, 1989). However, the researcher has to be more cautious about developing a whole new theory that could be presented as "uncharted waters", because this may turn into well-known theories through minimal efforts during literature review.

C. Descriptive (Illustrative) case studies are used to describe an event/ process in its natural ambit. The main objective is to answer *how*, *who* and *what* questions (Yin, 2003). This type of case study is used to describe an intervention or phenomenon and the real-life context in which it occurs (Yin, 2003). These are primarily descriptive studies. They typically utilize one or two instances of an event to show what a situation is like. Illustrative case studies serve primarily to make the unfamiliar familiar, and to give readers a common language about the topic in question.

4.9.1.2 When to Use the Case Study Approach

In academic research, case studies are widely used in different contexts with different objectives. According to Yin (2003) a case study can be employed in the following ways when:

(a) The objective of the study is to answer questions of "how" and "why

(b) The researcher cannot manipulate the attitude of the group members who are involved in the case study.

(c) The researcher seeks to cover contextual conditions that are relevant to the studied phenomenon

(d) There are no clear boundaries between the studied phenomenon and its context.

The majority of these reasons compliment the objectives of this research; making the case study, as a qualitative data collection approach, one of the most appropriate to this study.

4.9.2 Interviews

Interviews are strategies for gathering information on the individual basis, with the intent of exploring the characteristics of a large group or culture based on a smaller sample. Kvale defines the qualitative research interview as "an interview, whose purpose is to gather descriptions of the life-world of the interviewee with respect to interpretation of the meaning of the described phenomena" (Kvale, 1983, p. 174).

4.9.2.1 Interview Types

Interviews have different types, such as structured, semi-structured or unstructured. For structured interviews there is a tight structured sequence of questions that the interviewer asks each participant in the same way. The semi-structured interview includes a group of open-ended questions that allows the researcher to choose from them depending on the areas that the researcher wants to cover. Finally, the most flexible type is the open-ended interview, which provides the opportunity for both interviewer and interviewee to discuss some areas in more detail; this type uses a set of questions that allows the interviewer to cue or to encourage the interviewee to express freely his point of view towards the studied phenomenon (Hancock, 1998). In the next section we will provide an overview of each interview type.

4.9.2.1.1 Unstructured Interviews: No set format, but one in which the interviewer may have some key questions that can be changed or adapted to meet the interviewees' response. It proceeds like a friendly, non-threatening conversation. Unlike a structured interview the researcher does not offer a pre-set range of answers for interviewees to choose, and because there is no guide for this type of interview, the interviewer has to build rapport with interviewees. The researcher must have a clear plan in mind regarding the focus and goal of the interview, in getting interviewees to open-up and express themselves in their own way, and in listening to how each interviewee responds to the question.

4.9.2.1.2 Semi-Structured Interview: This type is a flexible interview that generally has a preset framework of themes to be explored, which the researcher can bring up during the interview as a result of what the interviewee says (this type can be used both to give and receive information). Semi-structured interviewing starts with more general questions or topics. Not all questions are phrased ahead of time; the majority of questions are developed during the interview. Thus, it is more beneficial for the researcher to have an interview guide prepared. This guide provides a clear set of instructions for interviewers and can offer sufficient data, which is an informal "grouping of topics and questions that the interviewer can ask in different ways to different participants" (Lindlof and Taylor, 2011, p: 195). This is a list of questions that need to be asked and covered during the interview, usually in a particular order.

4.9.2.1.3 Structured interview: The scope of this approach is as a means of collecting data for a statistical survey, which requires the interview to be presented with exactly the same order and format. Subsequently, the choice of answers to the questions are often fixed (close-ended) in advance, so the questions are always answered within the same context, though open-ended questions can sometimes also be included within a structured interview. This type of interview requires the researchers to develop an interview schedule that includes the wording and sequencing of questions, which involves a careful and thorough analysis to ensure that answers can be reliably aggregated and that comparisons can be made with confidence to determine the core competencies required.

4.9.2.2 The Advantages and Disadvantages of Different Interviews Techniques

Interviews can be done in several ways, but the most common types are face-to-face interviews, interviewing by telephone, which is also popular, and interviewing using the Internet, which is growing in use and currently replacing mail interviews. Kirti Ruikar summarized the advantages and disadvantages of each of these techniques in the following table.

Table 4.3 The advantages and disadvantages of each interview method Source: (Ruikar, 2004, p.17)

Advantages	Disadvantages
Personal Surveys	
• Interviewer can observe reactions, probe and clarify answers • Technique usually nets a high percentage of completed surveys • Flexibility with location and time for gathering information • Allows for good sampling control	• Costly • Time consuming • May contain interviewer biases
Telephone Surveys	
• Fast • Lower cost than personal surveys • Small response bias • Wide geographic reach compared to personal surveys	• Survey length is limited • Difficult to reach busy people • Difficult to discuss certain topics • Can be expensive compared to mail surveys
Mail Surveys	
• Wide distribution and low cost • Interviewer bias is eliminated • Anonymity of respondents • Respondent can answer at leisure	• Accurate lists are not always available • Response is not necessarily representative of the target population • Limited to length of survey • Not timely • Clarifying and probing of answers is not possible • Question order bias • Unable to guarantee a specific total sample

4.10 Purposeful Sampling

Purposeful sampling is the dominant strategy that is virtually synonymous with qualitative research. It is particularly relevant when the researcher is concerned with exploring and understanding the audience; it also seeks information-rich cases, which can be studied in depth (Patton, 1990). Although the list of "purposive" strategies which the researcher may follow is virtually endless, Patton identifies and describes 16 types of purposeful sampling, which include: extreme or deviant case sampling; typical case sampling; maximum variation sampling; snowball or chain sampling; confirming or disconfirming case sampling; politically important case sampling; convenience sampling; and others (169-183, Patton 1990).

Generally, Purposive sampling also known as "*judgmental*, *selective* or *subjective* sampling" (169-183, Patton 1990) because it relies on the *judgment* of the researcher, who targets a specific group of people who are very difficult to locate and recruit for a study. (e.g. people, cases/organizations, events, pieces of data) Usually, the sample being investigated is quite small, especially when compared with probability sampling techniques. Unlike the other sampling techniques, the goal of purposive sampling is not to randomly select units for the studied phenomena, but to focus on particular characteristics of a population that are of interest. This will best enable the researcher to answer relevant research questions.

4.10.1 Types of purposive sample

According to Patton, there are a broad number of purposive sampling techniques that can be used [refer to (Patton 1990) for a complete list]. Some purposive sampling strategies used in qualitative studies are summarized by the" Commonwealth Educational Media Centre for Asia" as the following:

- **Extreme Case Sampling:** Focuses on cases that are rich in information because they are unusual or special in some way. e.g. the only community in a region that prohibits felling of trees.
- **Maximum Variation Sampling:** Aims at capturing the central themes that cut across participant variations. e.g. persons of different age, gender, religion and marital status in an area protesting against child marriage.
- **Homogeneous Sampling:** Picks up a small sample with similar characteristics to describe some particular sub-group in depth. e.g. firewood cutters or snake charmers or bonded laborers.

- **Typical Case Sampling:** Uses one or more typical cases (individuals, families / households) to provide a local profile. The typical cases are carefully selected with the co-operation of the local people/ extension workers.
- **Critical Case Sampling:** Looks for critical cases that can make a point quite dramatically. e.g. farmers who have set an unusually high yield record of a crop.
- **Snowball or Chain Sampling:** Begins by asking people, "who knows a lot about ________". By asking a number of people, you can identify specific kinds of cases e.g. critical, typical, extreme etc.
- **Criterion Sampling:** Reviews and studies cases that meet some pre-set criterion of importance e.g. farming households where women make the decisions (Ch. 13, CEMCA 2010).

4.11 Types of Qualitative Data Collection Methods Used In This Research

In this dissertation, the researcher adopted a dual approach to collect data; that helps to increase the validity and reliability of the data by incorporating two data collection methods, as the strengths of one technique can counterbalance the weaknesses of another. On the other hand, duality in a study of a single phenomenon can result in the combination of two or more theories, data sources, methods, or for investigators to converge on a single construct; the sampling is performed on interviewees, case firms and document availability, etc. The following tactics will be used in data collection in this study.

4.11.1 Personal and Phone Interviews: Both semi-structured and structured interviews have been used in this study. The study started with flexible interviews that generally had a preset framework of BIM related workflow and BIM issues to be explored. Then, structured interviews were conducted to request more information about BIM related activities; the structured interview questions were presented in a specific order and format. The next chapter will discuss this more in detail.

4.11.2 Case Study Type: the descriptive (Illustrative) case study type has been used in this study, whereas the researcher is attempting to describe what is happening once BIM users face issues, what are the consequences and how they communicate. On the other hand, this case study type is useful to help interpret other data that may be available, such as literature or data from interviews.

4.12 Overview of Qualitative Research

While the qualitative research method has several research approaches (such as; Grounded Theory, ethnography, participation observation method, focus groups, etc.), which have different collection and analysis strategies, generally these methods share the same six main stages. These can be classified as the following:

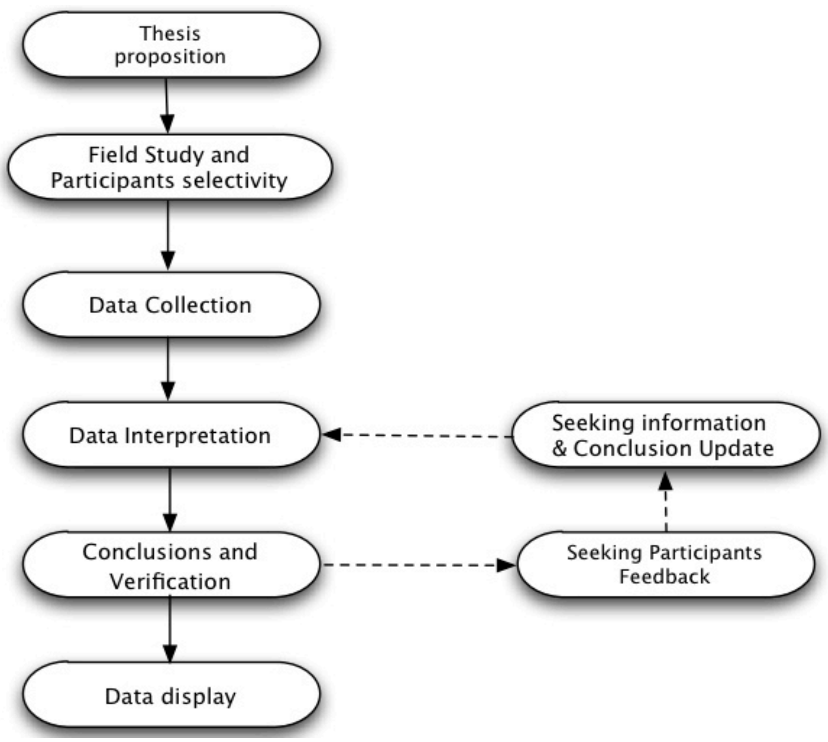


Figure 4.1 The Six Main Stages of the Qualitative Research
Source: (Bryman, 2001, pp. 266, quoted in Cai, 2007 pp. 58).

4.12.1 Thesis Proposition: Formulating a clear scope for the studied phenomenon through the thesis proposition and some general research questions.

4.12.2 Field of Study and Purposeful sampling: Selecting field(s) of study and targeted participants of the studied phenomenon (sampling procedure).

4.12.3 Data collection phase: this is usually determined by the research questions and subjected to data availability. It is important to note that when compared to quantitative research, the required amount of data for qualitative research is usually not quantifiable. However, it should be informative enough to answer all the research questions.

4.12.4 Data Collection and Data interpretation: In the data Interpretation phase, the researcher uses inductive reasoning to interpret the collected data; he/she should be aware of what might be considered as important, relevant and subjective data. It is required from the researcher to clarify how data is organized, refined and interpreted. One relevant strategy to help drive data analysis is the narrative scenarios, which is adopted in this dissertation to develop conceptual and theoretical work, as it helps to identify the importance of which of the stories are valuable to be reported.

4.12.5 Verifications and final Conclusions: Based on the feedback that the researcher gathers from participants and interviewees on the dissertation outcome, sometimes a frequent looping between Step 4 and Step 5 occurs. This usually occurs when adopting the Grounded Theory method, where collection and interpreting of information is a redundant characteristic to refine the research outcomes.

4.12.6 Data Display and Research Conclusions: Final conclusions accompanied with research findings are reached and written from the generalization of conceptual and theoretical work. (Bryman, 2001, p. 265-268).

4.13 Qualitative Tactics used in this Research

In the following section, the researcher will provide an overview of the qualitative method that has been implemented in the research, this overview will focus on three research stages; Data Collection, Data Reduction and Interpretation, Conclusions and Verifications.

4.13.1 Data collection: Data collection can be done in several ways, using a variety of different formats, each with its own strengths and weaknesses. In this dissertation data collection has been conducted by two major tactics, case studies and interviews. On the other hand, in the early phases of the research, the literature review helped develop some general research questions with the aim of formulating research hypotheses and also to draw a clear scope for the studied phenomenon. Later, interviews, and case studies were used as data collection strategies to collect and verify information interpreted from the literature.

4.13.2 Data analysis and interpretation: This phase involves data coding, data translation and interpretation. After choosing and confirming the target interviewees and selecting the target firms, data were collected. After data collection, inductive reasoning was used to help identify what might be considered as relevant or subjective data. By using analysis methods, such as constant comparative analysis and narrative analysis, data was sorted, organized, refined and interpreted.

4.13.3 Conclusions and Verification: Predominantly during the first phase, participants and other multiple sources of data are filtered and verified. Based on the previously stated methods, conclusions are summarized from theoretical work, the existing business process model was drawn, issues were identified and the data were then displayed.

4.14 Overview of Data Collection Techniques in This Research

This study incorporated two techniques for collecting data, the interviews, and case studies. Yet, the literature review in the beginning of this research helped formulate the selection criteria and the structure of the case studies and the interviews. Thus, the literature was one of the tactics that guided the research design but it was not one of the techniques that have been used in the data collection phase. This impact of literature review on the research questions and the case studies criteria will be explained more in the next chapter.

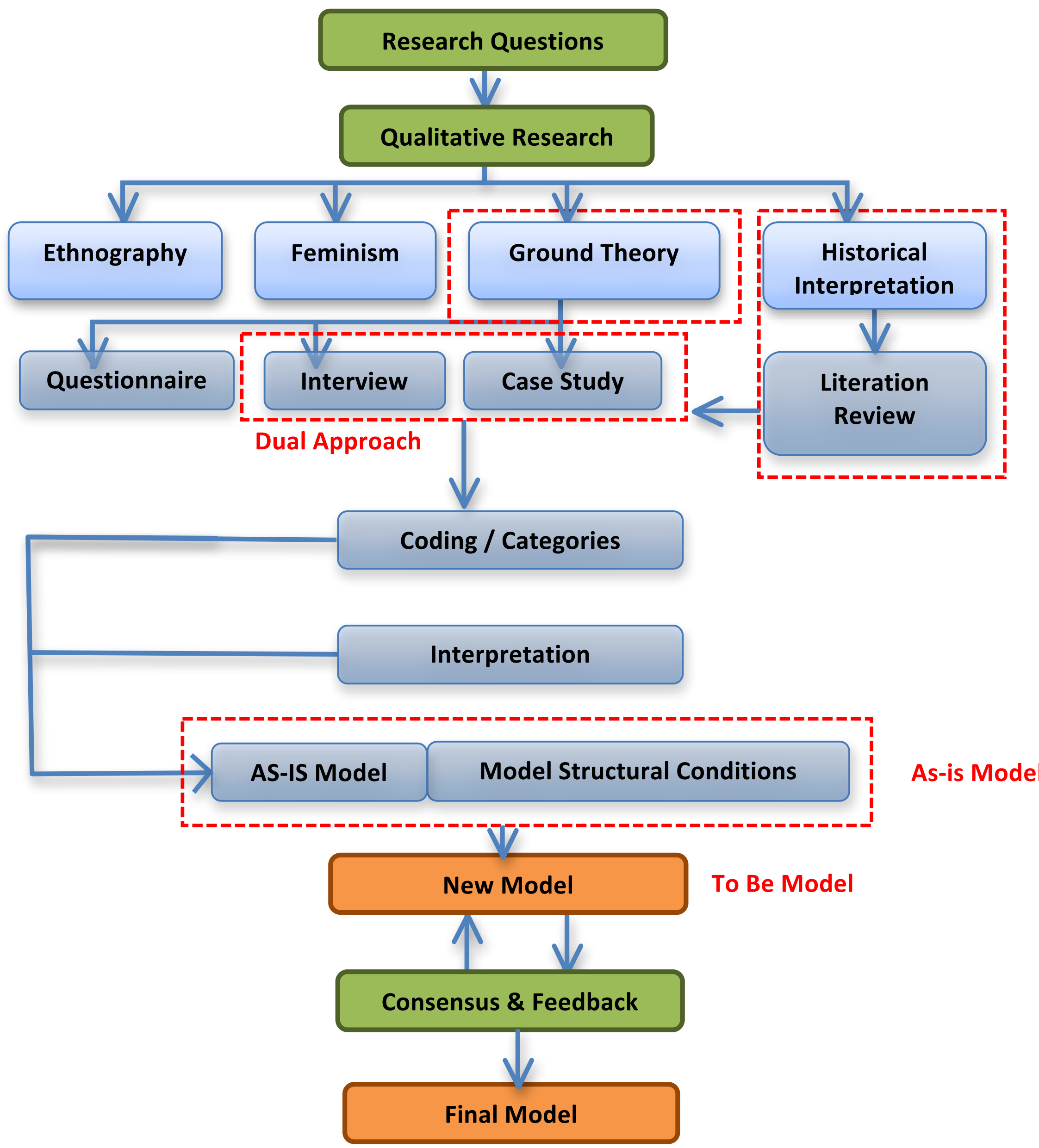


Figure 4.2 Overview of the Qualitative Research Tactics Used In This Study.

In addition to the reasons that have been explained earlier, the case study tactic has been adopted as an appropriate strategy to develop novel, testable, and empirically valid theories (Eisenhardt, 1989). Thus, the researcher applied the case study technique in this research to analyze different variables relevant to the studied phenomenon (Key, 1997). Furthermore, mapping a business process flow requires tracking and mapping of information exchange between BIM users and other various complicated activities, which have to be mapped within existing environments. So, the researcher conducted two case studies in two different mid-size firms, which provided rich and contextual data of the studied phenomena and covered many of the characteristics of the majority of the population in the field of the study.

Another reason to adopt the dual approach is that the case study strategy can be criticized because of the lack of measurability. The collected information is based on the researcher's perception and data analysis, which makes ambiguous, unclear or inexact quantification of research outcomes. Thus, to avoid the methodological weaknesses of the research, the researcher followed dual data collection strategies to verify collected data as much as possible: by carrying out both interviews, and case studies (Cai, 2007). In addition, extensive interviews with numerous BIM stakeholders have been conducted for different reasons; to provide rich and relevant data on the research subject, and also to cover any lack of information from the case studies, to achieve the generalizability of the process model, and to share common characteristics of the mapped business model with other mid-sized architectural firms.

4.15 Overview of Data Analysis Techniques used in this research

Usually, the second phase in qualitative research is the “ data analysis” where raw information is developed and data interpretation is performed, to condense these raw data into categories or themes based on valid inference. To interpret and to structure these data, one important analytical strategy that is being used in qualitative research is inductive reasoning, by which themes and categories are generated from the data through the researcher's careful examination and constant comparison.

Hsieh and Shannon mention three major strategies to interpret and analyze qualitative data, based on the level of the inductive reasoning for each one. Here we will briefly discuss these strategies.

1. The first strategy is the constant comparative analysis, which is being used for developing the Grounded Theory. Here, the coding categories are generated directly and inductively from the raw data, where a constant comparison between different pieces of information can help identify the similarities or differences between them and thus generate categories (Hsiu-Fang Hsieh, 2005, p: 3). This strategy will be implemented in the dissertation.

2. In the second strategy the initial coding starts with a pre-developed theory, and during data analysis the researcher's objective is to articulate the underlying assumptions and then to validate or extend his theory.

3. The third strategy is a summative analysis, which starts with the counting of words or describing the interviews' content to find out indicators in an inductive manner. Data is then sorted, organized, conceptualized, refined and finally interpreted (Hsiu-Fang Hsieh, 2005, p: 3).

However, with the beginning of the data collection phase, the process of data analysis is developed and moves back and forth between both strategy development and data collection. This helps in collecting the valid data from useful sources. Researchers have to be discerning of what might count as relevant or important data and subsequently develop and address the research questions. This is visible in the Grounded Theory method where data collection and interpretation is a looped process and a prominent characteristic of refining the findings (Miles and Huberman, 1994).

4.15.1 Grounded Theory Method as a Data Analysis Technique

The Grounded Theory, which was first introduced in 1967 by Glaser and Strauss as a master metaphor for qualitative research (Glaser and Strauss, 1968), is a general method of analysis which can be adopted to analyze data that have been gathered from interviews, experiments, and case studies as well as any other hybrid data collection for both qualitative and quantitative researches (Glaser and Strauss, 1968). Thus, the Grounded Theory was adopted in this dissertation to generate the desired business process model in contemporary architectural firms. Here the framework is generated from a sociological viewpoint and asks that individuals interpret their personal experience and everyday challenges to create a theoretical meaning out of those experiences and speculation (Bogdan and Biklen, 2007).

This section provides an overview of the Grounded Theory and its data analysis tools. As this will be the primary strategy of data analysis of this research, also discussed are the different methods of Grounded Theory coding and its process. Finally, we will discuss the coding method that is used to meet the needs of this research.

A. Input from the Grounded Theory for the “AS-IS” Model:

Grounded theory can be defined as a systematic methodology that is being used in the generation of theory from raw data. Based on Glaser's definition of Grounded Theory, this is a systematic methodology in the social sciences involving the generation of theory from data. The main concept in the Grounded Theory is a “theoretical sensitivity and logical analysis” (Glaser and Strauss, 1968), which entails the use of logical and theoretical analysis through a continuous interaction of the complex data, and interpreting them into meaningful data that can be filtered according to its importance. (Strauss and Corbin, 1998, p: 42).

It is important to note that the researcher does not commence the process with a predetermined theory, but the formulation of theories is instead developed from the collected data, which seeks to explain how users react to BIM events (Strauss and Corbin, 1998).

To map the existing "AS_IS" model, the next chapter will provide an overview of the whole process of investigation and data collection into the subject firms through case studies and the interviews. In addition to the literature review in the first chapter, all of these resources were utilized through the dual approach to better describe and analyze the flow of information and data exchanging in the subject firms. It will also describe the research paradigm adopted. The data collection and analysis methods and the validation method are presented in Chapters 6 and 7.

B. Input from the Grounded Theory for the "To-Be" Model:

At the end of the data collection process in this research, an explicit business process model was reached and developed. After this, Grounded Theory was used to generate a flexible and more effective business process model. First, the coding mechanism in Grounded Theory helped to generate categories. Then, the patterns were generated and the theory was developed in chapter 8 of the dissertation.

4.16 Overview of Data Coding Techniques

Usually, coding of Grounded Theory data depends on three main analytic techniques: open coding, axial coding, and selective coding (Strauss, 1987; Strauss and Corbin, 1990). The selection of the proper coding technique depends on the emerging theory, the concepts extracted, and their characteristics.

4.16.1 Open coding: Open coding is "the analytical process through which concepts are identified and their properties and dimensions are discovered in data" (Strauss and Corbin, 1998, 101). This technique is the most relevant during early stages of the research and depends on the properties and dimensions of categories and subcategories as variables of classification for describing the phenomena. Variables involved in the phenomenon are labeled, connected and categorizing in an outline form. Open coding depends on asking questions and the making of comparisons. Data are initially generated and then broken down by asking simple questions such as: what, where, how, when, how much, etc. Subsequently, comparing and grouping different events and incidents under systematic variations generates categorization (Strauss, 1987; Strauss and Corbin, 1990).

4.16.2 Axial coding: Strauss and Corbin stated "the process of relating categories to their subcategories, termed 'axial' because coding occurs around the axis of a category, linking categories at the level of properties and dimensions" (Strauss and Corbin, 1998, p: 123). This technique depends on making connections between a category and its sub-categories; the basic framework of generic relationships includes conditions, cause-and-effect relationships, and interactions (Strauss and Corbin 1990, 1998). The objective of the axial coding process is to organize and classify how categories relate to subcategories based on their properties, dimensions and incidents (Strauss and Corbin, 1998).

4.16.3 Selective coding: Although Selective coding will not be used in this study, but it is important to shed light on this type of coding because of its popularity. The selective coding technique is usually done after finding the tentative core of the studied phenomena, or what is thought to be the core. Then, the selective technique integrates categories and subcategories with this central core and provides sufficient detail and density for the evolving theory. The core explains the experience and speculation of the participants and their response to the different challenges. Sampling of the selective coding phase is very directed and intended to fill more details, as a variation and to clarify final outcomes of the research project (Strauss and Corbin, 1998).

4.17 Strategies To Address Limitations to the Qualitative research method

Quantitative methods can be used to seek empirical hypotheses for a specific type of research. An important issue related to the qualitative method is that it produces outputs that are only related to specific cases, and more general conclusions can be considered propositions. In addition to this, Bent Flyvbjerg argues that the qualitative approach may be used not only for the particular cases studied, but also for both hypotheses-testing and for generalizing. Bryman identified four types of problems that usually limit the applicability of the qualitative approach; subjectiveness, replication, generalization and transparency (Bryman, 2001, p: 282-283).

1. **Subjectiveness:** The outputs and the findings of qualitative research depend on the unsystematic approach of the researcher. This may vary from one researcher to another. As such, some variables like the researcher's personal relationships play an important role during the phase of gathering information. The qualitative research approach usually starts with relatively open–ended questions and then narrows the research scope while moving forward to the problem formulation stage (Usually, at the start of the qualitative research, the researcher gives some clues as to why the research area has been chosen and the focus of the study.) Obviously, all of these factors make the qualitative research more subjective than quantitative methods.
2. **Replication:** Based on the subjectiveness of the qualitative method, there are potential replication problems as a result of the importance and the significance of issues and variables, which the researcher considers in his/her research. Cyclically, the unstructured nature of qualitative data impacts the interviewers' impression. Thus, interviewers may consider the research important while others do not. Subsequently, their responses may be varied based on this impression and also based on the researcher's

characteristics and personality (such as; age, gender, etc.). The researcher usually receives critical attention because of the difficulty of having a "neutral" position and reflects his/her opinion while touching more problems while in research. Rossman and Rallis suggest that qualitative research is "quintessentially interactive", where the qualitative researcher is taken into a complex and varied interactions with the participants [(Rossman and Rallis 2003, p: 35) quoted on (Cai, 2007, p: 55)].

3. **Generalization:** One important issue with qualitative research is that the study cases are usually selected purposefully- whether or not they are typical to certain characteristics or contextual conditions. Here, the argument that one or two cases are not representative of all other cases, or that the "the cogency of the theoretical reasoning" [(Mitchell, 1983, p: 207) quoted on (Bryman, 2001, p: 283)] has a big impact on the quality of the qualitative research. Theoretical reasoning has a broad number of different variables such as the criteria of selecting the interviewees or selecting the case study itself. On the other hand, some people consider this helpful to generalize final results rather than rigid statistical criteria.

4. **Transparency:** Sometimes qualitative research is unclear about different variables such as: the selectivity of the case study, interviewers and of data analysis tactics. Moreover, data analysis can take various forms to reach understandable holistic and contextual results. This also directly impacts the quality of the qualitative research, findings and conclusions of the research.

To avoid these four potential problems, the researcher adopted these steps:

1. Minimizing the impact of "subjectivity", via the use of more than one method of data gathering in the research. These methods include: observation and monitoring the participants' interactions, interviews and monitoring the different types of communication between participants. This not only helped

to gather the required information but also to provide a dual approach to verify the collected data.

2. Furthermore, to limit the impact of "generalization" and also the issue of "transparency", the selection of the case studies and the methods of data analysis will be presented later. Transparent tactics that are always regarded by the researcher as essential, for example; many qualitative methods require the researcher to carefully code data and discern themes consistently and reliably. The next chapter discusses these methods and explains the reasons in choosing the Grounded Theory method and the coding strategies used for the dissertation.
3. It was difficult to overcome the "replication" issue, because of the nature of the qualitative method and the way that the participants respond differently during the data collection phase.

4.18 Summary

This chapter focuses on the research methodology applied in the dissertation. Firstly, the chapter offers a retrospective perspective of the research methods that are generally used in the scientific research (qualitative and quantitative research methods). Then, the researcher fully delineates why qualitative research methods were chosen for this dissertation, and discusses the sequential flow of the qualitative research methods. The qualitative method has different data collection strategies, such as; case study, interviews, focus groups, participant observation, Grounded Theory method, and data analysis methods.

Based on these research methods, two case studies in two mid sized architectural firms have been conducted by the researcher, also various interviews with different BIM stakeholders have been conducted to map the existing process model, and to develop a new flexible business process model, the results of the case studies and the interviews will be presented in the next chapter.

Chapter 5

Data Collection and Analysis

5.1 Introduction

Different approaches to data collection for qualitative research were presented in chapter 4. These approaches included participants' observation, focus groups, interviews and the case study method. Collected data could take the form of field notes, texts, sketches, etc. It was previously established that there are various methodological strategies that could be utilized for obtaining data when applying a qualitative approach. In this research the case study and interview tactics were used, which will both be discussed in chapter 5.

5.2 Research objectives

From chapter one it was outlined that this research focuses on two BIM domains, the Process and Technology domains, to identify both communication and information constraints that are facing BIM users during the Schematic Design (S.D) and Design Development (D.D) phases. To meet this objective, the research first attempted to map the "As-is" BIM related business process model, and identify the issues associated with these two domains. The next objective was to develop a new "To-Be" BIM related process model that helps to overcome these constraints, which would then be expected to improve BIM related process flow in the realm of mid-size architectural firms.

5.3 Research methods

The researcher adopts a qualitative method, as it is suitable for the goals and objectives for this research. The qualitative approach that will be used in this research is the Grounded Theory, which depends upon inductive reasoning to generate theories or models from empirical data. Also, because there are very few existing business process models for mid-size architectural firms, thus, the situational interpretive aspect of the

Grounded Theory method seemed appropriate for this research. Moreover, Grounded Theory provides guidelines for the collection of data that are applicable for the research when there is little pre-knowledge of these data, which is the case in this study.

5.4 Overview of Data Collection

As it was introduced in chapter 4, interviews and case studies have been used through three phases of data collection, which can be summarized as the following (Figure 5-1).

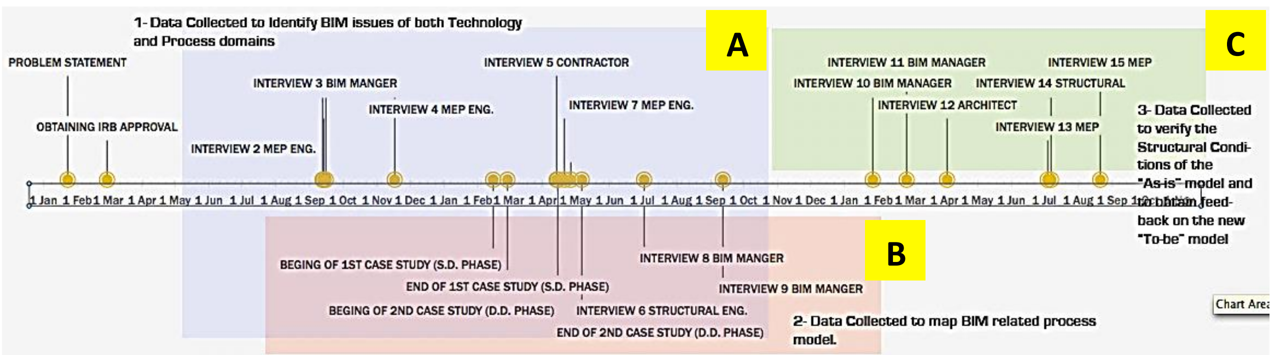


Figure 5-1 Timeline of Data Collection Phases in This Study

A. **(Blue zone)** Data Collected to Identify BIM issues of both Technology and Process domains (Interviews and case studies)

B. **(Red Zone)** Data Collected to map the BIM related process model (Interviews and case study)

C. **(Green Zone)** Data Collected to verify the Structural Conditions of the "As-is" model and to obtain feedback on the new "To-be" model

5.4.1 First objective – Data Collected to Identify BIM issues (Interviews and case studies): During the first phase of this investigation, the researcher conducted several interviews (semi structured interviews) and case studies to collect data that could help identify BIM related issues (Figure 5-2), and the links between them and the existing BIM related business process model.

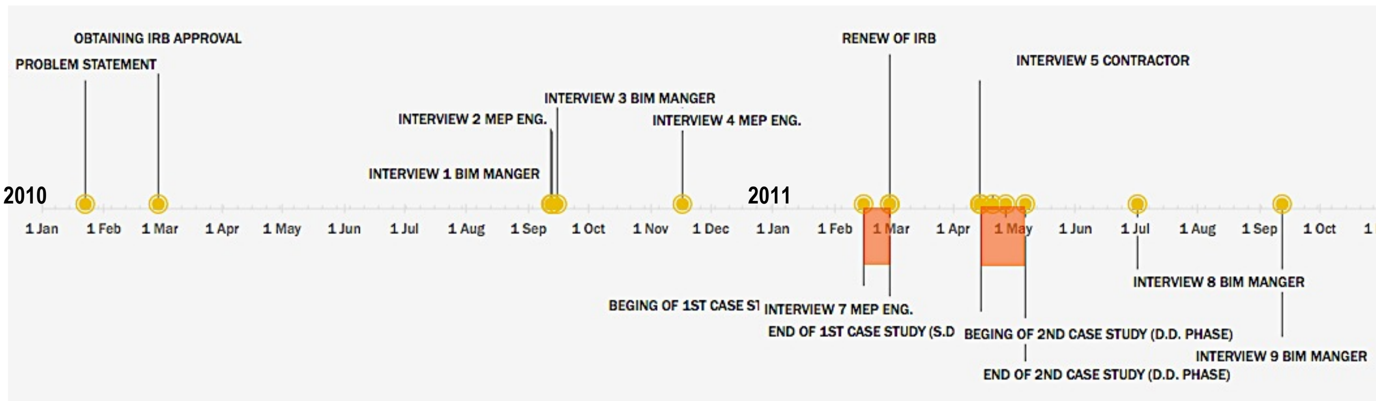


Figure 5-2 Timeline of data collected to Identify BIM related issues

(Interviews and case studies)

5.4.2 Second objective – Data Collected to map the "As-is" workflow (Interviews and case study): Case studies were conducted to map BIM related process modes, however the duration of the case studies was not long enough to develop a map for the entire BIM related business process model. Thus there was a need for collecting more data using interviews to develop a complete preliminary "As-is" business process model thus another round of interviews (structured interviews) were conducted, where interviewees were asked to recall their roles and activities inside the targeted firms, as well as to describe the routes of information flow and how decisions are made (Figure 5-3).

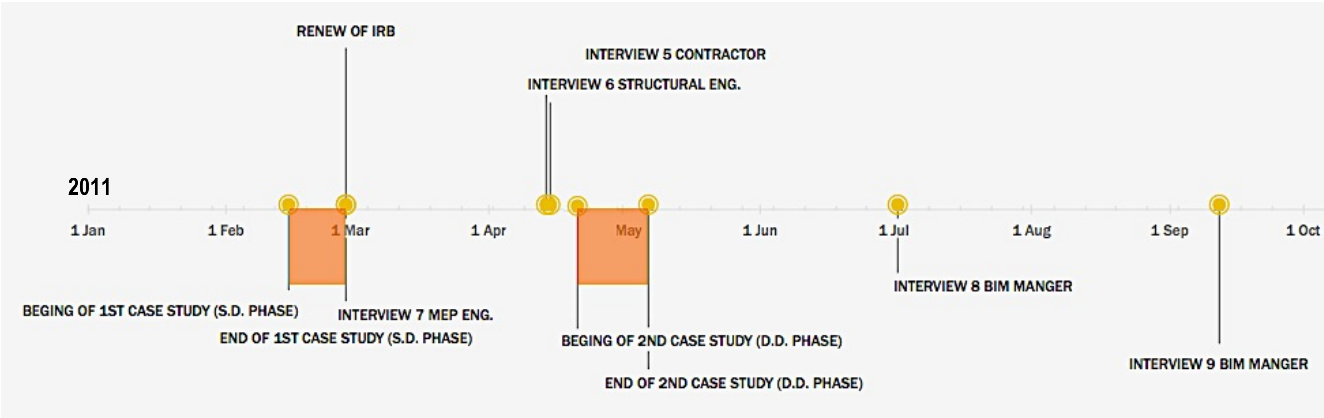


Figure 5-3 Timeline of Data Collected to map the "As-is" BIM related process model **(Interviews and case study)**

5.4.3 Third objective – Data Collected to verify the "As-is" model and to obtain feedback on the new "To-be" model (Phone Interviews):

After developing the "As-is" BIM related model, the researcher conducts a third round of interviews to obtain BIM users' feedback on the new BIM related process model. In order to generalize the research results, the researcher requested feedback from two groups of BIM users, the first group of participants contains BIM users who participated earlier in the research, while the second group contains new participants who provided their feedback on the research findings and if they are facing similar BIM related issues in their firms (Figure 5-4).

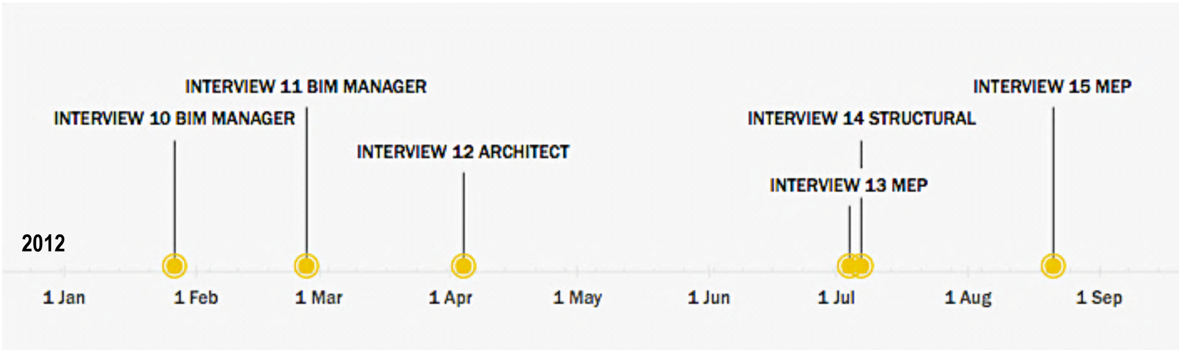


Figure 5-4 Timeline of Data Collected to verify the Structural Conditions of the "As-is" model and to obtain feedback on the new "To-be" model

(Interviews and Online questionnaire):

5.5 Overview of Purposeful Sampling

As mentioned in Chapter 4, one important advantage of the theoretical saturation in the Grounded Theory is that it provides clear guidance on how to conduct purposeful sampling and when to stop data collection. The purposeful sampling for the case studies in this dissertation started with collecting information about the particular characteristics of BIM users, which will best enable the researcher to answer the research questions.

It is important to note that the sample may not represent the majority of the population in the studied phenomenon. Rather, it depends on the type of purposeful sampling technique that is used. Thus, in this dissertation the researcher used the homogeneous sampling technique, where the selected firms have similar and homogeneous characteristics. Such characteristics are of particular interest to the researcher. This method improves the quality of the collected data by focusing on a smaller group.

In the next section, we will focus on the interview, the sampling criteria for interviewees, the interview questions, and characteristics of interviewees.

5.6 Interviews as a Data Collection Method

The interviews have been conducted through three rounds that took place during the period of June 2010 through April 2012 (Figure 5-5), but only after approval from Virginia Polytechnic Institute and State University (Virginia Tech) Institutional Review Board (VT IRB). (Appendix 2).

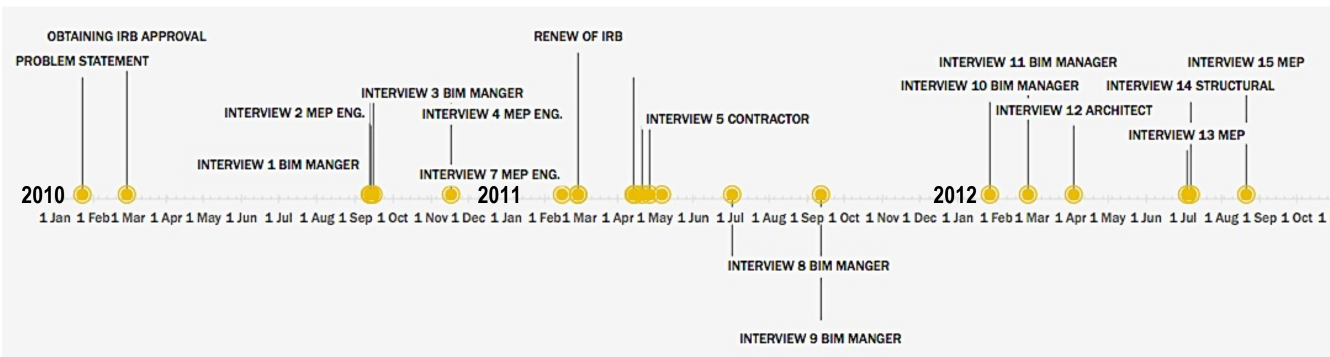


Figure 5-5 Timeline of interviews period.

5.6.1 The Interviewee Characteristics and Purposeful Sampling

Sampling criteria for interviewees used in this study were informed by the method of data analysis (Grounded Theory) and the type of coding that will be described later in this document. According to the Grounded Theory approach, the goal of theoretical sampling at the early phase of data collection is to keep the process more flexible and open to all possibilities. This provides the biggest opportunity for discovery (Strauss and Corbin, 1998). Subsequently, sampling using open coding requires keeping the data collection process open, including all interviewees, places and type of questions.

Thus, it was necessary for the researcher to start interviewing different BIM users from various disciplines, with a broad range of skills and years of experience to get a wide spectrum of ideas and points of views, which adds value to the research. On the other hand, exchanging knowledge between experienced and less experienced BIM users encouraged some of them to get more involved in the research and help find solutions for their daily problems. For example, a mechanical engineer, who has 3 years of experience, stated in the beginning of the interview that she has no issues when using BIM, but once the interview went further, she discovered that she has many issues that she considered "normal daily issues" and that the use of BIM could be improved. Later, she shared her thoughts and got more involved in the research by exploring ways to overcome these issues.

5.6.2 Interview mechanisms

Using interviews as a tactic, the researcher initially sent an email that contained an overview, targets, and expected outcomes of the research to the BIM manger in the subject firms. During the interview, the researcher provided more information about the research (Appendix 2), for example; why, when and how the investigation will be conducted, which helped the interviewees to better understand the research strategy, and to subsequently provide the researcher with relevant information. Interviews began with a top-down management strategy: The researcher started by interviewing stakeholders and BIM/project managers in the targeted firms, and then proceeded to the operational staff and other BIM stakeholders (Cai, 2007, p.86). At the end of the first interview, the researcher asks BIM/project managers to introduce key persons in their BIM related business process. Other interviewees are then contacted and interviews were scheduled.

The interviews started with one or two interviewees and then proceeded with parallel data analysis to avoid being overwhelmed by massive amounts of information, which emerged and were updated during data collection. Furthermore, the questions that arise from the first interview helped to develop and guide the adjustments for the next round of interviews (Strauss and Corbin, 1998, p.206).

This strategy helped to obtain an overview of the "As-is" BIM related business process model and then to develop this model according to the information obtained from the other stakeholders in the targeted firms. This top-down strategy provided the researcher with the required level of support from the senior decision makers in the targeted firms, and enabled access to the other management levels of the firms.

5.6.2.1 First round interview (BIM challenges): In this round of investigation, participants were asked to freely express their thoughts and ideas concerning BIM related issues. This data, in addition to data obtained from the case studies, were later coded and interpreted to provide sufficient information that helps to build a holistic understanding of the As-is BIM related business process model.

5.6.2.2 Second round interviews: The second round of interviews was conducted to complete the layout of BIM related workflow. For this, the interviewees were asked questions that helped to narratively describe the scenarios of information flows and how tasks are performed. Then, these scenarios were developed and verified based on stories from different BIM users. One advantage for the narrative description is that it can be easily understood, discussed and verified with the other interviewees. Additionally, an important advantage for this strategy is that the BIM related business process model is developed at the top management level first, and then decomposed into operational levels based on the data collected from lower level BIM stakeholders (Cai 2007).

5.6.2.3 Third round interviews: For this round, interviews were conducted to obtain users' feedback on the new "To-be" BIM model. Also, because the proposed "As-is" BIM related process model is generic, participants were asked to provide their opinions on which of the structural conditions could have the highest impact on the "As-is" model, and subsequently these conditions could suggest a change in the layout of the model. More details about this round of interviews are provided in chapter 7.

5.6.3 Impact of literature review on Interview Questions

Although the literature review for this study was not one of the primary data collection resources, it helped in formulating both interview questions and case studies criteria. The structure of interview questions of the first round was generated from the literature reviews, whereas the challenges of BIM where the focus of the questionnaire. The table below presents some of the interview question and related BIM challenges.

Table 5-1 The relation between BIM issues from the literature review and interviews questions.

BIM issue: Controlling Data Feed
• **Are you able to identify whom usually feed/modify BIM models with information at any stage of the project?** • **What is the validation method of this information?** • **Do you have an assigned staff that will manage and update the data?** • **How do you track data in your area of responsibility and keep it current?**

BIM issue: Method of collaboration
• **Please describe in detail the procedures that are usually followed to resolve a design problem (Design conflicts)?** • **How do BIM users usually communicate with each other once there is a need for design changes? (For example; they exchange emails, sharing the model, sending PDF's, etc.)** • **How long does it usually take to resolve the design modifications and conflict issues?**

The overall arrangement of the interview questions followed the "funnel" technique, which involves starting with general questions, and then "homing in" on a point in each answer, and asking more and more detailed questions at each level. The researcher starts with general questions that are interesting and easy for the interviewees to answer, for the purpose of brainstorming and get interviewees involved in the studied phenomena. Then, the more difficult questions, which take time to consider and are more specific, are placed in the middle of the interview. At the end, the researcher again placed general questions that are easier to answer and more interesting for the interviewees. The last question is of an open nature through which the interviewees can express their thoughts and points of view; these could cover any aspects of the research.

As was indicated earlier, the questions and the criteria of interview were developed from one interview to another. Thus, the interviews were conducted in an informal manner with semi-structured questions (Appendix 3). Mainly, interview questions were prepared in an open form in advance, to explore the information flow and BIM challenges. By the end of the first interview with the BIM manger, the researcher requested a list of other potential interviewees.

5.6.4 Interviewees Demographics

The interviews took place over the course of seven months from November 2010 to June 2011 with a total of 12 interviewees. Some of the interviews were conducted over the phone and the others were in personal. The following table summarizes the interview process. Table 5-2 represents participants' demographics based on their BIM activities, experience, interview types and durations.

Table 5-2 Participant demographics for case studies and interviews

Participants	Discipline	Firm 1	Firm 2	Other BIM users	Work Experience in years	Interview Mode	Interview Media	Interview Rounds	
								Round 1 (BIM Issues)	Round 2 (Completing As-is workflow)
Participant (1)	BIM manager	*			15	Semi-structured/ Structured	Personal	* (Interview 1)	* (Interview 13)
Participant (2)	MEP	*			7	Semi-structured	Personal	* (Interview 2)	
Participant (3)	BIM manager			*	10	Semi-structured/ Structured	Personal	* (Interview 3)	* (Interview 14)
Participant (4)	MEP			*	4	Semi-structured	Personal	* (Interview 4)	
Participant (5)	Contractor	*			3	Semi-structured/ Structured	Phone	* (Interview 5)	* (Interview 15)
Participant (6)	Structural	*			5	Semi-structured	Phone	* (Interview 6)	
Participant (7)	MEP			*	3	Semi-structured	Personal	* (Interview 7)	
Participant (8)	BIM Manager		*		3	Semi-structured	Personal	* (Interview 8)	
Participant (9)	BIM Manager		*		2	Semi-structured	Personal	* (Interview 9)	
Participant (10)	Architect		*		8	Semi-structured	Personal	* (Interview 10)	
Participant (11)	MEP		*		4	Semi-structured/ Structured	Phone	* (Interview 11)	* (Interview 16)
Participant (12)	Structural			*	13	Semi-structured	Personal	* (Interview 12)	

5.7 Case Study as a Data Collection Method

The Case study is one of two data collection strategies that were adopted for this dissertation, the other source being interviews. The case study typically requires the researcher to become a member of an architectural team for several weeks to gain closer insight into practices and to identify BIM related issues. In the following section we will discuss the criteria for the case studies.

5.7.1 Case study purposeful sampling

The sampling process was initiated by gathering information about the specifications of the mid-size architectural firms in the USA, which range from small family firms to large companies. According to "revitinside.com" (last update: June 2, 2010) 500 of registered architectural firms are using BIM not only as the design delivery tool but also as a collaboration tool. This represents 2.5% of the 20,000 registered architectural firms in the USA. Communication technology advancement has made it possible for some firms to open offices at multiple locations and/or to establish communication with other firms in the US or in different parts of the world.

5.7.2 Characteristics of the Case studies

According to Kennedy, a rich and representative case study is one that helps to strengthen the generalization inference in the field of study. For this reason, the subject firms were carefully selected according to the following criteria.

1. **Firm Type:** The subject firms are mid-size architectural ones in the USA. The firm should contain 5 to 50 employees organized structurally in different departments such as design, production, business development, and construction administration.
2. **Firm Experience:** The subject firms should offer a variety of business services in addition to its ability to complete technically challenging

projects. Also, the firm should be able to conduct simulations and comparative analysis, either environmental; to measure the facility's predicted performance, or construction simulation for sequencing the construction process. Moreover, it should also have the ability to manage and produce construction documents and specifications, and to follow up its progress.

3. **Project types:** As previously mentioned in chapter one, this study focuses on mid-size to large-scale projects (commercial buildings, educational, etc.). These projects were chosen as a limit for this research for two reasons. First is that the number of communication issues that might typically emerge in mid-size to large-scale projects is more than for small-scale projects. BIM also is most often used in large projects where many stakeholders are typically involved during the design phase. Each of these stakeholders brings his/her expertise to a specific design domain. Thus, it is expected that the vast majority of communication occurs between team members for these situations.
   Secondly, adapting BIM as a new technology in architectural firms can add cost to the overall project. Consequently the design firm leaders try to pass this added cost on to their clients, who will pay more only for something they perceive as having positive impact. For now, it can be difficult to demonstrate BIM's benefits, and therefore challenging to convince the client to pay more.
4. **Clients:** The firm should have a broad range of clients (e.g. the government, private developers, etc.) and supervise various project types, such as industrial and civic facilities. This wide range of business patterns will provide multiple perspectives for the business processes that are used in mid-sized architectural firms.
5. **BIM manager:** Although every organization may have different functional departments, it is important for the subject firms to have a BIM manager who is able to facilitate all the necessary procedures to

manage BIM, understands the workflows, who has a technical knowledge of BIM applications and has strong communication skills. The manager should also have the ability to coordinate the information from the different teams, coordinate project reference points and develop the 4D schedule, and more importantly has the ability to make decisions that support the goals of the projects. Moreover, this manager should be open-minded and sympathetic to the importance of this research, as it would otherwise be difficult for the researcher to gather all the information and monitor the workflow without the aid of the BIM manager.

5.7.2 Objectives of the case studies

To map the flow of information in the case studies, Strauss & Corbin identified ten questions that would help to analyze any existing business process; these questions assisted the researcher in understanding what to look for inside both firms. (Strauss & Corbin 1998, p.168)

1. What is going on here?
2. What problems, issues and happenings are being handled through action/interaction, and what forms does it take?
3. What conditions combine to create the context in which the action/interaction is located?
4. Why is the action/interaction staying the same?
5. Why and how is it changing?
6. Are actions/interactions aligned or misaligned?
7. What conditions or activities connect one sequence of events to another?
8. What happens to the form, flow, continuity and rhythm of action/interaction when conditions change, that is, it becomes misaligned or is interrupted or disrupted because of contingency (unplanned or unexpected changes in conditions)?
9. How is action/interaction taken in response to problems or contingencies

similar to, or different from, action/interaction that is routine?

10. How do the consequences of one set of actions/interactions play into the next sequence of actions/interactions to either alter the actions/interactions or allow them to stay the same?

These questions guided the researcher during the case studies in mapping the information flow and subsequently generating the "As-is" BIM related business process model. Especially important were the last few questions, which focus on the consequence of action/interactions. These often become part of the conditional context that indicates the location of the next action/interactional situation. Thus, by referring back to the two major research objectives: (1) to identify BIM challenges in both Schematic Design and Design Development phase, and (2) in addition to mapping the As-is BIM related business process model.

5.7.2.1 Using Case Studies to Identify BIM Challenges

In addition to interviews, the case studies were important for the following reasons:

A. **Determining the importance of BIM issues:** The researcher tried to determine the importance and the frequency of occurrences of each BIM issue for both the Schematic Design and Design Development phases.

B. **Linking these challenges to the proposed "As-is" model**: This helped identify the areas of conflicts for the As-is BIM related workflow, and suggested some solutions to resolve these issues.

C. **Understanding the communication mechanisms that are taken by BIM users to solve BIM issues:** In addition to mapping the communication mechanisms, the flow and the form of information that are transferred between users, is also important.

5.7.2.2 Using Case Studies to map the As-is BIM related process model

Relying on theoretical and logical propositions to map the existing business process model, these propositions will focus on the following two aspects:

A. **Mapping the structure of the subject firms:** an important factor to conducting case studies is to map the structure of the targeted firms. The relation between structure and process is a key factor when analyzing the process. Strauss and Corbin state *"Action/interaction evolves or can change in response to shifts in the context. In turn, action/interaction can bring about changes in the context, thus becoming part of the conditions framing the next action/interactional sequence"* (165, Strauss and Corbin 1998). Thus, by relating process to structure, we are better able to connect categories. Strauss and Corbin also state *"studying the routinization of action/interaction, especially in organizations and discovering what conditions make it possible to stay routine in the face of contingencies (unanticipated happenings) can be just as important a contribution to knowledge development as is studying the novel and problematic action/interaction".* (168, Strauss and Corbin 1998). This highlights the importance of case studies, where mapping of information and routinization of action/interaction of BIM is modeled for enhancing and developing the process map.

B. **Mapping the sequencing of BIM stakeholders' existing activities:** An important question for this research was: How to clearly identify participants' roles, activities, tasks sequences, and information flow for the existing business processes?

C. **Categorization of the existing activities:** What is the best classification of the existing activities and the best rearrangement of tasks within the existing As-is model? And what is the proper rearrangement/redefinition of these activities under the new business model contexts to maintain the flexibility of the model.

5.7.3 Timeline of Case Studies

The communication with the first firm (Firm 1) started in September 2010, while the researcher conducted the case study over two weeks in February 2011. The second case study was (Firm 2) conducted from the last two weeks in April 2011 to the first week in May 2011.

Figure 5-6 Case Studies Timeline

5.7.4 The method of conducting the case studies

The researchers entered both firms as an investigator after receiving Virginia Polytechnic Institute and State University (Virginia Tech) Institutional Review Board (VT IRB) approval. To maintain confidentiality, both firms will be referred to as firms 1 & 2.

The protocol of the case study started with an introductory interview with BIM managers from both firms, which included a presentation of four documents; 1) Research overview (what, why and how the research is to be conducted), 2) case study questions, 3) case study requirements and 4) expected outputs (Appendix 3). For the two case studies used in this investigation the researcher observed the day-to-day operations, team interactions and communication exchanges for a period of several weeks for each firm. The researcher took notes, drew diagrams and conducted interviews.

5.7.5 Characteristics of the First Case Study (Firm 1)

This firm is located in VA and contains 37 architects and employees, in addition to a BIM manager, who has 10 years experience with BIM issues, and 15 years in overall experience, which helped to reveal several communication problems inside the firm. The subject project is a "University Clinical Laboratory Extension". The architectural teamwork for this project consists of at least one member to fill the following categories: shell, enclosure, interior, site and custom objects (People work in separate tasks). The MEP team has four engineers working on this project: HVAC, fire protection, electric, and plumbing engineer, while the structural team has three engineers who work on structural design and analysis.

From both case studies it was clearly shown that BIM could be constrained when not implemented probably. Some pitfalls can be attributed to poor communication and lack of adapting a good business process workflow.

5.7.5.1 Criteria for selecting the first firm as a Case Study

What makes a case ideal for this research is an important question to consider. Thus, by referring back to the sampling criteria for the case studies, we will find that some of these criteria were applied as followings:

1. **Firm Type:** The firm is a mid-size firm that contains 37 Architects/Engineers and also BIM manager. Also, team members were working in distant locations all over the US, which makes communication an important factor in the workflow.
2. **Firm Experience:** The firm has more than 7 years experience working with BIM, while the BIM manager has more than 15 years overall experience.
3. **Scope of the Case Study:** Schematic Design Phase
4. **Project types:** University lab extension – (Educational)

5. **BIM manager:** This case study includes a BIM manager who helps to execute and capture the firm's goals and objectives and supports the communication at the early stages of the project.

The BIM manager was a key factor in this case study. According to the interviews that were conducted with this BIM manager, it has been shown that he is able to facilitate all the procedures necessary to manage BIM, understands the workflows, has a technical knowledge of BIM and has made use of most conventional communication technologies, but he does not support the provision of a "BIM Central Model" or 'all-in-one' computer network. Thus, it was important for the research to monitor how the BIM manager deals with the daily issues of BIM and how he resolves problems.

5.7.6 Characteristics of the Second Case Study (Firm 2)

The second firm contains 48 architects and related employees. The subject project is the "Science/Research Greenhouse Extension – Located in North Carolina"

5.7.6.1 Criteria for selecting this firm as the second Case Study

Like the previous case study, there were certain criteria that made this case study ideal for the research.

1. **Firm Type:** Similar to the first case study, this firm is a mid-size firm that contains 48 Architects/Engineers and a BIM manager.
2. **Project Nature:** The project characteristics are important factors for this case study. The project is a Science/Research Center, which requires early involvement of different disciplines. Managing the communication between all those disciplines, also obtaining the necessary information in a proper time frame are important issues.
3. **Firm Experience:** The firm has more than 10 years of experience working with BIM, while the BIM manager has more than 10 years of experience.
4. **Scope of the Case Study:** Design Development Phase
5. **Project type:** "Science/Research Center" (Educational)

6. **BIM manager:** Similar to the previous case study, the BIM manager had more than 10 years of experience, also assisted in the development of and support for BIM systems that facilitate the procurement, development, management, construction, scheduling and estimating, and the facilities services functions of the firm.

It was noted that both firms are similar in their organizational structure; the characteristics of participants and the disciplines using BIM. Through the case studies and interviews the researcher was able to identify different BIM challenges. The interpretations of the observations from the case studies will be presented later.

5.8 Summary and Examples of Data

During the data collection process, different tactics were used to record the flow of information and activities/tasks related to BIM users. When coding data, it was found to be more effective with multiple sources. The data sources included researcher memos and drawing diagrams, company documents and interviews transcripts.

5.8.1 Researcher Notes and Diagrams

The notes of the researcher were considered to be an important analytical rather than descriptive tool. Researcher drawings were considered visual tools that describe the relationships between the process components and the related concepts. These notes and diagrams were also important in recording some structural issues inside the targeted firms. These included BIM issues, work progress, information flow, and firm structure. Other psychological aspects that can not be obtained from documents, such as personal issues, thoughts, human feelings, etc. were essential in understanding the issues that may impact BIM implementation. These were also documented when possible (Figure 5-7).

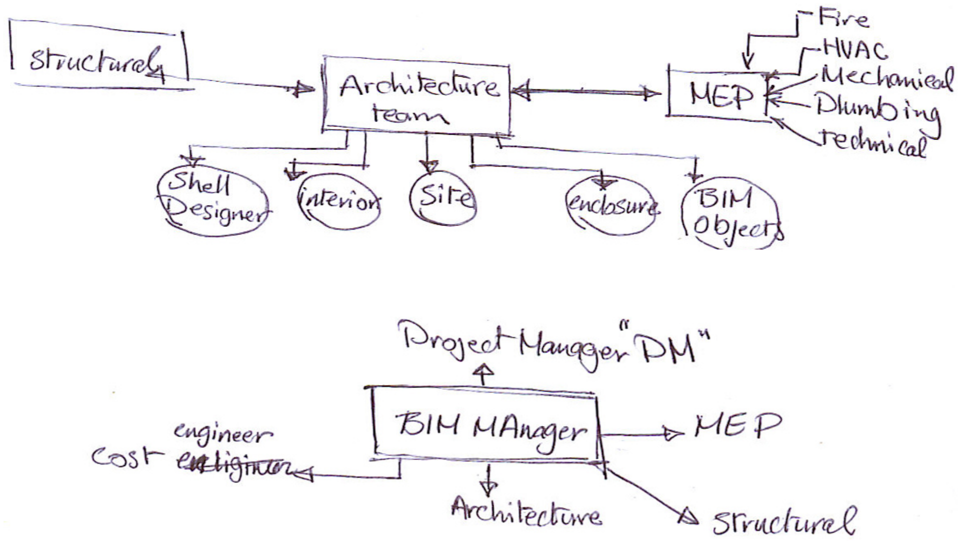


Figure 5-7 Researcher 's Diagrams

The notes of the researcher were useful for data analysis using the grounded theory approach. These notes took several forms, including code notes, operational notes, memos, etc… They were analyzed to help inform procedures later during the coding process, as well as to develop the research concepts, understand the collected data and support development of the process maps that will be developed during the coding process (Figure 5-8).

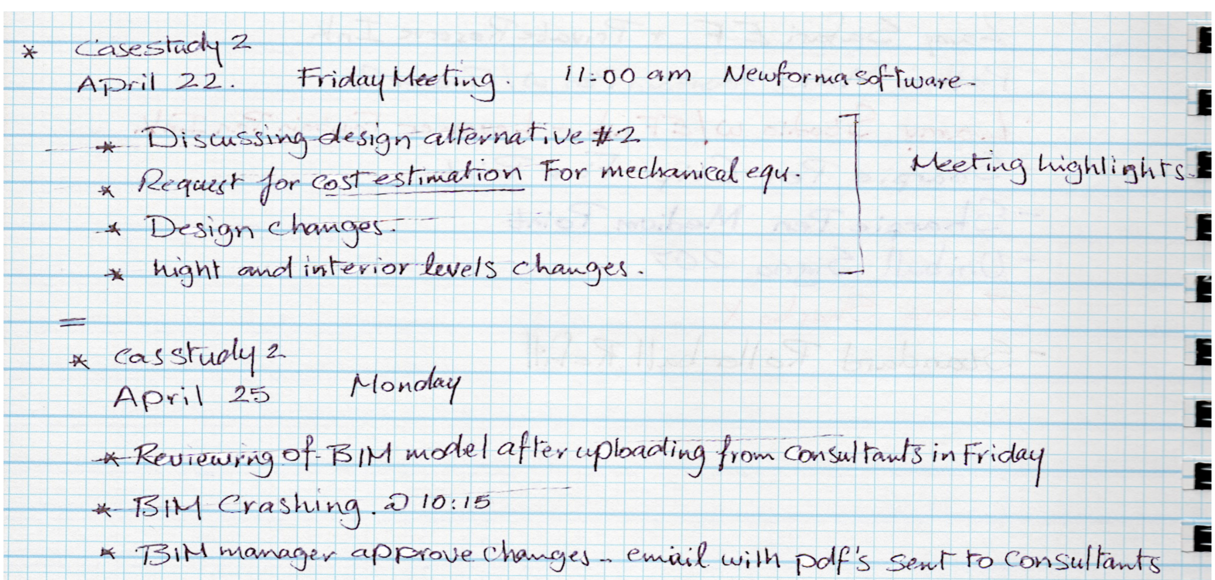


Figure 5-8 Researcher's Notes

5.8.2 Firm documents

BIM documents were collected from the case study firms during the first meeting with BIM managers. These documents provide information concerning how firms handle BIM, including the BIM roadmap, execution plan, Flowchart, etc. Figure 5-9 shows one of these documents (BIM execution plan).

Proprietary Information

Table of Contents

[redacted] BIM Execution Plan   **Page 1**

[redacted]

Figure 5-9 BIM execution plan

5.9 Summary

This chapter has presented the data collection strategies adopted in the dissertation. It reviews different data collection strategies that have been adopted, and then discusses, in detail, both interviews and case studies as approaches. The next chapter also introduces the data analysis undertaken using these methods.

Chapter 6

BIM “As is” Model

6.1 Introduction

As previously introduced, the four main objectives for this research were as follows:

1) Mapping the existing workflow as it relates to BIM implementation (as-is model) for mid-size architectural firms.
2) Mapping the existing challenges that limit BIM implementation during S.D and D.D. phases in mid-size architectural firms.
3) Identifying the variables and structural conditions that would impact or change the existing workflow.
4) Developing a new model that supports BIM implementation in mid-size architectural firms.

Throughout this chapter, the researcher will focus on the first two objectives, mapping the “As-is” workflow and mapping the existing BIM challenges that limit BIM implementation. In addition, there will be an initial attempt to relate these challenges to the workflow, for example, when they occur, in what form and how these issues would impact the BIM related process model. These findings are elaborated further in this chapter.

6.2 Mapping the “As-is” workflow

As was previously stated, interviews and case studies were used to map the “As-is” BIM related process map. Essentially, the first case study was focused on the schematic design phase of clinical labs on a university campus, over two weeks in February 2011. The second case study was conducted over a two to three weeks period in April-May 2011. During the case studies and interviews, the researcher was able to map the “As-is” BIM related process model, in addition to mapping BIM issues that were related to both Schematic Design and Design Development phases. The occurrence of these issues on BIM workflow was also documented.

6.2.1 BIM "As-is" workflow – Schematic Design phase

With the aid of different data resources, including; researcher's notes, diagrams and memos that were gathered during the case studies, in addition to the interviews that were conducted to understand BIM activities and tasks in the Schematic Design phase, the researcher was able to map BIM workflow as the following.

1. The workflow usually starts once the client initiates the need for the project. Usually, the client has preconceived knowledge of the project's purpose and what benefits should be achieved.

   > *"In a typical project at our firm, the process would begin at the point of initial contact from the client. The firm is presented with a list of requirements and the reasons backing them. From this, a project brief is prepared, along with the establishment of consultants. A BIM manager is appointed for these tasks and the future guidance of the team. Upon preparation of the project brief, the effort moved on to diagrammatic methodologies, including bubble-diagraming and rudimentary massing models done in Sketch-Up." Participant (1) Interview (13)*

2. Then the process inside mid-size firm starts with Preparation of the project brief and the establishment of stakeholders' involvement which is followed by the appointed BIM manager who starts an overall process review, that includes planning, managing project documents, and preparation of the project brief.
3. After preparing the project brief, the next step is the bubble diagram, followed by the start of schematic sketching that is requested by the project manager, who typically assigns someone to get the proposal/proposals

schematically into Sketch-Up. At this point the model typically only represents the project proportion and massing (Bubble Diagram).

> *"The workflow in my office is as follows. The architect draws and models in Sketch-UP then after several meetings with the client to discuss the different design alternatives, he gives the model to me to re-draw in Revit." Participant (8) Interview (8)*

4. Once the Sketch-up model reaches the final stage of the conceptual design, the architect usually has a meeting with the client to agree upon the layout.
5. At the same time the project manager assigns another person with the task of laying it out schematically on Revit (Pre-Schematic Drawings). Once the model is transferred to Revit, the process goes back and forth between the appointed BIM manager and the architectural team to develop the concept and basic framework for the design of the project.
6. The model will also be developed to provide "preliminary LEED documents".

> *"The architectural team develops the BIM model to illustrate more aspects of the proposed design as well as verify compliance with US building codes and LEED project guidelines. The outcome would be the "preliminary LEED documents", such as checklists and reference guides. Participant (1) Interview (13)*

7. The next step is to prepare the preliminary feasibility study, which should be reviewed and approved later by the BIM manager.
8. If the preliminary feasibility study is accepted, the execution plan and design management report (including design process, budget and schedule, communication protocols as well as roles and responsibilities of the various parties) will be presented to the client for the "Schematic Design Approval".

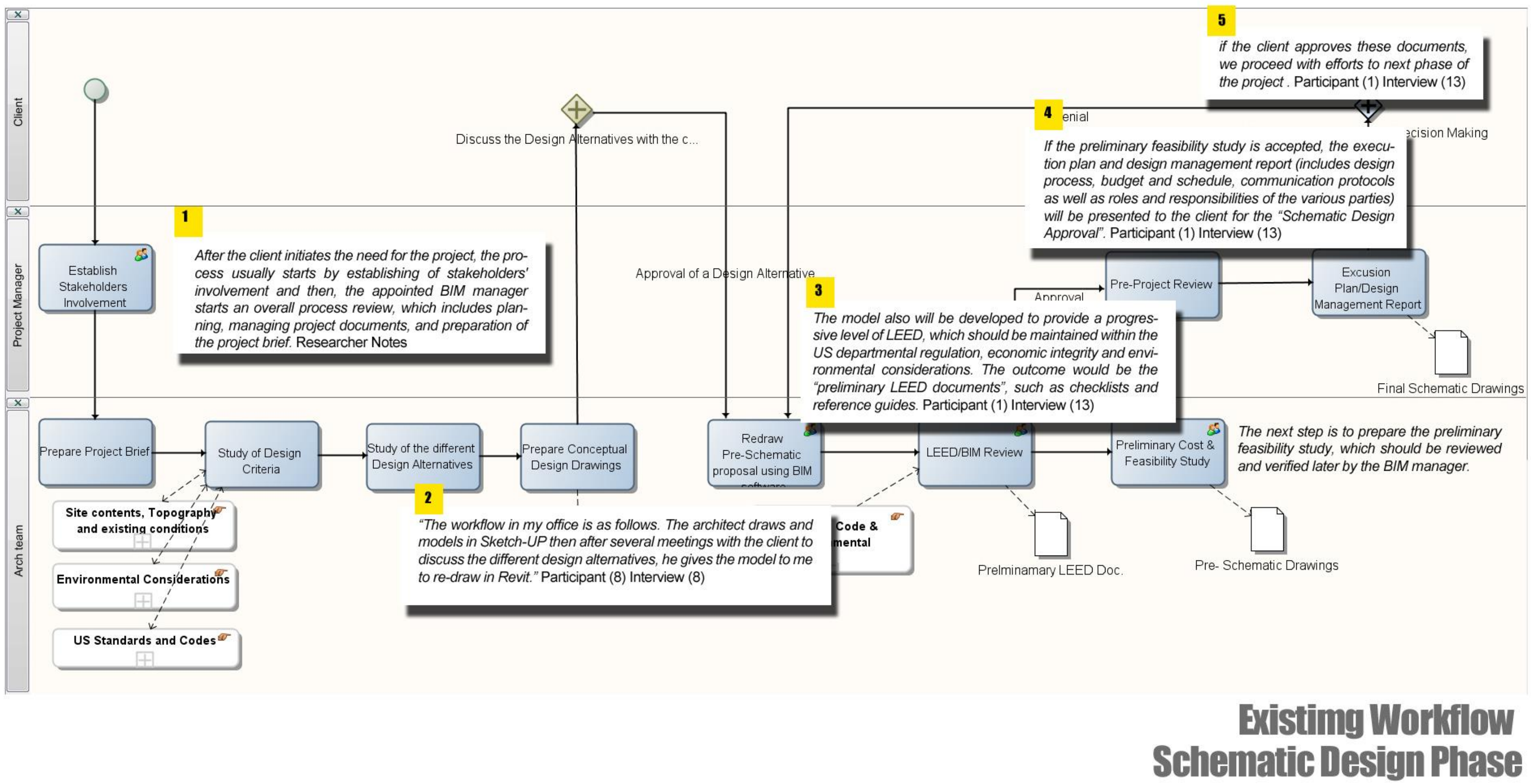


Figure 6-1 Schematic Design Phase- BIM workflow

> *"With client approval of the basic scheme and its transfer to Revit, comes the preparation of the feasibility study, which is reviewed and overseen by the BIM Manager. The acceptance of this study accompanies the go-ahead for the preparation and presentation of the project flow chart and design management report (includes design process, budget and schedule, communication protocols as well as roles and responsibilities of the various parties) to the client as the "Schematic Design Approval". Participant (1) Interview (13)*

9. Then, if the client approves these documents, they can proceed to the next phase of the project.

This sequence of activities has been represented using the BPMN method as mentioned in chapter 3. This method describes the sequence of activities and the flow of information in more detail. It should be noted that any "As-is" model is composed of different levels of details; these details may unveil some confidential information about the targeted firms. Thus, the As-is model here does not show BIM activities in detail, but all the constraints of the BIM process components are presented in figure 6-1.

6.2.2. BIM "As-is" workflow – Design Development phase

The Design Development phase involves more inputs from different disciplines. Typically, these inputs are not found in the Schematic Design phase and may include the development of architectural drawings, structural drawings, building services drawings (MEP+HVAC), fabrication drawings and cost estimation. Thus, this phase is more interlinked than the Schematic Design phase and its process model tries to represent dependencies and overall information flow from different disciplines. The model also presents the information feedback mechanisms and hence the iterative nature of using BIM in the Design Development phase. The existing model for this phase can be summarized in the following steps:

1. After the approval of the schematic design, the architectural team develops the BIM model to illustrate more in-depth aspects of the proposed design; they also verify that the proposed design complies with US building codes and LEED project compliance.

2. After this revision, the project stakeholders usually have a "kick off meeting", in which they identify the project keys, such as; each stakeholder's responsibility, scopes, standards, who's modeling what, levels of detail, push for extra time and fee if it's more than you've budgeted, etc.

   "The BIM kick-off meeting is key (before anyone starts). We determine scopes, standards, who's modeling what, levels of detail, push for extra time and fee if it's more than you've budgeted... and find out who's doing what with the models, Navis coordination, fabrication, owner FM... it might affect how you do things." Participant (3) Interview (14)

3. In the "best case scenario", the appointed BIM manager sends the BIM model to the MEP team so they simultaneously start MEP and HVAC design earlier at the beginning of the design development phase. Thus, the MEP team starts the development and expansion of the mechanical Schematic Design documents and criteria for lighting, electrical and communications systems that have been suggested by the architectural team.

   "MEP gets involved at the beginning of the DD. As soon as we have a form, we invite them to begin brainstorming, things changing too much after the schematic phase. We just have some architectural directions before starting." Participant (1) Interview (13)

   Basically we have six of us working in this particular project, and we have 6 different work groups: Micheal does sanitary and waste piping, I do domestic water piping, we got two electrical guys over there one will *layout lighting and one will lay out the power and things would go in walls , fire alarms, signals and anything like that". And we have two other folks one does the mechanical piping and the other one takes care of the duct work." Participant (11) Interview (11)*

4. Upon the approval of the MEP and HVAC feasibility study, the BIM manager sends the model to the structural team.

   Upon the primary approval of the MEP and HVAC feasibility study, we send the model to the structural team. They start to develop the structural system and dimensions, final structural design criteria, foundation design criteria, coordination clearances, and finally outlines of specifications/materials lists. Participant (3) Interview (14)

5. After making the required changes, the last step on the structural design is to prepare the feasibility study. Once the feasibility study is accepted, the BIM manager will review the whole business process and project documents. At this time, the architectural team works on landscape design and documentation services as well as the development of outline specifications or materials lists to establish the final scope and preliminary details for on-site and off-site civil engineering work and landscaping work.

   When we receive a Revit Architecture file from an Architect, we start linking that file into our Revit Structure file. We use the Copy-monitor tool to generate columns, walls, grids, levels and floors. The architectural model gives us a starting point for the structural design, based on the architect's design intent. If the architect has defined structural components in the initial linked file (either because they are part of the architectural visual design, or as a starting point to calculate clearance between the structural beams and the ceilings for example) we usually don't use them and will create a new structural *system by creating new elements on top of the architectural linked model.*

This work process is quite common and completely reasonable - since we are responsible for the structural design and the architect is not! Participant (12) Interview (12)

6. The next step is the review of the process by the BIM manager. Upon approval, he/she sends the BIM model or the generated project documents to the project manager and the architectural team to review the feasibility case study, prepare the design coordination strategy and cost documents. If the cost estimation needs updating, which may require design changes, the process once more starts again from the beginning by updating the architectural design, which subsequently may require further changes in MEP or Structural Design.

7. The final step in the design development phase is the project review, which includes reviewing project delivery procedures, construction sequencing, and also review and update previously established schedules for the project. Then client approval is obtained before proceeding to the Construction Documents Phase. Figure 6-2 summarizes the design development workflow.

6.3 Modeling BIM As-is Workflow Using the IDEF Technique

As was previously presented in chapter 3, the existing process model with BIM use will be presented using two modeling approaches; IDEF and BPMN, to combine the advantages of both methods and also to avoid the weaknesses of each approach. Initially, the IDEF technique was used to perform the basic analysis and begins to describe the overall BIM related activities. It was also employed to help capture the interrelations and sequencing among activities, without consideration of whom or what decisions are made to perform each activity.

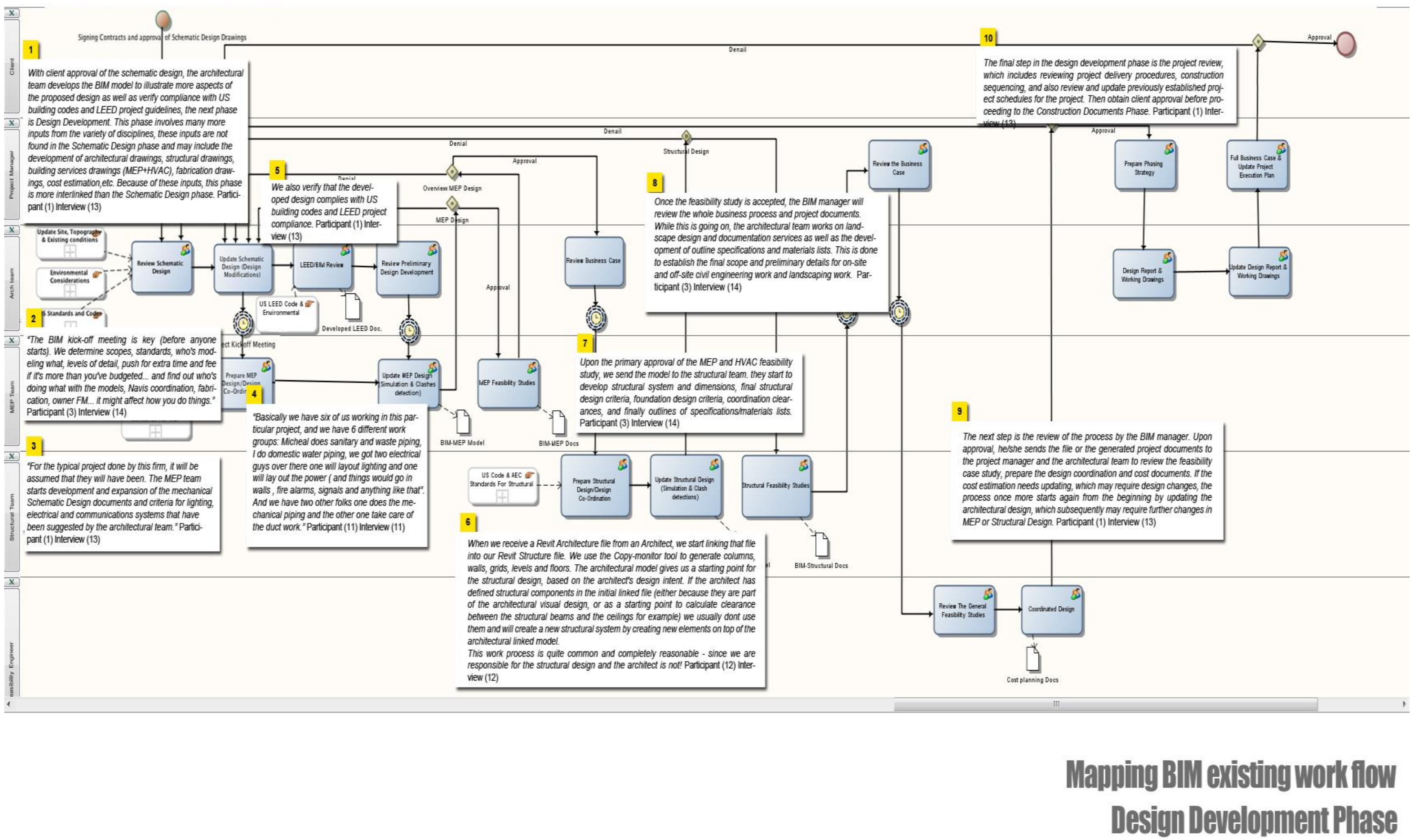


Figure 6-2 Design Development Phase- BIM workflow

This model was initially distributed to different BIM stakeholders in order to obtain their feedback (figure 6-1). The IDEF modeling approach consists of a graphic language and a modeling process that can be used to develop a rich process description. It is an intuitive way to define, analyze and document the business as a whole and the processes of it.

6.3.1 The Expected Benefits of Using IDEF

1. **Easy Understanding of the process model:** Modeling using IDEF method helps non-professionals to understand the nature of the business that is modeled.
2. **Communication:** once understanding has been reached, the nature of the BIM related business processes can be documented and these documents easily exchanged between BIM stakeholders.
3. **Development:** The IDEF model helps to easily identify deficient areas of the BIM related business processes in order to improve them.
4. **Remodeling:** The model provides a tangible basis for redesigning the BIM related process and performing simulations of the redesigned (To-Be) process as defined by the strategy.
5. **Enlightenment:** modeling helps uncover anomalies and redundancies.

Having used the IDEF modeling technique for the "As-is" BIM related process workflow, the expectations of the researcher were not confirmed as it was discovered that this modeling technique had little or no advantages to interviewees and BIM users. It seems that interviewees are not very interested in an IDEF model but were more interactive with BPMN model, citing that BPMN was easier to understand. In addition, it provides greater detail about the BIM related workflow, inputs, outputs, actions, tasks and who is doing what, which is vital for the overall comprehension of the workflow, as seen in figure (6-3).

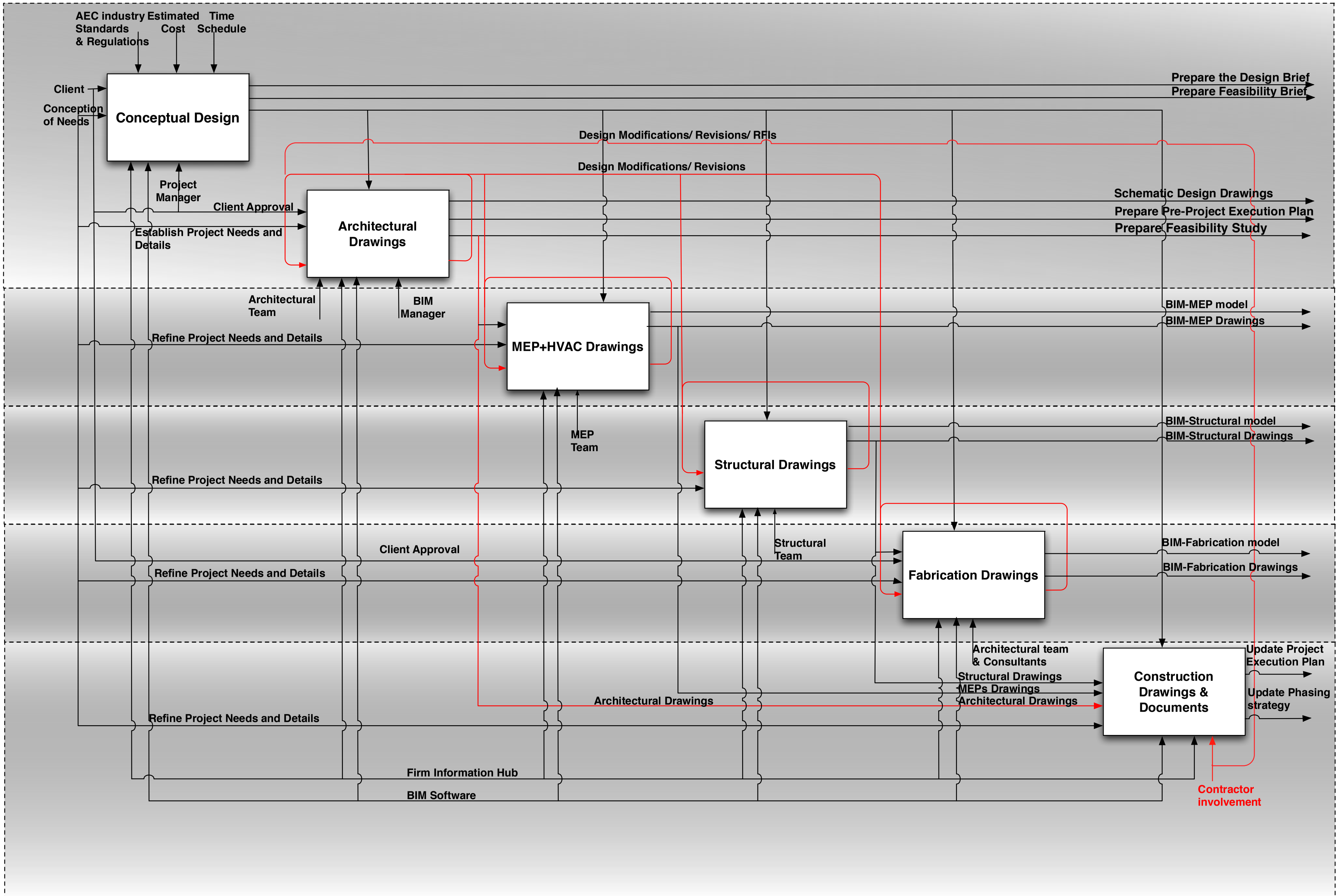


Figure 6-3 the existing BIM process model using IDEF0 technique

6.4 Modeling As-is Workflow Using the BPMN Technique

The BIM related process model has also been generated using the BPMN method as mentioned in chapter 3. This method describes the sequence of activities and the flow of information in more detail. It should be noted that any As-is model is composed of different levels of details; which could reveal some confidential information about the case study firms. Thus, the As-is model here does not show the BIM activities in detail, however the constraints associated with the workflow are summarized in table 6-1

The BPMN model was distributed to a sample of BIM stakeholders upon their requests for more information about BIM procedures and also to compare BIM functions from one firm to another. At this point, the researcher had to go into each business component to explain in detail; activities, decisions, communication types, 'performed by whom', and the flow of information. This helped the researcher to get more specific comments and feedback concerning how BIM stakeholders see the existing model and also to identify the problems, which limit a more complete BIM implementation.

The BPMN model presented here is composed of three levels (subjected firm, model process-component and activity/tasks levels), the model displays different kinds of decisions which are taken by BIM members, plus the exchange of information between them.

It is important to point out that the BPMN model shown here represents a more general BIM AS-IS model that has been developed based on a desirable role-task match. This has been done to reveal how BIM models are created and fed with information by the different BIM (internal or external) team members in a sequential manner. The model sheds light on how BIM functional tasks and roles can be performed in a more desirable way.

The generated workflow model is a general and flexible template that not only represents one mid-sized firm in the field of study, but also, according to interviewees' feedback, reflects a broad number of mid-sized firms in the USA with similar BIM practices. The proposed model can be used in cases of process improvement in the future. It is important to mention that the details of the As-is model are not listed in this thesis to protect the privacy of the case study firms. Nonetheless, table (6-1) presents the detailed procedures for exchanging information and the chain of BIM activities.

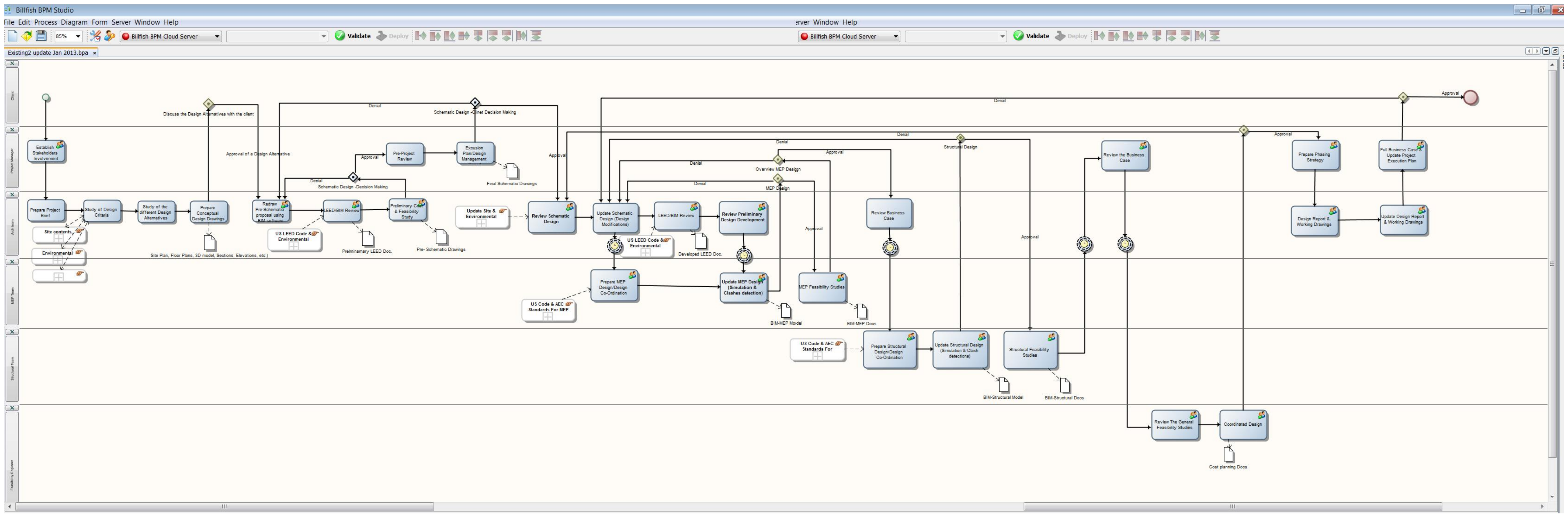


Figure 6-4 Mapping the existing BIM process model using BPMN Technique

Table 6-1 BIM "As-is" related process components

No	Task type	BIM members	Input	Activity/task	Output	Notes
1	Start Event - Initial action	Client			Client requirements	
2	Starting of Process	Project Manager	Client requirements	Establish Stakeholders Involvement		
3	Sub- Process			Prepare Project Brief		
4	End of Process			Prepare Design Concept (Bubble Diagram)	Bubble Diagram	Beginning of architectural team involvement
5	Starting of Process	Architectural team	Site & Environmental Analysis	Pre-Schematic Design		
6	Sub- Process		US LEED Code & Environmental Considerations	LEED/BIM Review	Preliminary LEED Doc.	
7	End of Process		Material enquiries + Previous project Databases	Initial Cost & Feasibility Study	Pre- Schematic Drawings or alternative designs + quantities + design-specific advices and method statement	Drawings and project documents returned to Project Manager (Pre- Schematic Drawings)
8	Decision Making	Project Manager Planning engineer + Estimator + Engineering consultant + Operation engineer	Pre- Schematic Drawings	Denied	Returned to step 5	Revision of Schematic design phase
9				Approved	Pre-Project Review	
10	End- Process			Execution Plan/Design Management Report	Final Schematic Drawings	Forwarded to client

Table 6-1 BIM "As-is" related process components (Continued)

No	Task type	BIM member	Input	Activity/task	Output	Notes
11	Decision Making	Client	Schematic Design and other documents	Denied	Returned to step 5	Revision of Schematic design phase
				Approved	Signing Contract- Move to Next Project Phase (Design Document)	Move to the Design Development Phase
	End of Schematic Design Phase- Beginning of Design Development Phase					
12	Start Process	Architectural team	Pre- Schematic Drawings & Update Site & Environmental Considerations	Review Schematic Design	Reviewed strategies in planning, program, design, material and subcontract procurement	
13	Sub Process			Update Schematic Design (Design Modifications)		Beginning of MEP team involvement
14	Sub Process		US LEED Code & Environmental Considerations	LEED/BIM Review	Developed LEED Doc.	
15	End Process			Review Preliminary Design Development		Documents are reviewed with MEP team
16	Start process	MEP Team	US Code & AEC Standards For MEP	Prepare MEP Design/Design Co-ordination	Material enquiries + Previous project databases	Initiating communication from step 13
17	Sub-Process			Update MEP Design (Simulation & Clashes detection)		BIM-MEP Model

Table 6-1 BIM "As-is" related process components (Continued)

No	Task type	BIM member	Input	Activity/task	Output	Notes
18	Decision Making	Project Manager	MEP + Schematic Drawing	Denied	Returned to step 13	
19				Approved	MEP + Schematic Drawing	
20	End Process	MEP Team	Approved MEP + Schematic Drawing	MEP Feasibility Studies	BIM-MEP Drawings + MEP Cost analysis report with material list + enquiries issued+ list of suppliers invited to quote, etc.	Drawings and documents returned to Project Manager for approval
21	Start Process	Architectural team		Review Business Case		Beginning of Structural Team Involvement
22	Sub Process	Structural Team		Prepare Structural Design/Design Co-Ordination		
23				Update Structural Design (Simulation & Clash detections)	BIM-Structural Model	Drawings returned to Project Manager for approval
	Decision Making	Project Manager	Structural Design and other documents	Denied	Returned to step 13	Revision of Design Development Drawing
				Approved	Move to Structural Feasibility	
24	End Process	Structural Team		Structural Feasibility Studies	BIM-Structural Docs + Structural Cost analysis report with material list + enquires issued+ list of suppliers invited to quote, etc.	Drawings and documents returned to Project Manager for approval

Table 6-1 BIM "As-is" related process components (Continued)

N	Task type	BIM member	Input	Activity/task	Output	Notes
25						
26	Decision Making	Project Manager+ Engineering consultant + Planning + Risk manager + Bid manager + Insurance manager + Legal manager + Financial manager + Subcontractor	MEP + Structural + Schematic Drawing	Review the Business Case		
27	Start Process	Planning engineer + Estimator + Engineering consultant + Operation engineer	MEP + Structural + Schematic Drawing	Review The General Feasibility Studies & Other Documents		
28	End Process			Coordinated Design	Overall Cost estimation (including Direct cost + Staff cost + Financing cost + Insurance + Site indirect cost + works cost + other cost + Markup & Overheads + Tax, etc.)	Drawings returned to Project Manager for approval

Table 6-1 BIM "As-is" related process components (Continued)

29	Decision Making	Project Manager	Overall project documents	Denied	Returned to step 13	Revision of Design Development Drawing
30				Approved	Prepare Phasing Strategy	
31	Start Process	` Project Manager	Overall project documents	Prepare Phasing Strategy		
32	Start Process	Architectural team	Overall project documents	Design Report & Working Drawings		
33	End Process		Overall project documents (with required amount of copies)	Update Design Report & Working Drawings	Project Review Report + Qualifications	
34	End Process	` Project Manager	Overall project documents (with required amount of copies)	Full Business Case & Update Project Execution Plan	Reviewed strategies in planning, program, design, material and subcontract procurement + Controlled work directions and progress	
35	Decision Making	Client	Overall project documents	Denied	Returned to step 13	Revision of Design Development Drawing
36				Approved	Prepare Construction Documents (Next Phase)	

6.5 Mapping As-is workflow

As previously mentioned, the second objective of this thesis is to map the As-is issues related to BIM, when they occur in the workflow, to determine how these issues would impact the BIM related process model. These findings are presented in the next section.

6.5.1 BIM related issues- Schematic Design Phase

In the following section, the researcher presents further research findings from issues that limit the optimum implementation of BIM during the Schematic Design phase. Initially, the issues were classified into two domains, the first being the "Technology domain"; the second the "Process domain".

6.5.1.1 Technology domain issues - Schematic Design Phase

Although the researcher was not expecting to find any technology related domain issues in the Schematic Design phase, because BIM is less frequently used in this phase, but contrary to expectation, one major problem was revealed through the first case study. BIM and early stage design applications are not formatted for easy integration, which results in BIM users often redrawing the entire project after reaching the final stage of conceptual design.

6.5.1.1.1 BIM Interoperability

It has been revealed to the researcher that using two software packages in the Schematic Design phase would slow the workflow. Interviewee 3 commented on the issue.

> *"One main issue that we are facing is that here are two different programs who can't talk to each other by sharing the information. This is because they are from two different families. This issue could be understood as originating from the flexibility of modeling by using "Sketch Up", which is easier for many architects to use than Revit at this phase." Participant (3) Interview (3)*

> Another Participant commented on the modeling during the schematic design process by saying, *"I wish the project managers had the tools to begin the bubble diagram and sketching on Revit, but they don't feel free yet, tools are not as fluid as*

pen and paper yet. It's difficult to stop sketching on paper, tools are not there yet!" Participant (1) Interview (1)

"There is no way to bring in a Sketch-Up model into Revit and allow it to be manipulated, I've brought Sketch-Up models in Revit different times before, but it comes in as a solid un-editable block. "Participant (10) Interview (10)

6.5.1.1.2 Impact of Interoperability issue on the existing workflow

The workflow can be described as the following, after the preparation of the project brief, schematic sketching started instantly upon the project manager's request that someone get it schematically right in "Sketch-Up". This model should represent the project proportion and massing (Bubble Diagram). Once the project reaches the final stage of the conceptual design, the architect usually has a meeting with the client to agree upon the layout. Later, the project manager then tasks another person to layout the approved model schematically in Revit, to make use of BIM power in generating LEED documents (if required) and extracting a fairly precise cost estimation.

"The workflow in my office is as follows. The architect draws and models in Sketch-UP then after several meetings with the client to discuss the different design alternatives, he gives the model to me to re-draw in Revit. I link the Sketch-Up file into Revit and use the model as a basis. The problem is sometimes when you scale objects in Sketch-UP, Revit can´t read the objects properly, so I have to redraw the whole project again to make sure there is no missing parts or information… This sounds like the workflow in MANY architect's office because for numerous middle-aged architects out there, Sketch-Up is king and Revit is complicated thus undesirable. Probably this is because they aren't advanced enough in their abilities to use it."

The researcher has found that because drawings have to be initially presented using design software such as Sketch-up, and then redraw the whole project using BIM software, this usually causes a redundancy in workflow, in addition to loss of time. Unfortunately, this is the standard workflow for many mid-sized firms in the USA. Figure 6-5 describes this issue.

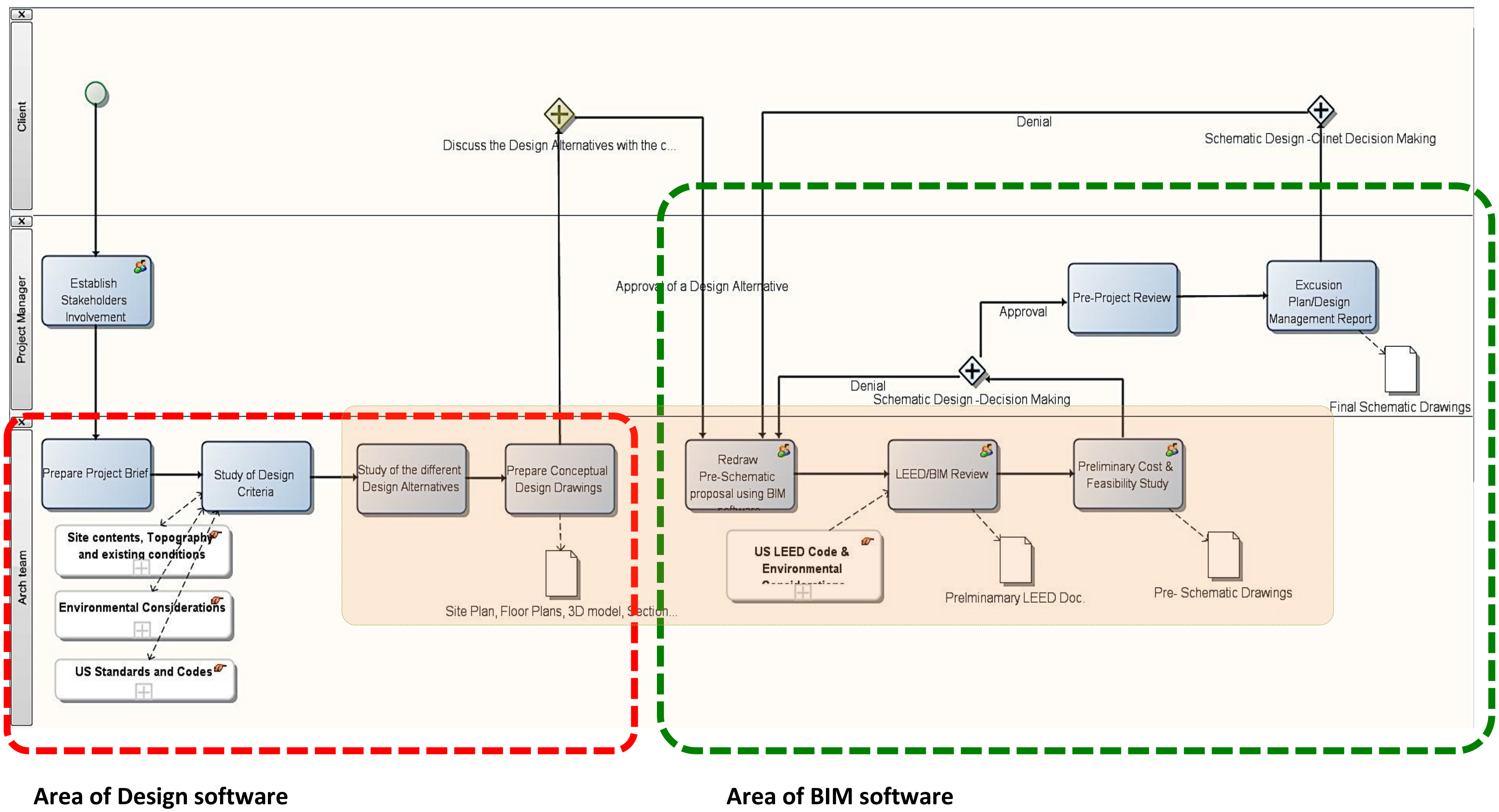


Figure 6-5 Interoperability and duplicated activities – Schematic Design Phase

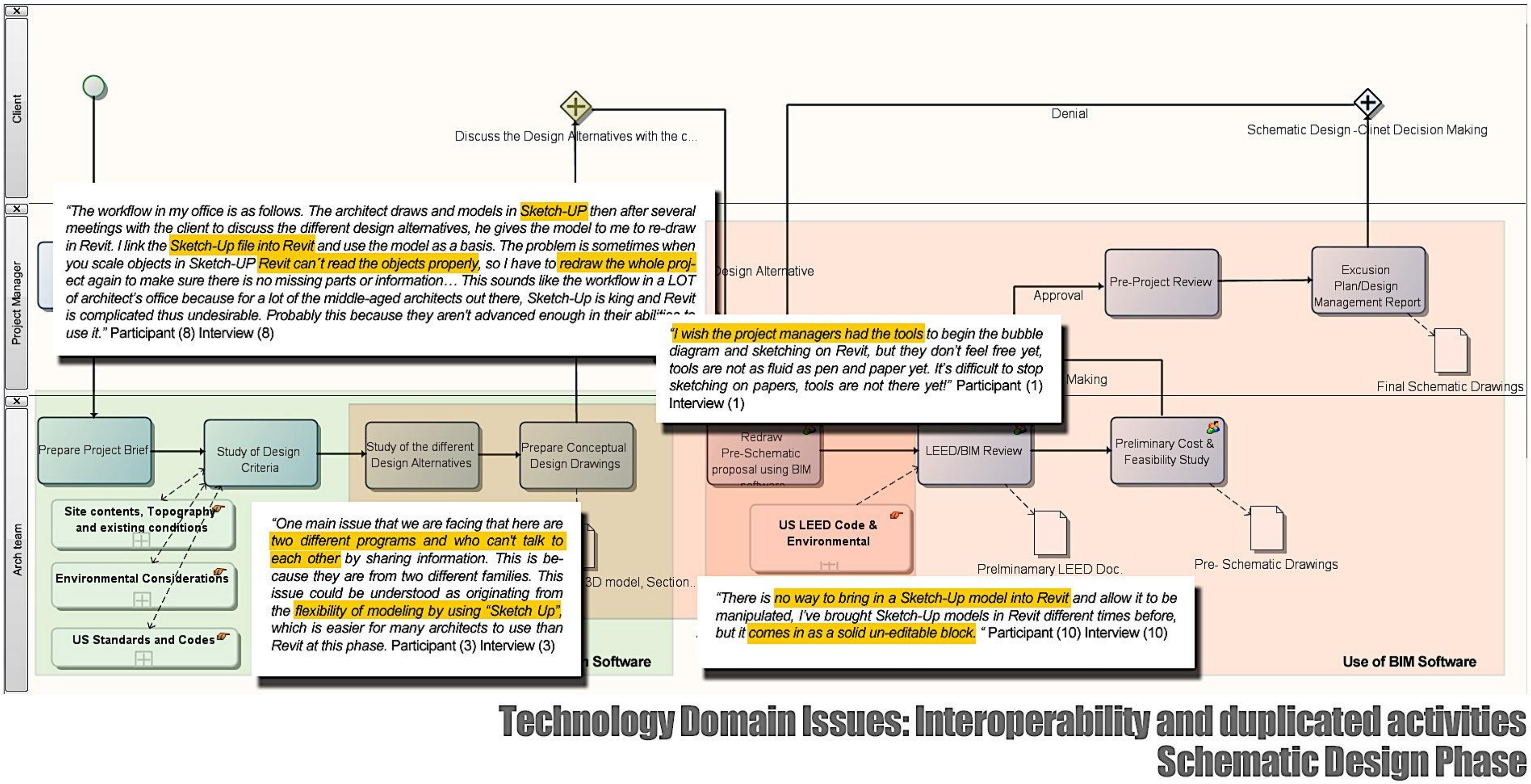


Figure 6-5 Interoperability and duplicated activities – Schematic Design Phase

6.5.1.2 Process Domain issue- Schematic Design phase

The first case study, in addition to the interviews, revealed two major Process domain issues. First was the lack of contractor involvement in the schematic design phase and second the similarity of the existing BIM workflow with old CAD workflow. In the next section these issues will be discussed.

6.5.1.2.1 Lack of Contractor Involvement:

Through the first case study it was shown that the contractor had little, if any, involvement in the Schematic Design phase. The reason might be due to the Design-Bid-Build method that was used for this project. Although there are a number of construction project delivery methods in addition to the traditional and most common Design-Bid-Build (DBB). The method used should support collaboration between the architect, contractor, and other design disciplines in order to engage with the owner and the BIM manager/Project manager on aspects such as planning, design, constructability reviews, material selection, and cost engineering reviews. Using the common Design-Bid-Build method, in this case study the contractor was brought into the project rather late in the design process.

> Participant (1) relates this issue to the following *"Design -bid Build is pretty big with us. Universities hire us to design a project and sometimes they don't have a contractor in place and we don't have an interface with them based on university choice. But the way the universities tend to work is they don't pick one early in most cases, sometimes they have already chosen a contractor or are in a process of picking one. When that's the case, it's really wonderful, but it's not always the case." Participant (1) Interview (1)*

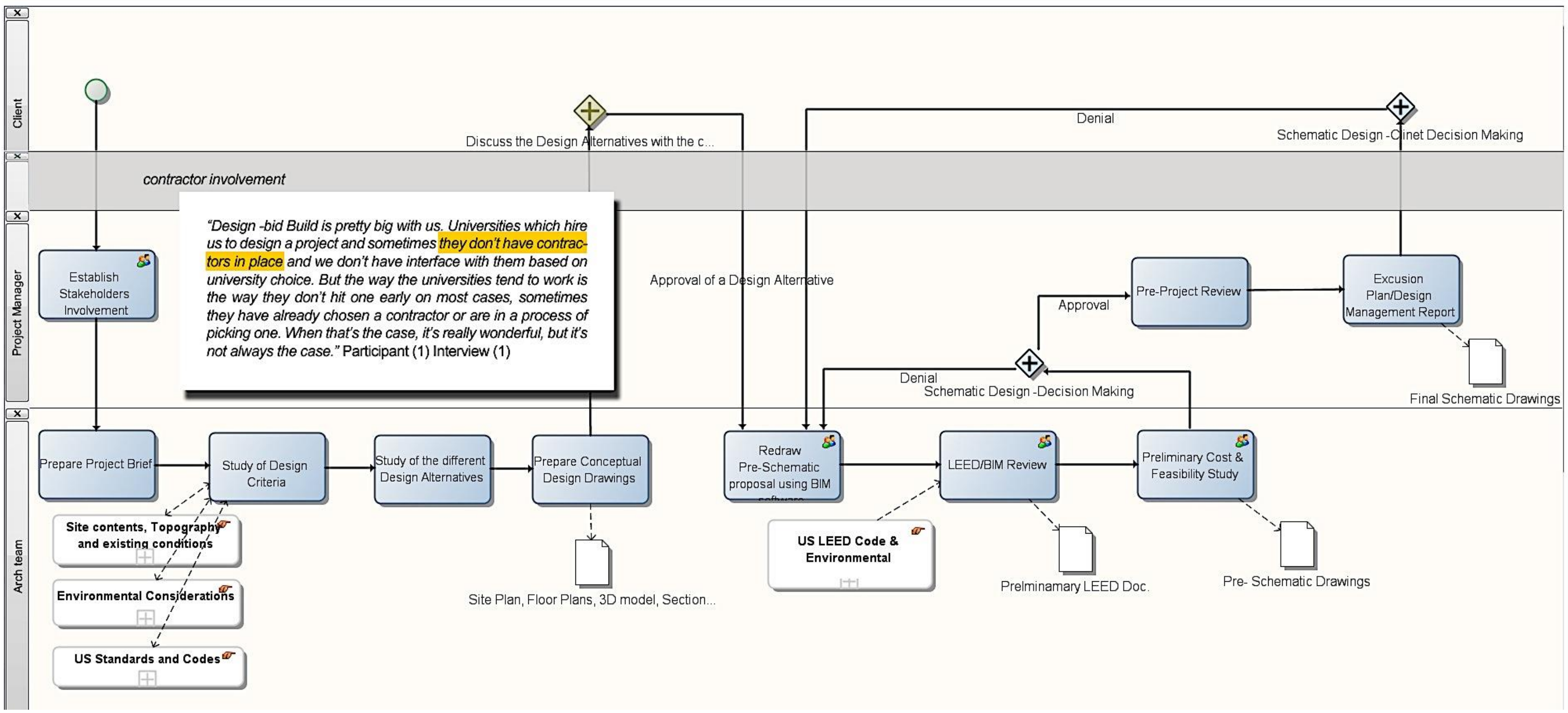


Figure 6-7 Lack of Contractor involvement – Schematic Design Phase

6.5.2 BIM related issues- Design Development Phase

It is important to mention that generally during the Schematic Design and Design Development phases there is poor communication between team members. Some participants mentioned that there is a lack of communication between different BIM users, which results in loss of time and duplicated effort. In the following both Technology and Process domain issues that have been found through case studies are presented. First, the issues for the design development phase are presented. As in the Schematic Design phase, issues for the Design Development phase were classified according to the two BIM domains "Process domain issues" and "Technology domain issues".

6.5.2.1 Process domain issues

The process domain issues in the Design Development phase can be classified as follows:

1- Lack of contractor involvement
2- Routing of information and lack of a central model
3- Sequence of activities.

6.5.2.1.1 Process domain issues - Lack of contractor involvement

Similar to the Schematic design phase, mapping the workflow as it relates to the use of BIM in the Design Development phase revealed the lack of the contractor involvement. The researcher questioned one of the interviewees about what could be the process scenario due to the lack of contractor involvement, he answered; "*the contractor got the BIM model, and because of the lack of embedded information in the model, the contractor started to embed his own data. He filled all the category fields and added new categories to show the model to his own subcontractor". Participant (3) Interview (3)*

Participant (2) stated that this issue arose for a variety of reasons saying "*because there was no contractor since the beginning of the project, the model usually has a certain amount of information that may be too much or too little; then we started to build into the model, whether these information is accurate or not but we have to add it anyway. The problem occurs once the contractor gets involved and requests more information (RFI's), someone has* *to go back to plug-in more data or to check it. When these requests come in at the last minute this may cause a lot of extra work*." *Participant (2) Interview (2)*

As previously stated, both subject firms confirmed that for most of their projects they use a Design-Bid-Build delivery approach, which is currently the most common method used in the American market. However, it is recommended that there should be collaboration between the architect, contractor, and other project stakeholders in the early stages of the project. Unfortunately sometimes this was difficult to achieve because of formatting barriers for data exchange, Participants (3, 12) relates this issue to the following:

> *"Contractor involvement depends on the project; sometimes we don't have him on at the beginning. Some of our work, like apartment buildings, usually goes in bid." Participant (3) Interview (3)*
>
> *"No collaboration with contractor, all what we have is contact with the client (the architect), client requirements that's all we got". Participant (12) Interview (12)*

6.5.2.1.2 Process domain issues - Routing of information and lack of a central model

The lack of a BIM central model and the difficult routing of information, are related issues. The second case study showed that because there wasn't a BIM central model to act as a central communication/information hub, information routing was difficult. In the next section the concept of a central BIM model is presented in terms of how this could affect the flow of information.

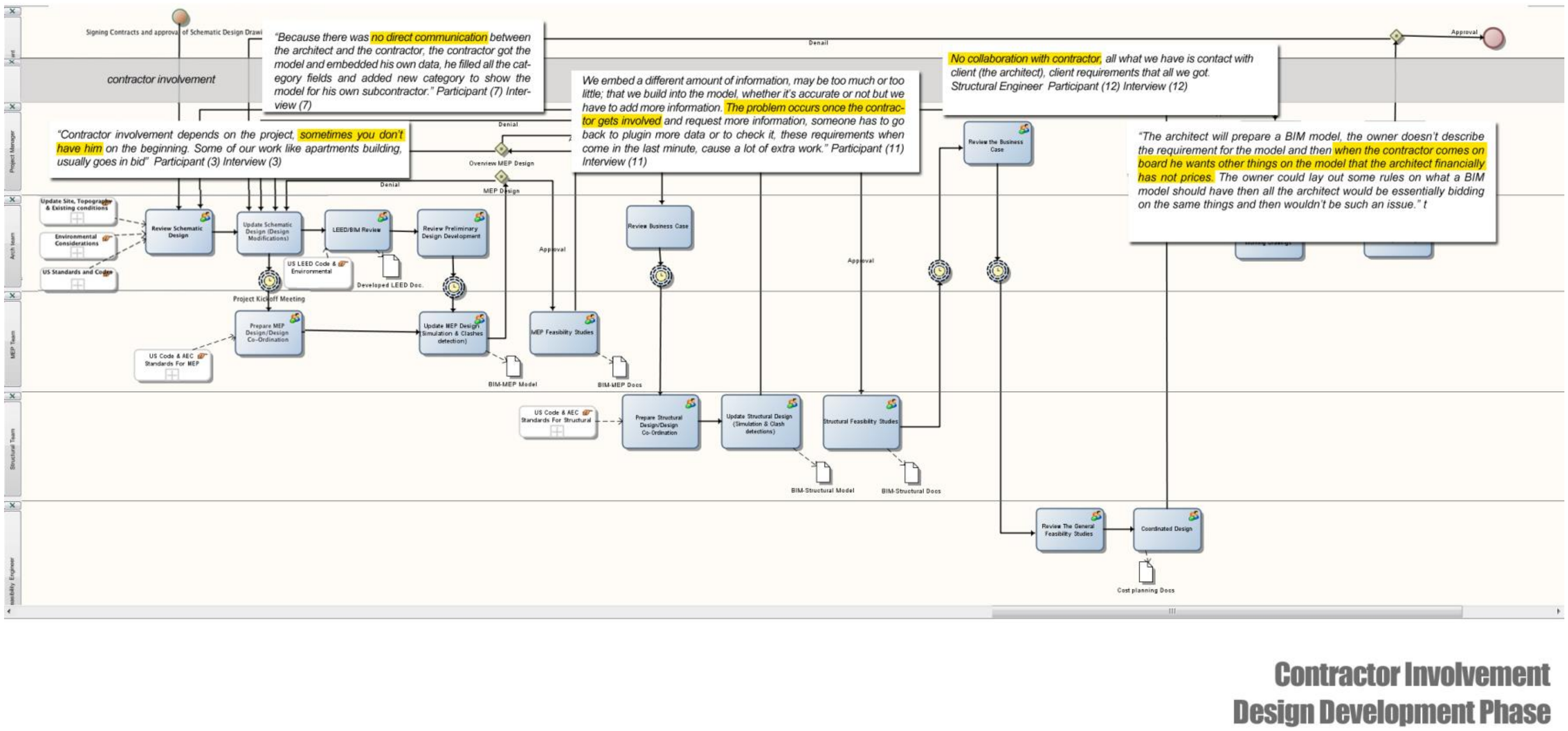


Figure 6-6 Lack of contractor Involvement – Design Development Phase

6.5.2.1.2.1 Lack of a Central BIM Model

For the purpose in this research a BIM model can be defined as a "central hub of information", whereas the model acts as a single source that enables easier and faster interdisciplinary communications, and subsequently reduces the number of communication interfaces between different BIM stakeholders and supports the BIM collaborative environment. To explain the importance of the "central model" further, Olcay Çetiner states "The idea is that if you want to interconnect a large number of nodes, you can reduce the number of interfaces by creating a central node. The nodes can be models of different applications, domains, or disciplines. The central node can be called the central model, or core model, or kernel model, etc." (3, Underwood and Isikdag 2010).

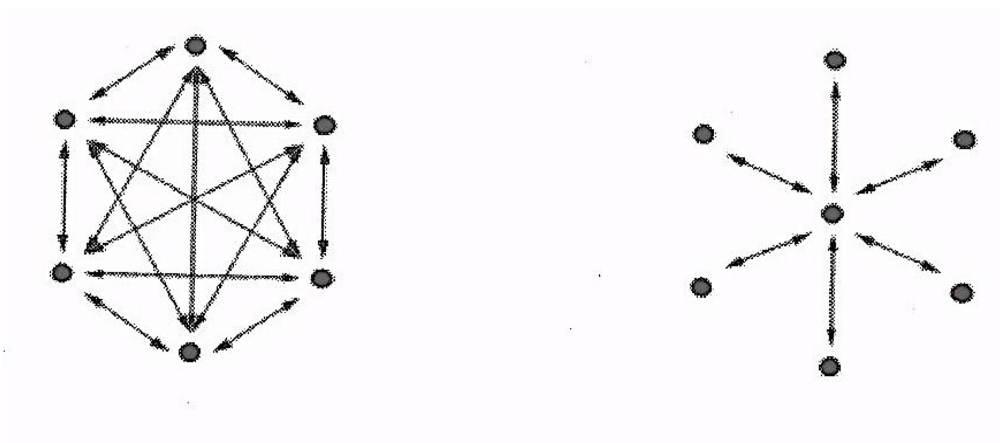


Figure 6-9 Communication Nodes (3, Underwood and Isikdag 2010)

Without a central node (left picture- Figure 6-9) the number of interfaces between n nodes is [n (n-1)], whereas the number of interfaces with a central node (right image) is reduced to 2n. For example, if we have six BIM stakeholders who need to communicate for an hour with each other, without the aid of a central BIM model, this would take [6 (6-1)] hours, or up to thirty hours of communications, while communicating directly through the central BIM model only twelve hours (2n= 12 hours) is needed, which is a savings of eighteen hours. Unfortunately, the "central model" scenario is not implemented in many mid-size firms. This is due to the situation that for many of these firms their MEP or Structural engineering teams are remotely located. Thus, the BIM stakeholders share the model through separate files (Similar to CAD systems) and not as a central model (for example: one BIM file for MEP data, one for the structural data, and one for the architectural team).

> *"BIM is one file, but multiple people are working on it live in the architectural firm, same with the MEP office and structural engineer, but we don't exchange the model lively between us and consultants until Fridays, they copy the latest version and upload it to the ftp[1] server, so everybody shares and sees the other guys work, but we are not going to see what MEP is doing or what are the structural changes until Friday." Participant (9) Interview (9)*

Thus, BIM is typically a collection of files, inside each of the BIM stakeholders' office, and BIM users don't share the model because of the file size and limited Internet capabilities (This may also refer to Technology domain issues). Moreover, the researcher found that in some cases, the BIM model could be broken up into several files to limit file sizes for certain projects.

> "*I work for a firm that does a lot of university work and I am encountering the same problem. It is quite common to have two or more separate projects occurring simultaneously in the same building. And often there are different design teams on each one, requiring duplicate models for each project. When all is said and done, the information from each model needs to be compiled into a master file to have an accurate record of the building." Participant (3) Interview (3)*

---

[1] **File Transfer Protocol** (**FTP**) is a standard network protocol used to transfer files from one host or to another host over a TCP-based network, such as the Internet.

6.5.2.1.2.2 Routing of information

The researcher observed that because of the lack of a central BIM model, there is no direct communication between BIM users, which subsequently affects the flow of information by increasing the communication route. It was observed that BIM mangers in both firms have control of everything regarding BIM data and documents. All BIM users for both firms have to send information through a FTP server to be verified and approved by the BIM mangers before sending it to other BIM users, or they may contact him/her if they need help with any missing information. With this structure, the BIM manager contacts the other consultants or BIM users, while the BIM users do not have direct communication between each other. The main BIM model is updated to the FTP server once a week, usually Fridays. Thus, on that day, each team copies the latest version and uploads it to the ftp server, enabling the exchange and sharing of the model and seeing the progress of the other teams. Unfortunately this means that they do not see the progress of other teams until the end of the week.

> *"The office is broken into teams; each project team consists of four to seven members based on the project size. Each team consists of at least one member to fill those categories, which are shell, enclosure, interior, site and one for custom objects. People work in separate tasks and the BIM manager is responsible for managing the work between them." Participant (9) Interview (9)*

> *"We don't share the model, but the model is being updated to the ftp site once a week, usually Fridays, and they wait until Friday when they see the model to see if it has been fixed, it could take five days to see changes on my model if we notice a problem on Monday". Participant (11) Interview (11)*

> *The problem that we are encountering now is as its follows; let's say there are two projects going on in the same building. One project is done by an in-house person on our network, the other project is being given out to a consultant (off-network). So essentially, there are now two master files -the one in-house that we are working (A & MEP) and a copy of the master that was given to the*

consultant at a snapshot in time (either before the in-house project started, or during). Participant (8) Interview (8)

The researcher observed that all project members have to email library objects to BIM managers for review and to check that there is no broken content or content that doesn't fit in the project. It is then posted to the open directory, which contains the whole project library, to make it available to all other members.

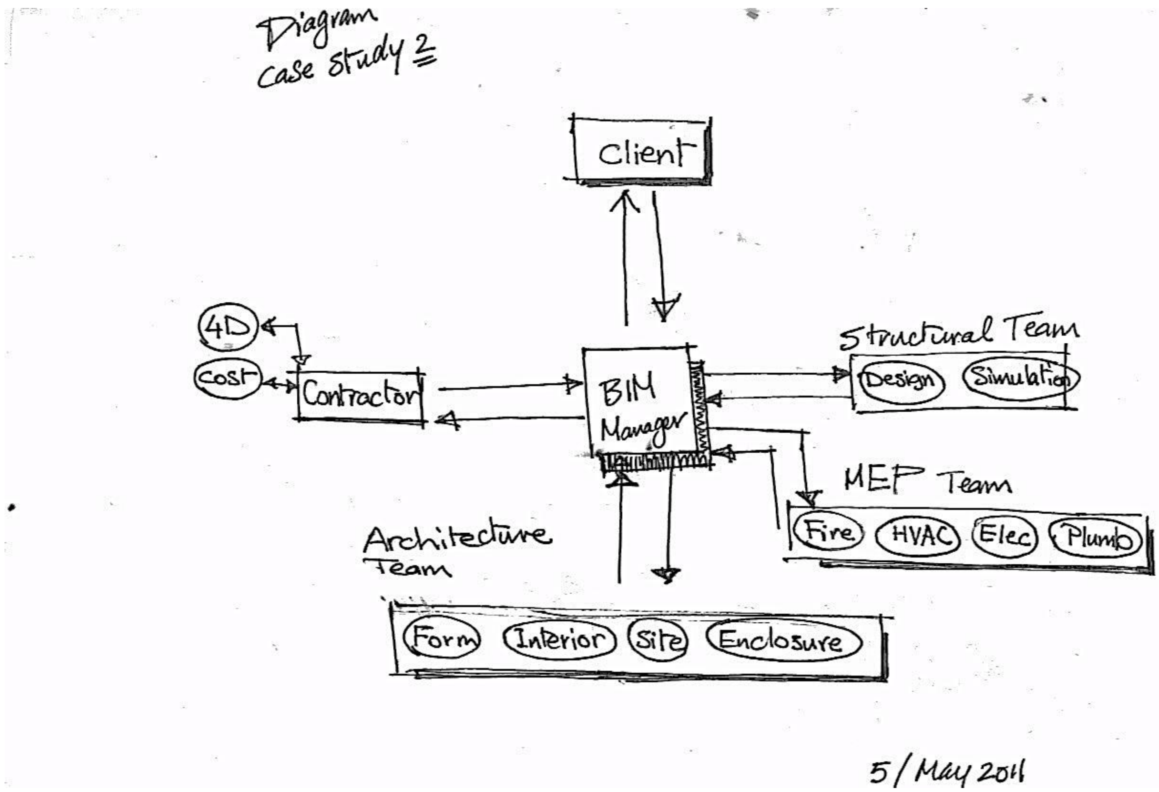


Figure 6-10 Diagram Sketch of Information flow Using BIM Source: Researcher

6.5.2.1.2.3 Impact of Routing of information and lack of a central model on BIM workflow

Because of poor communication with the central BIM model, and the resulting longer route for information flow that is common in mid-size firms, it is expected that for this situation BIM users are losing time. To further explain the impact of no "BIM central model", the researcher found another major issue in Firm 2. The architectural team decided to make changes to the elevation of a ceiling (the height) for this they decided to delete and re-input the ceiling. As there was no direct communication between teams, at the meeting on the following Friday, they discovered that some of the MEP components that were attached to that ceiling were no longer attached and were in fact floating. Thus, the MEP team had to rework their system. It took at least two days to fix this issue.

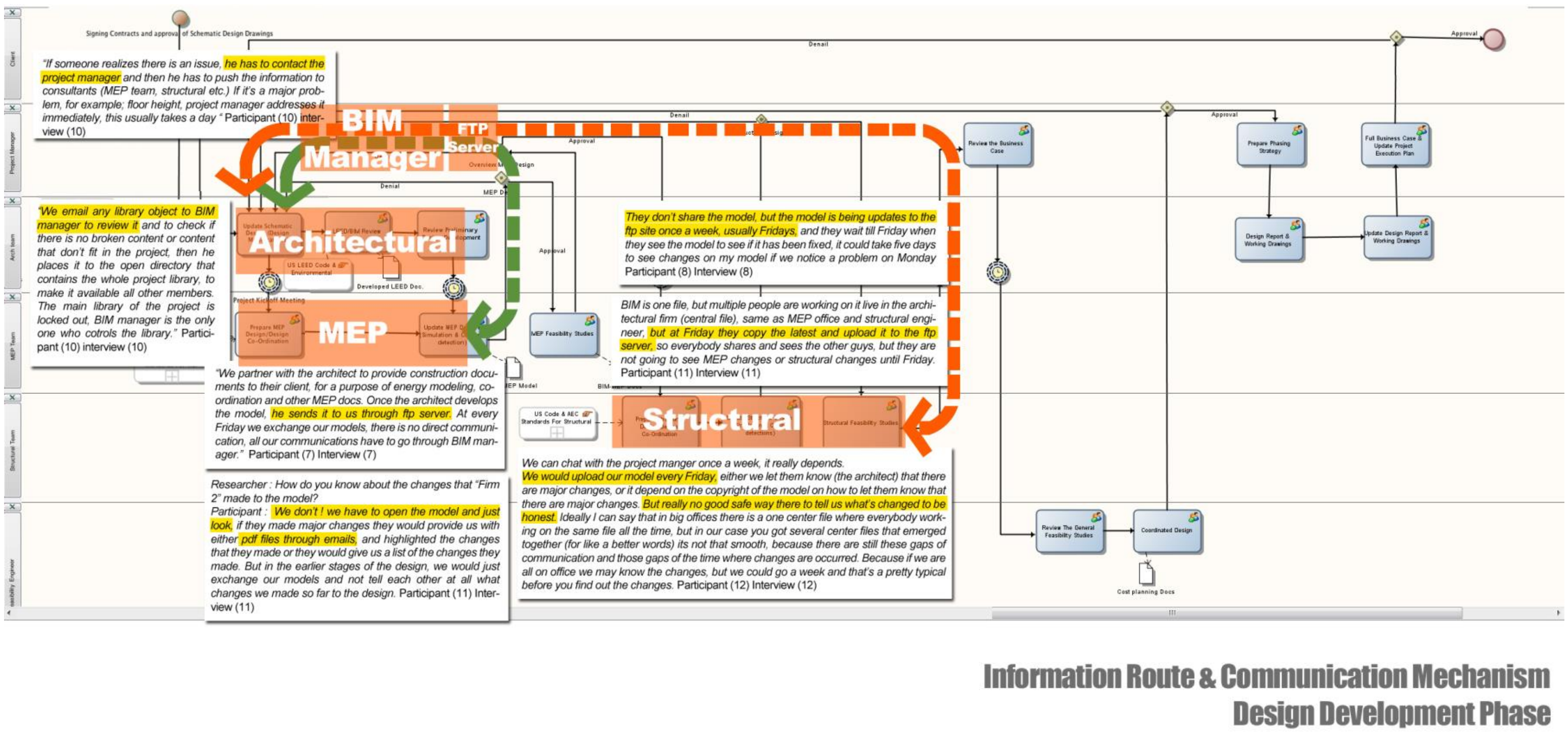


Figure 6-11 Information route and communication mechanism – Design Development Phase

Participant 4 suggests that this problem is associated with difficulties with sharing the BIM model and how information flows inside the office

> "*I think the internet is what causes not to collaborate live right now, and I think if there is a way to link our BIM model through the internet to the structural or MEP team that would be perfect. Although, we have Gotomeeting software and we can share our desktop but we can't share the model".* Participant (4) Interview (4)

The researcher observed that all teams have to wait until Friday to see the updated model. Sometimes it could take five days to see important changes on the model if a problem was noticed on Monday. On the other hand, participant 5 commented on the methods of communications between the teams saying, *"If we knew that they wanted to delete the ceiling, we would reattach our devices, but we didn't. This took a couple of days to finish all these ceiling issues, we were exchanging emails and phone calls between us, and sometimes we were using a program called New Forma."*

> Participant 5 describes another issue because of the lack of communication between teams: *"Ceiling coordination was definitely one of the issues we faced, also who owns the devices. We own the lights and diffusers, in this project (Firm2) had to show it in the model. After the architect finished his drawings, for some reasons we had to move it a couple of inches based on the real dimensions and specifications. The whole project lights and diffusers locations had to be reviewed and adjusted because there was no direct communication between us in the beginning."*

Later, there was another issue that has been reported to the BIM manager. This issue required a change on the HVAC height in one area in the project. Similar to the previous issue and because of the lack of the communication between the HVAC engineer and the architectural team, this issue took a day from the HVAC engineer to adjust the new height of the system. The researcher requested more information from participant 6 about the communications and the flow of information between teams "

Researcher: *How do you know about the changes that "Firm 2" made to the model?* Participant (6): *We don't! We have to open the model and just look, if they have made major changes they would provide us with either pdf files through emails, and highlighted the changes that they made or they would give us a list of the changes they made. But in the earlier stages of the design, we would just exchange our models and not tell each other at all what changes we made so far to the design.*

Researcher: *Have you tried to work in real time with the architect on the same file?* Participant (6): *No, I don't even know how to do that."*

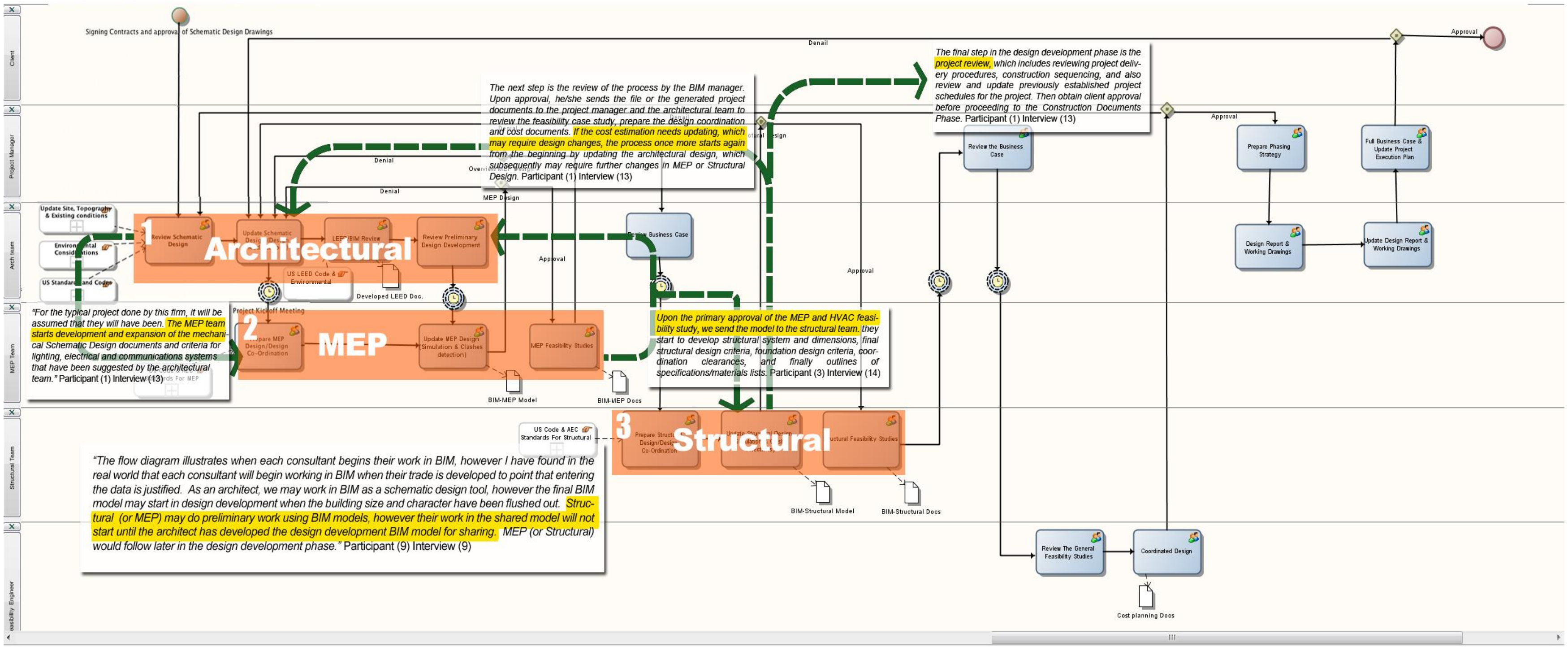
BIM typically includes sets of details and large quantities of data that are included for each object in the 3D model, often resulting in huge file sizes. This limits the navigation, rendering, managing, and sharing of the model. In addition, one computer typically can't manage and share all of these details, attributes, 3D models and information, and then go one step further and generate a 3D simulation and analysis. Participant 7 gives an explanation for not sharing the model saying,

> *"We never exchange the model if these issues are discovered, especially towards the end of the project, our model is so large and runs slowly. So anytime we have to make a change or adjust something we have to wait for Revit to calculate the adjustment." Participant (7) Interview (7)*

6.5.2.1.3 Process domain issues - Sequence of activities

It was found that many BIM related activities are linear, rather than parallel activities. This usually causes redundancy in the "As-is" workflow, because once a new BIM group of activities is added, the new BIM users, who are responsible for this group of activities, have to rebuild/modify/update the BIM model to fulfill their needs. For example, it was found that in the "best case scenario", the appointed BIM manager sends the BIM model to the MEP team so they start MEP and HVAC design earlier in the design development phase. Thus, the MEP team starts the development and expansion of the mechanical Schematic Design documents and criteria for lighting, electrical and communications systems that have been suggested by the architectural team. At this stage the development of specifications or a materials list begins. Because the MEP was not involved in the Schematic Design phase, there is a certain level of model revision involved. Apparently, they start from scratch to revise equipment sizes, capacities, layouts, required space for equipment, chases and clearances, energy conservation measures, etc. Once the MEP team finalizes updating the design, they send it to the BIM manager for approval. Once the design is approved, the MEP team continues to work on the feasibility study for the MEP design (figure 6-12).

Similar to the MEP team, the structural team starts work on the model after the MEP team finishes, sometimes the structural team comes into the workflow before the MEP team, which depends on the project type, but because of the nature of the project for the second case study, which requires earlier MEP involvement, the structural team got involved later in the workflow. It is at this point that the structural team starts to develop the dimension and structural system, establish the final structural design criteria, foundation design criteria, coordinate clearances, and finally outlines of specifications/materials lists. In some cases the structural design may require changes in the architectural design, in this case the MEP may also have to be updated based upon these changes.



Sequence of Main Group of Activities
Design Development Phase

Figure 6-12 Sequence of Activities – Design Development Phase

6.5.2.2 Technology domain issues

Only one issue was identified for the technology domain for the Design Development phase: the lack of interoperability. This impact on the "As-is" BIM will be explained in the upcoming section.

6.5.2.2.1 Technology domain issues - Lack of interoperability

Participants in the interview indicated that the lack of interoperability is a significant constraint to achieving an efficient workflow between architectural, structural, MEP and other building services design disciplines. Progress is being made in this area with the development of open standards such as IFC (Industry Foundation Classes) and CIS/2, yet the researcher discovered that these standards have some limitations that prevent BIM users from using them in their firms. For example, when exporting from a BIM model to IFC there can be loss of some important information, particularly for energy-simulation. Also IFC lacks a sufficiently complete representation for structural analysis. In relation to IFC, CIS/2 is smaller in scope and more focused on structural steel applications rather than on the entire spectrum of tasks involved with the design, construction, and operation of buildings.

> *"IFC's is a common ground between programs but it reduces data, it doesn't maintain all data, the conversion process is not clean and interoperable as it should be. Its similar to DXF as a trans-format to other programs in old CAD systems, but you lose a lot of things, this is similar to IFCs, you may get the geometry, but you lose a lot of data." Participant (3) Interview (3)*

These issues can be partially alleviated by using multiple applications from the same vendor. However, no one vendor has all of the solutions, so using 3rd party applications, to some degree, is to be expected. Also, when transferring from an old version to a new one: some BIM systems cannot access a newer file version. It is in this way that suppliers 'encourage' the use of the latest software and thus increase sales. This doesn't help the firm if they are using different types of BIM applications.

> Participant 8 commented on this issue saying, *"We lose information switching between applications; two applications should have a neutral ground to talk to each other. But usually, when you lower your embedded information to switch, that means you lose a lot of information, which strips out much information and time."* Participant 9 emphasizes the challenge of Interoperability saying, *"That's a big issue, the idea is BIM is data rich, but as soon as you switch between programs, you lose a lot of information"*

6.5.2.2.1.1 Impact of interoperability on BIM workflow

Based on numerous examples of interoperability issues identified in both firms, it seems likely that any new BIM user has to incorporate his/her own BIM data into his/her model, and should expect to deal with interoperability issues by redrawing or editing the model, which consumes time for updating the model.

> *"The architect sends us a model and basically what we would do is we would go in and reconcile everything that needs reconciliation. The architect usually locates the plumbing fixtures because he is the only one who decides how many he needs, where these have to be located, in terms of how far from the wall, or which one requires grab-bars for ADA compliance, etc. So we re-revit the whole project again as they lose all the intelligence it's not like we have any type of piping connections. So we reinvent that process, hide in place all the plumping fixtures coming from the architecture model, and then we super impose our fixtures on top of theirs." Participant (11) interview (11)*

“We redo the whole model because we miss information and lose the model intelligence. One of the biggest issues is that we lose room tags, room titles, and spaces (interoperability). So, we first start by synchronizing our levels, if we don’t do that then we got lost. And then we copy-monitor that if they change the level it’s still the same. But the point is that if you don’t follow their exact name enclosure to the tea, they don’t make this co-relation neither this association.” Participant (6) Interview (6)

Figure 6-13 identifies the areas of redundant activities caused by the redrawing/editing or embedding of new information into BIM models, which subsequently consumes more time to solve interoperability issues on the “As-is” BIM model.

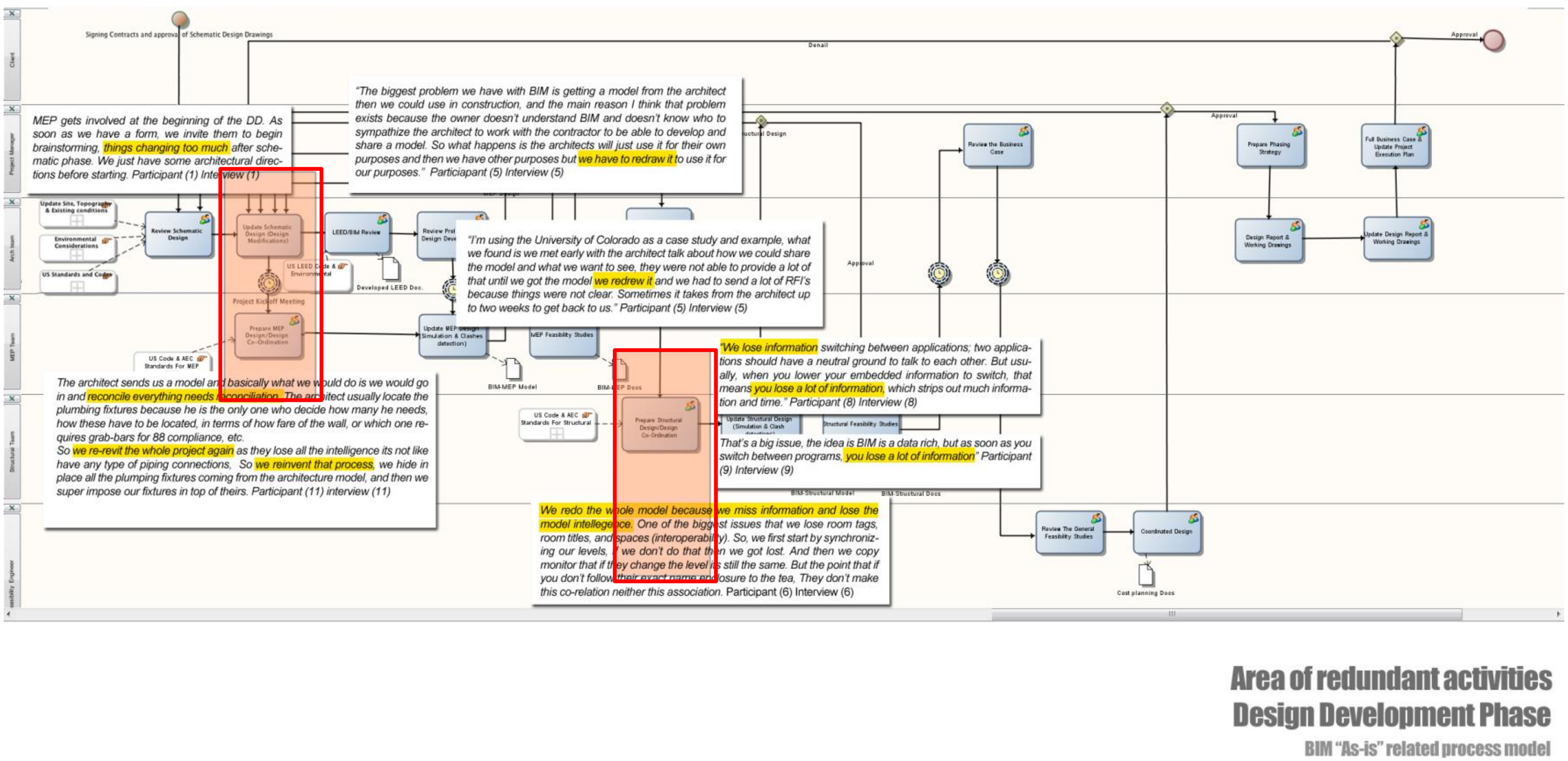


Figure 6-13 Areas of redundant activities – Design Development Phase

6.6 Summary

This chapter summarizes the data collection and the challenges for BIM implementation in mid-sized firms. The interviews and two case studies are also summarized.

Through interpretation of these data it was found that BIM is facing different types of issues. For example, direct communication challenges, missing of a “central model”, poor flow of information, lack of control for data feed, lack of interoperability, etc. The research findings were triangulated with feedback from BIM members not in the first round of interviews. Theoretical saturation is reached when no new relevant data emerges and an initial concept about the categories of tasks/activities is well developed. Narrative scenarios, interviews transcripts, case studies, in addition to the other types of data helped to form an initial workflow model. In the next chapter, these data will be interpreted using coding methods to develop and present the existing BIM process model.

Chapter 7

Workflow Structural Conditions

7.1 Introduction

The main objectives of this study included the following. First, mapping the "As-is" BIM process workflow. Second, mapping the challenges related to the "As-is" BIM workflow, third; exploring the structural conditions that could change this workflow, and forth; developing a new "To-be" BIM related process model that can enhance BIM implementation in mid-size firms.

This chapter focuses on the third objective, which is exploring the structural conditions that may change or affect the "As-is" BIM workflow. The chapter works according to the roadmap of grounded theory that is presented in chapter 4. Thus, the data collected from case studies and interviews have been coded. Then, the generated categories and research hypothesis have been presented back to interviewees combined with the "As-is" BIM related workflow requiring their feedback on these categories. By the end of this chapter, the researcher presents the possible structural conditions that may affect "As-is" BIM workflow.

7.2 Overview of Structural Conditions

According to Strauss and Corbin, coding for a process requires investigating both the workflow; including actions and tasks, in addition to mapping the structural conditions, which can be defined as the changes that could affect these actions/interactions and tasks. Strauss and Corbin state "action/interaction and trace it over time to note how and if it changes or what enables it to remain the same with changes in structural conditions" (Strauss and Corbin, 1998: 163). Thus, mapping the "As-is" BIM related process cannot be detached from the different contexts whereas these business processes reside in. On the other hand, it is expected that the "As-is"

BIM workflow that has been presented in the previous chapter to be generic, as it is expected that some conditions may affect the flow of information and subsequently change the sequence of activities and tasks. Thus, it has been found that identifying these structural conditions is an important issue.

In order to identify these conditions, the Grounded Theory was found to be suitable for the studied phenomenon, whereas data can be broken apart using an open coding process to extract codes and then group them into categories based on similarity of properties. Then, the relationships between the codes are generated through axial coding. Finally, after selective coding, the hypotheses is generated from the concepts and their relationships. The results are presented later in this chapter.

7.3 Coding process

To start the coding process for the interview transcripts, the researcher initially performed open coding, followed by Axial coding, which involves putting data together in different ways by making connections between categories that have emerged from open coding in the first round of data analysis (168, Strauss and Corbin 1998). Finally, selective coding was conducted to choose one main category to work as the core category, and then relating other categories to it. Selective coding is an important step that leads to finding the main drivers to the research. Figure 7-1 shows how the coding process flows in this study.

In addition to interviews, the researcher's notes that were taken during the case studies period also helped in the process of coding the structural conditions. They also assisted in selecting which codes were important during the coding process. After identifying these codes, they were grouped together based on their properties. Then, different categories were developed according to their properties and importance.

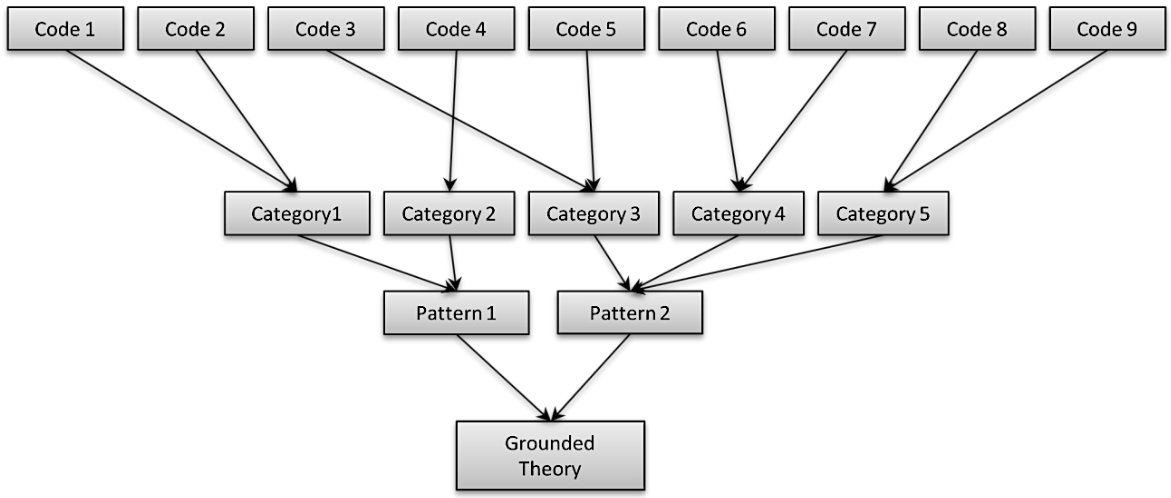


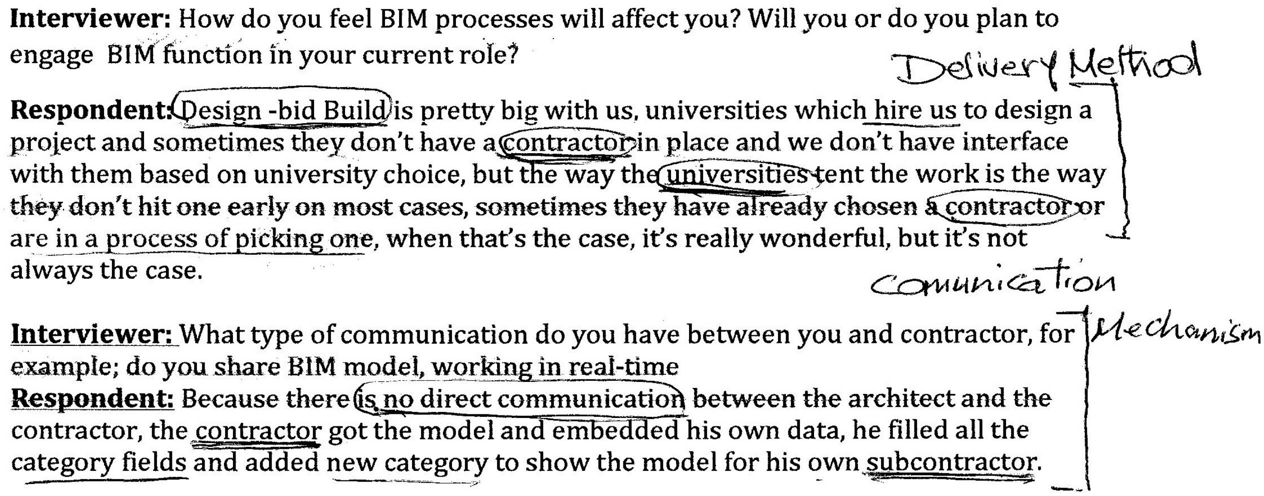
Figure 7-1 Coding Mechanism Source: Khandkar 2009

7.4 Coding Techniques

Usually, most major qualitative methods employ different coding techniques to help organize, analyze and interpret the overwhelming amount of research data, which is frequently collected from different sources (i.e. field notes, interviews recordings, firm documents, memos, etc.) As such, in most cases, the researcher starts coding manually, or it may take place in Word. The next level of coding may require using coding software to provide the researcher with answers to research questions. In the next pages, coding techniques will be discussed further.

7.4.1 Manual Coding

Manual coding can only provide help at the early stages of the coding process, whereas the researcher prepares text-based coding and analyzes interview transcripts, field notes, and memos. Usually, the researcher starts to highlight words and short phrases by circling, highlighting, bolding, underlining, or coloring rich or significant participant quotes or passages. Preferably, the researcher separates the text into short paragraph-length units with a line break in-between them whenever the topic or subtopic appears to change. Furthermore, the researcher should have the knowledge and feeling to be aware of what is important and what isn't, and thus the code which rises to the surface. Figure 7-2 below presents an example of manual coding.


Interviewer: How do you feel BIM processes will affect you? Will you or do you plan to engage BIM function in your current role?

Respondent: Design -bid Build is pretty big with us, universities which hire us to design a project and sometimes they don't have a contractor in place and we don't have interface with them based on university choice, but the way the universities tent the work is the way they don't hit one early on most cases, sometimes they have already chosen a contractor or are in a process of picking one, when that's the case, it's really wonderful, but it's not always the case.

Interviewer: What type of communication do you have between you and contractor, for example; do you share BIM model, working in real-time

Respondent: Because there is no direct communication between the architect and the contractor, the contractor got the model and embedded his own data, he filled all the category fields and added new category to show the model for his own subcontractor.

Figure 7-2: Open coding process with pen and paper

7.4.2 Coding Software

There are different software applications, which can be used in the coding phase. These include CAQDAS Comparison, Saturate, NUDIST, or Atlas.ti. Saturate has been developed by Dr. Sillito as a free web based tool, while Atlas.ti is a commercial qualitative data analysis tool (it is important to note that software is incapable of comprehending the meaning of words or sentences). In this research, the advantages of using computer-aided scripts coding software to generate or manage the coding results has been explored; Atlas.ti was used for transcripts coding and the extraction of conceptual knowledge from these transcripts (theory building).

Although coding software can order, structure, retrieve and visualize codes easier than manual coding of text-processing software like Text Pad or Microsoft Word, manual coding has more advantages in sorting and reporting functions. Coding software is able to create the required coding hierarchy and simply move or copy coding nodes to a new taxonomy, which subsequently develops the concepts by sorting these codes. Once the coding process is completed, coding results can be presented in various ways such as project, document or node reports (Cai 2007). The advantage of project reports is that they lists all nodes coded in documents, while node reports present the coded texts at the selected node with section numbers, paragraph numbers and Data Link details. The software has the ability to represent the statistics of the selected nodes and/or the groundedness of a certain node in a simple way (127, Cai 2007).

7.5 Coding Techniques used in this study

Initially, the researcher started the coding process manually by printing out the interviews transcripts, highlighting the important keywords/concepts or text segments of different interviews[1] and then writing codes. For example, of words related to; changing the workflow, critical events, activities, events, etc. (Table 6.2), this identifies the major coding concepts that would lead to identifying the structural conditions related to BIM workflow. According to Strauss and Corbin, those codes are abstractly categorized in higher order in the open coding process, for example category 1, category 2, category 3, etc. (Figure 7-1) (136, Strauss, 1998). This process can only help at the initial stages of the coding process- once the research further proceeds to an advanced level, the manual open coding process is not accurate, especially when we have to deal with large amounts of data generated from different disciplines/interviewees, which could cause unwanted errors and generates inaccurate results.

Thus, the researcher started to use coding software Atlas.ti, in order to examine raw data and to saturate categories developed from the manual coding. Creswell describes this process: “Using the constant comparative approach, the researcher attempts to “saturate” the categories—to look for instances that represent the category and to continue looking and interviewing until the new information does not provide further insight into the category” (151, Creswell 1981).

[1] According to Strauss and Corbin, this process can be identified as “Microscopic Examination”

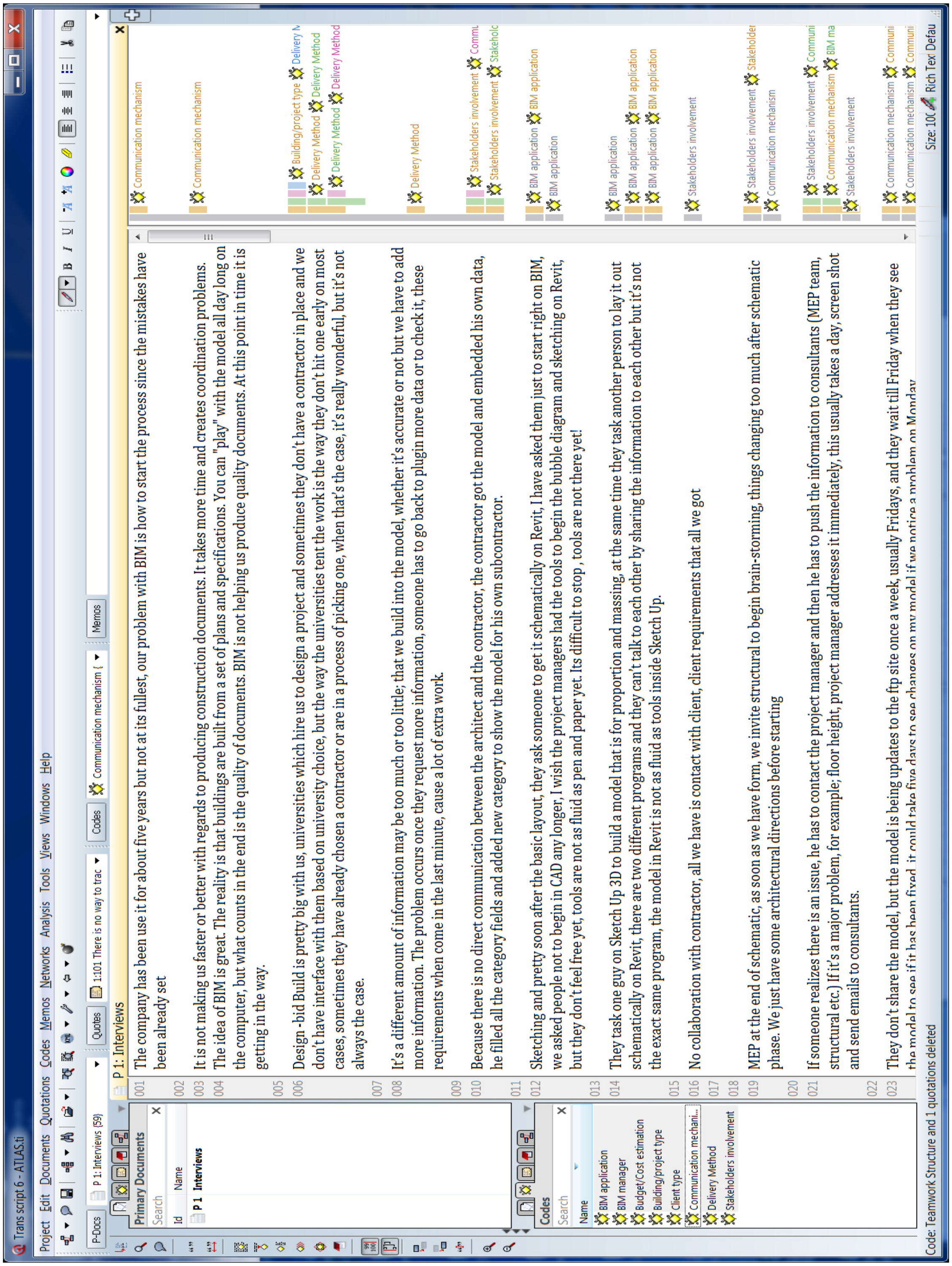


Figure 7-3 Atlas.ti Coding Software

7.6 Results of Open Coding For Structural Conditions

As it has already been stated, open coding was used as a preliminary coding approach in the first phase of data interpretation to generate codes related to structural conditions. In open coding, interviews scripts were broken down into parts, then were closely examined and compared for similarities and differences in order to discover codes. The researcher's main objective was to identify words that indicate events that may change BIM workflow, happenings, and actions/interactions that are found to be conceptually similar in nature or related in meaning. These helped to generate categories after the axial coding phase. The table below presents some codes that have been extracted from one interview using open coding; codes are organized according to their similarities.

Table 7-1 Example of extracted codes

- There is no direct communication.
- He has to contact the project manager.
- We share screen shots and send emails.
- They don't share the model.
- Files are being updated to the ftp site once a week.
- It could take five days to see changes.
- At Friday they copy the latest and upload it to the ftp server.
- Internet what causes not to collaborate live right now.
- We can share our desktop but we can't share the model.
- Email any library object to BIM manager to review.

Table 7-1 Example of extracted codes (continued)

• Bubble diagram • Two different programs • Sketching • Sketch Up 3D • Revit • Reconcile • Re-Revit • CAD

Usually, extracting codes does not always provide in-depth information. Thus, after the first stage of coding, microanalysis was needed for more in-depth interpretation. The more refined examination of data and the memos were also important to analyze data for both differences and similarities among categories. At this point, axial and selective coding was used to develop hypotheses.

7.7 Axial coding for structural conditions

Axial coding can be defined as “the process of relating categories to their subcategories, termed ‘axial’ because coding occurs around the axis of a category, linking categories at the level of properties and dimensions” (Strauss and Corbin, 1998: 123). During this round of coding, data is put together in a new way by creating connections between categories that have emerged from the open coding phase (168, Strauss and Corbin 1998). These categories impose the specific contexts for the structural conditions.

Thus, after closely examining these codes for differences and similarities, and relationships between codes, the categories were organized in a hierarchal order along the axis of categories- every category sits at a different level of detail (168, Strauss and Corbin 1998).

7.8 Generating Categories

Strauss and Corbin explain that the main components of a paradigm usually include conditions, activities/tasks and reactions. The conditions are a set of circumstances to explain why, where and when certain phenomena occur. The activities/tasks are routine activities explaining whom and how these actions are performed. The consequences are the outcomes of actions/interactions, which answers what happens as a result of those actions/interactions in a timely manner. This method would develop a workflow model that tracks activities, roles and BIM information flow and would also denote the different business processes of BIM inside the targeted firms. (128, Strauss and Corbin 1998).

As it was outlined in the previous chapter, data collection has been conducted through a top-down approach. Similarly, the "To-Be" business process model has also been developed in a top-down approach; an overview of firm business model was attained first. Followed by, the model's further decomposition to the operational level.

The following table presents a list of categories that have been identified following axial coding. The list represents the specific contexts for structural conditions that may impact BIM workflow in mid-size firms.

Table 7-2 List of categories extracted after axial coding

Category	Name
1	Delivery Method
2	Client type
3	Building/project type
4	Stakeholders involvement → ***Subcategory:*** Contractor involvement
5	Budget/Cost estimation
6	Communication mechanism → ***Subcategory:*** BIM application
7	BIM manager

Exploring the relationships between these categories helped to generate hypotheses following the axial coding phase. Relationships between categories are explored in such a way that hypotheses about connections between categories emerge. The researcher then developed the research taxonomy, which grouped the categories and codes into a hierarchy. As long as the coding continues, new codes and/or categories emerge. During the process of generating hypotheses covering the structural conditions, codes and core categories were reviewed and used to inform the subjective coding.

7.9 Hypotheses

The result of the axial coding is the development of seven hypotheses. These hypotheses are proposed from the categories of the different structural conditions related to BIM. As previously mentioned, these structural conditions have been explored through the literature review chapter one. This was subsequently used to develop the interview questions. The following seven hypotheses were verified through the next round of investigations.

Hypothesis 1: Each delivery method[2] has a different BIM process model, changing the project delivery method would alter the process model.
(Category 1: **Delivery Method**)

Hypothesis 2: Different clients (Government and private) affect the workflow of BIM based on the various pre-qualification processes, as well as their requirements.
(Category 2: **client type**)

Hypothesis 3: Different building types have a variety of BIM related process models, the building type could change the process model components, sequential tasks order, and activities sequence.
(Category 3: **Project Type, Project Nature**)

Hypothesis 4: Changing the sequence of flow between BIM members would change the process model.
(Category 4: Stakeholders involvement)

Hypothesis 4 | subcategory: Having the contractor involved earlier in the project would change the process model
(Subcategory 6: Contractor involvement)

[2] Please refer to chapter 1 for more details about delivery methods and BIM

Hypothesis 5: Projects with large project size or bid value have different business processes.
(Category 5: **Budget Constraints**)

Hypothesis 6: Different communication mechanisms of exchanging BIM information would change the process model. Manipulating the communication path would change the generated BIM model
(Category 6: **Communication Mechanism**)

Hypothesis 6 | subcategory: BIM software have different issues that represent another hurdle for full BIM implementation. For example (large file size, interoperability, versions compatibility, etc.) Resolving these issues would change the process model
(Subcategory 6: BIM Application)

Hypothesis 7: Minimizing the number of decisions that are made at the end of each project phase would change the model. This may be achieved by replacing the central communications that go through the BIM manager with direct communication between team members.
(Category 7: **BIM Manger**)

7.10 Selective Coding

Selective coding can be defined as "the process of integrating and refining the theory …. Once an analyst explains in detail how he or she arrived at a conceptualization, other researchers, regardless of their perspective, should be able to follow the analyst's path of logic and agree that it is one plausible explanation for what is going on" (Strauss and Corbin, 1998: 143-146).

After the axial coding, the next step is to outline the overarching theoretical scheme, and then to develop the theory. The central category represents the main theme of the research. Strauss and Corbin identified the criteria for choosing a central category in selective coding as the following (Strauss and Corbin, 1998: 147) quoted in (Cia, 2007: 109)

1. It must be central; that is, all other categories can be related to it.

2. It must appear frequently in the data. This means that within all or almost all cases, there are indicators pointing to that concept.

3. The explanation that evolves by relating the categories is logical and consistent. There is no forcing of data.

4. The name or phase used to describe the central category should be sufficiently abstract so that it can be used to do research in other substantive areas, leading to the development of a more general theory.

5. As the concept is refined analytically through integration with other concepts, the theory grows in depth and explanatory power.

6. The concept is able to explain variation as well as the main point made by the data; that is, when conditions vary, the explanation still holds, although the way in which a phenomenon is expressed might look somewhat different. One also should be able to explain contradictory or alternative cases in terms of that central idea.

Furthermore, Strauss and Corbin state (1998: 148), "to aid integration, there are several techniques that can be used to facilitate identification of the central category and the integration of concepts. Among these are writing the storyline, making use of diagrams, and reviewing and sorting memos either by hand or by computer program".

By using the coding software, in addition to the criteria that have been mentioned above, the sorting of all the conditions that may affect BIM workflow made the open coding and axial coding process much easier. While in the selective coding, the software allowed the researcher to create an amended coding hierarchy and move or copy the nodes to a new taxonomy. On the other hand, the software can show simple statistics of the codes and categories, such as the groundedness of a certain category.

7.11 Central Category – Client Type

According to the earlier stated criteria of Strauss and Corbin, and by the help of coding software, it has been found that the "Client type" category represents the central category for BIM structural conditions, whereas it forms the path of logic and the plausible explanation for any changes in BIM workflow. In the next section we will define the relation between that central category (Client Type) and the other categories extracted from the axial coding, also how the change in the delivery method might affect other categories (structural conditions).

"Client type" is the central category that would highly impact the workflow of BIM, in addition to affecting all the other related structural conditions. Although the type of clients in both case studies were not enough to reveal all types of clients in the US market, during interviews it was revealed that the US market has four types of clients;

1- **Private:** who are usually domestic clients that would like to have a house building altered, extended or maintained,

2- **Commercial clients:** who are usually factory or business that needs to undertake building works in order to produce goods or process.

3- **Public limited companies:** such as companies or banks

4- **The Government:** which gets involved in construction at three levels: through local councils, devolved administrations (Welsh Assembly and Scottish

Parliament), and central government (BTEC, 2008).

This classification indicates that the "client type" would have an impact on different factors during the lifecycle of the building, such as; the project size, project type, client requirements, bidding strategy, time constraints and money flow. These factors will subsequently affect the roles and involvements of the different BIM disciplines and also subsequently affect BIM workflow. On the other hand, participant 5 (contractor) clearly puts the responsibility of a healthy BIM workflow on the shoulders of the client and his understanding of BIM requirements.

> *"The biggest problem we have with BIM is getting a model from the architect that we could use in construction, and the main reason I think is that a problem exists because the owner who doesn't understand BIM and doesn't know how to sympathize the architect to work with the contractor to be able to develop and share a model. So what happens is the architects will just use it for their own purposes and then we have other purposes but we have to redraw it to use it for our purposes."* Participant 5- Interview 15.

In the following section we will discuss in more detail the relation between the central category (client type) and other categories (structural conditions).

7.12 The Relation Between the Central Category and Other Categories

The relationship between the central category and other categories can be explained through the storyline of any project. Usually the project starts with the "Client" **(Central category)**, and based on his/her requirements, the client selects the "Project type" **(category 3)** and controls the "Budget" **(category 5)**.

Then, based on the client's preparation for the project, he/she controls the "Stakeholders involvement" **(Category 4)**, in some cases, the client may start the project with the "Contractor" on board and sometimes not **(Subcategory 4)**, which by its turn shapes the Delivery Method of the project **(Category 1)**.

The communication between the team members **(Category 6)** can be defined later based on the stakeholders' involvement, usually the BIM manager **(Category 7)** controls this type of communication as previously explained, in addition to which BIM application **(Subcategory 6)** will be used and the flow of information.

From the previous storyline, it is clear that the client controls different structural conditions that affect BIM workflow. In the following section we will discuss more some of these structural conditions/categories and the relation between the client and these conditions.

7.12.1 Building Type, Project Nature

Having already established, the US market has four types of clients, Private, Commercial clients, Public limited companies, and the Government. Each of these client types has his/her own building type, which can subsequently affect BIM workflow.

a) **Private Clients:** This type of client usually has small projects such as a house alteration, extended or maintained. They enter into private agreements with a builder to undertake the work or they may have an architect who has produced the drawings and oversee construction (BTEC, 2008). This type of client is typically not interested in implementing BIM as it adds cost to the project.

b) **Commercial Clients:** These clients usually look for projects to produce a revenue stream such as factories or buildings that produce a product or process. These projects have to be built quickly at a lower cost. Some of these customers may or may not implement BIM.

c) **Public limited companies**: Clients such as banks which have several branches and need them to be maintained or have a new one to be built, or companies that plan to have a large headquarters in a major city, which will need similar work to be done. These clients may implement BIM in their projects because they understand its importance in comparison to its additional cost.

d) **The Government**: Governmental projects such as schools, administrative and governmental buildings, Cultural centers, etc. These projects run on different levels: through local councils, development administrations, and central government. According to the new governmental requirements, a BIM model is needed in many states for all construction projects after September 2009.

Thus, based on the client type, BIM may be implemented or required in some projects while other projects do not.

7.12.2 Budget constraint

Budget constraint is another important factor that could impact the BIM model. Usually, the client (central category) considers the project cost against some major factors in the design and sets targets for the design team to work within, for example, the capital cost, waste management, energy costs and life cycle costs. This kind of budget control impacts the project specifications and the paths of communication in the BIM model, and subsequently defines the role of members and who will be involved in the process flow.

7.12.3 Delivery method

The opening chapter of the thesis sets out that there are two major methods of project delivery for capital projects, Design Bid Build (DBB) and Design Build (DB). According to the Smart market report, the DBB is the most common method of delivery in the US market, this is reflected in the case studies and the As-is model (McGraw-Hill, 2008). However, based on the method of delivery, the involvement of the different BIM discipline changes and subsequently the model will be altered. Usually, the client starts the project with an architect, and then goes to bid to hire a contractor.

> Participant (1) relates this issue to the following *"Design -bid Build is pretty big with us. Universities hire us to design a project and sometimes they don't have a contractor in place and we don't have an interface with them based on university choice. But the way the universities tend to work is they don't pick one early on in most cases, sometimes they have already chosen a contractor or are in the process of picking one. When that's the case, it's really wonderful, but it's not always the case." Participant (1) Interview (1)*

> *"DBB is a sequential form of project delivery that separates the design process from the construction and awards the construction contract in lump sum to the lowest responsive bidder. DB is a project delivery methodology that melds the selection and contract of the architectural firm and general contractor or merchant developer. Under this structure a single procurement action is taken in which a team comprised of the architect and developer/contractor is selected."* (White, 2008)

7.12.4 BIM Stakeholders and Team Members involvement

Mainly, the client type, project nature and then the delivery method, in that order, would impact the sequence of stakeholders' involvement. For example, the second case study (Science/Research Greenhouse Labs) has required the earlier involvement of the MEP team for HVAC calculations to inform design decisions, the structural engineer got involved later in this project. In other projects, modeling the building performance and energy use may require the early involvement of LEED and energy consultants, which will impact the sequential involvement of BIM members. Other projects, such as stadiums or airports, may require the early involvement of a structural engineer. Thus, the streamlined coordination between the different BIM disciplines could be altered based on the project type.

7.13 Summary

This chapter focuses on the third objective on this study, which is identifying the structural conditions that may affect or change the "As-is" BIM related process model. The data interpretation for these structural conditions was explored with a qualitative analysis tool, Atlas.ti, which was used through three rounds of coding. These rounds are the open coding, axial coding, and selective coding. At the second level of coding, the Axial coding, has generated seven categories and seven hypotheses of structural conditions. In the Selective coding, it was found that the client type is the central category that may change the BIM workflow.

In the next chapter, the new "To-be" BIM related process model will be discussed, as well as the feedback from interviewees on the model.

Chapter 8

BIM "To-Be" Related Model

8.1 Introduction

As previously mentioned, the fourth objective in this study was to develop a new process model that can enhance BIM implementation in mid-size firms. Although redesigning any existing workflow could take different approaches, the researcher proposes changes to the activities within the "As-is" BIM related process model; these could be achieved by rearranging the process components, merging and compressing some workflows and/or changing the process flow sequence.

This chapter will discuss different issues, associated with the To-be model and discuss the best approaches to resolve BIM issues that were previously discussed in chapter 6, member checking is also applied to gain consensus for the model.

8.2 Developing the "To-be" BIM Related Process Model

The fourth objective in this study was to design a "To-be" BIM related business process model that can support BIM implementation in mid-sized firms. Usually there are two approaches to redesign process workflows, "top-down" and "bottom-up" (Sharp and McDermott 2009). These approaches will be explained here.

8.2.1 "Top-Down" Approach

According to Sharp and Dermott, the top-down approach usually starts with major changes in the roles of team members, or adding a significant component to the existing process. The outcome is a new business process that looks like an organizational chart. The "Top-Down" approach may face some issues because of "the intense gravitational pull of the current enterprise structure" (Sharp and McDermott 2009).

Sharp and Dermott suggest three advantages of this approach include, "(a) the clients always give you more detail than you want, (b) it's easier to start by capturing detail in the flow, and (c) people like to see where the processes came from with respect to activities they recognize. "(Sharp and McDermott 2009)(pp.98)

8.2.2 "Bottom-Up" Approach

The "Bottom-Up" approach is usually performed when there is a need to redefine the activities associated with the members of the process. The process usually starts with a facilitated session to discuss those activities to generate a richer base of information to work with. According to Sharp and Dermott for the Bottom-up approach, the researcher plays an important role in connecting peoples' activities, through the use of "Post-its", analysis of the new links, and then developing the new business processes (Sharp and McDermott 2009). This is because people usually identify the "processes" as legitimate activities that are more confined than a complete business process. But the good thing is that during this process of identifying roles and activities, people usually highlight the bottlenecks by themselves. According to Cai, these bottlenecks can be identified using three criteria:

- **Efficiency:** The researcher has to identify any redundant activities, time wastage and so on.
- **Effectiveness:** The researcher tries to highlight any extra costs spent on trivial activities, or if there is any incomplete, wrong, and/or lack of information, or if "*information is given to the right person at the right time and so on"*.
- **Flexibility:** The researcher has to identify if the new process will match with a company's strategic development or policy changes. (Cai 2007)

8.3 Method of redesigning the "As-is" BIM workflow

Sharp and Dermott argue that, a bottom-up approach can redefine a large group of activities that is required to be performed within the given process and then connect these activities together, while the top-down approach works best in cases where there is need to identify the major processes through progressive decomposition, which was similar to the focus of this research. Since the focus of this research was on the first two phases of the building lifecycle, Schematic and Design Development, these phases have relatively few activities to be redefined. On the other hand, different BIM teams often work separately on one project, in this case it is relatively easy to redefine their activities (Sharp and McDermott 2009).

In chapter 6, the researcher identified the bottlenecks of the "As-is" BIM related business process model. Also the main causes of these issues were investigated. Then, the "To-be" scenario is presented here as a solution to solve these problems. Upon completing the analysis, a new model design began with the existing BIM process model, followed by the "Top-Bottom" strategy being performed, making it possible to identify the To-be scenarios at the higher level of the organization then descended to the micro level. The researcher based the analysis on the roles of BIM users in both Schematic and Design Development phase, then decomposed teams activities to redesign each member roles and tasks that are aligned with others in the same team (if needed), also the relationship within the team and the manner that they apply to handle their tasks, then redesigning how they would communicate and exchange information, and what are the strategies to overcome these issues.

Moreover, the redesigning process suggested the need to involve some members who were not included in the first two phases of the project; these included the contractor (a new process component), to facilitate communication and to avoid redundancy of some sub-processes. The three aspects for the approach were, 1) the redesigning of the existing workflow, 2) sequence redesign and 3) content redesign. By adapting these aspects, the new business process can be identified for organization structure, roles and responsibilities, and a desirable match between roles and tasks. Furthermore, IT tools can be used to improve the business process; the next chapter will discuss some IT strategies to help improve the implementation of the new model.

8.4 Overview of the BIM "To-be" Model

The new BIM process model was developed based on issues of the BIM As-is model in both Schematic Design and Design Development phases. In the following section, we will highlight the major aspects of the new model.

8.4.1 "To-Be" BIM workflow- Schematic Design Phase

As previously mentioned, the "As-is" BIM workflow for the Schematic Design phase, has issues for both the Process and Technology domains. In the following section we will discuss how to improve BIM implementation by developing a new "To-be" BIM workflow model.

8.4.1.1 Resolving Process Domain related issues- Lack of Contractor Involvement

According to the American Institute of Steel Construction "A 1996 Construction Industry Institute study in conjunction with Penn State University, for 351 projects that included the contractor before 20% design completion this often resulted in lower cost, and improved scheduling and quality. A 2001 survey of 70 contractors found that in projects contractors rated as "excellent" the specialty contactor was engaged when the design was between 15% and 45% complete." (AISC 2008).

The new "To be" BIM workflow suggests the early involvement of the contractors. The new "To-be" BIM workflow redefines contactors' involvement. Through the interpretation of interviews and case studies it became clear that contractors influence some of the most critical decisions that when not included in the workflow may result in redoing, updating or changing the BIM model. Thus, the new workflow includes the contractors early in the process, as shown in figure 8-1.

This may suggest that traditional Design-Bid-Build delivery methods do not work well for BIM workflow and other delivery methods, such as "Design Build" or "Construction management at-risk" would be more appropriate for full BIM implementation

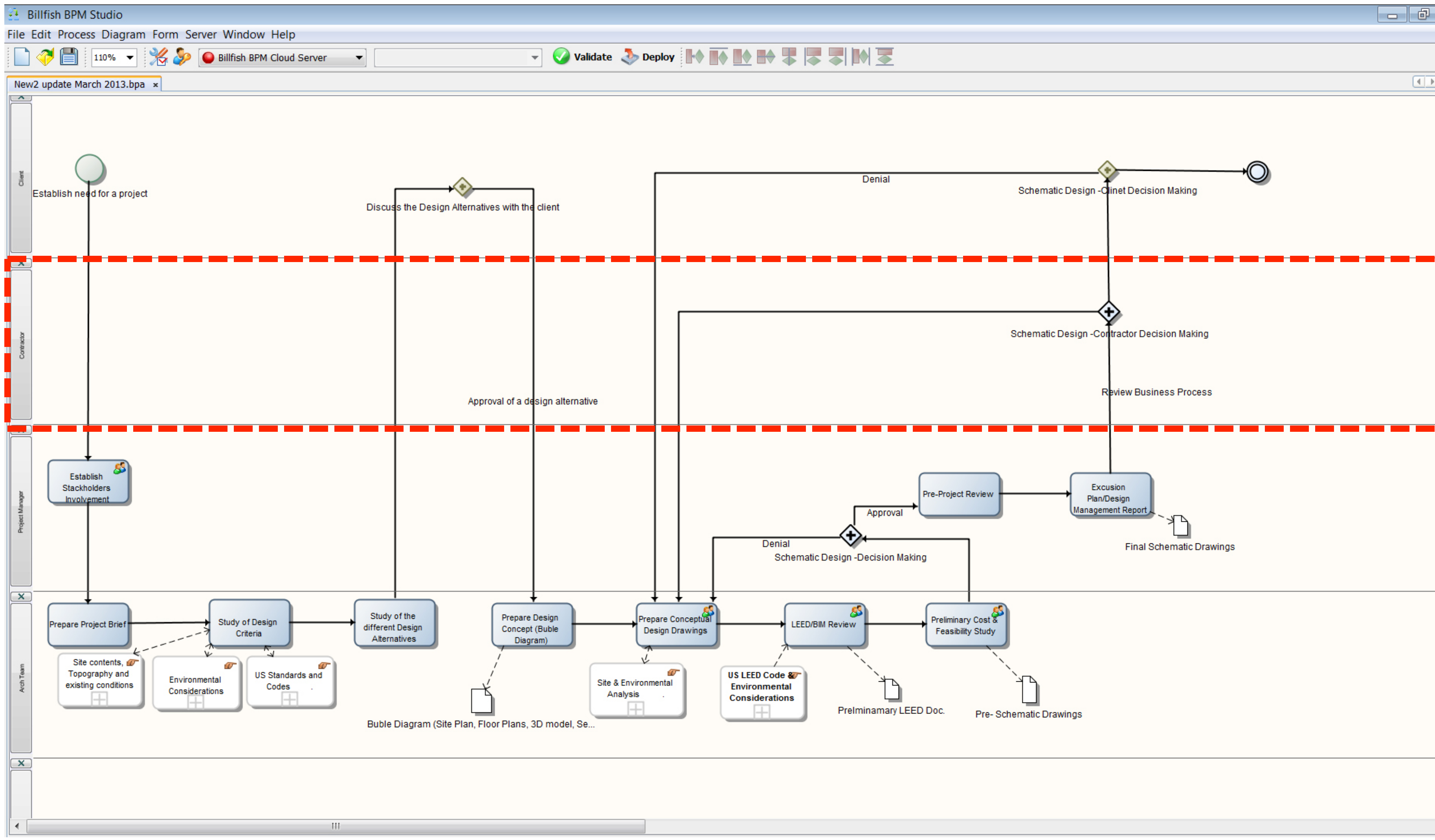


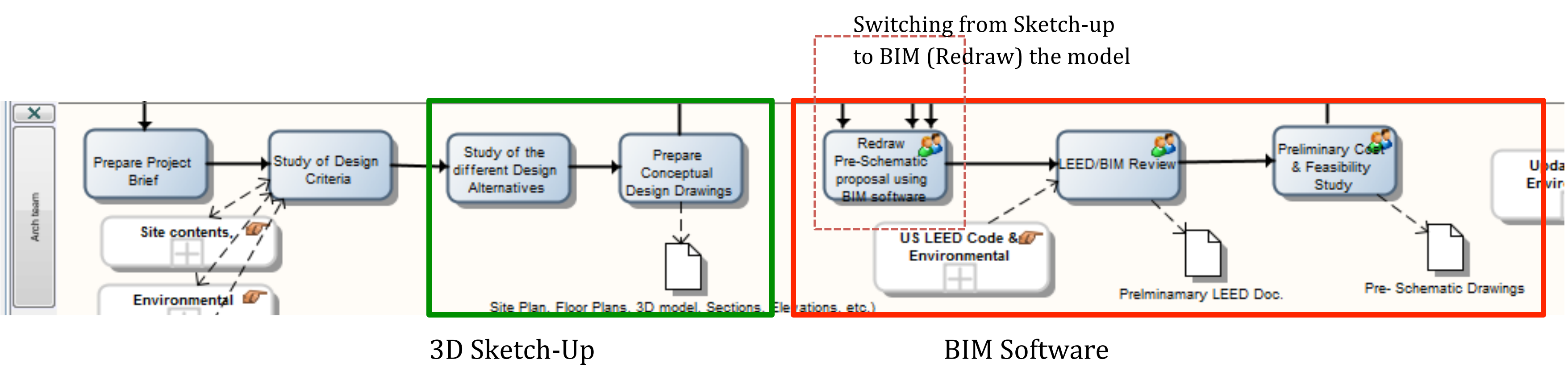
Figure 8-1 Involvement of Contractor in the Schematic Design Phase- New “To-be” Workflow

8.4.1.2 Resolving Technology domain related issues – Lack of Interoperability in the Schematic Design Phase

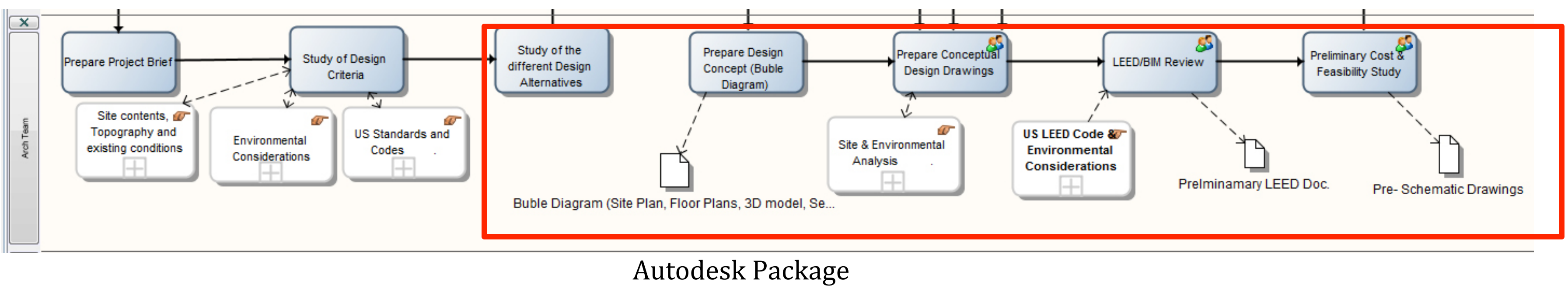
As previously mentioned in chapter 6, early design drawings are often developed using software such as 3D Sketch up, and then redrawn later using Revit, which causes redundancy in the BIM workflow. This can also result in lost information. Unfortunately, this is the common workflow for many mid-sized firms in the USA.

Usually, lack of interoperability occurs because of different software coding, which refers back to the use of programming languages and the companies that design the software to be proprietary. In our case, Sketch-up which was developed by startup company called Last Software and later bought by Google, uses Ruby as the programming language, while Revit uses NET API and the C# programming languages. Both Ruby and C# typically lose information when switching between both environments.

Although not the ideal solution this suggests that architectural firms should try to work with software in the same family. For example; starting the Schematic Design phase using AutoCAD, 3D Studio Max and later in the Schematic Design phase switch to Revit, which may help resolve many of the interoperability issues. Figure 8-2 describes the expected changes in the "To-be" BIM workflow when using compatible software.



A) The “As-is” BIM related model – Interoperability Issue and Using of two different software Families



B) The new “To-be” BIM related model – Resolving Interoperability Issue

Figure 8-2 Resolving Interoperability Issue in the new “To-Be” BIM workflow

8.4.2 “To-Be” BIM workflow- Design Development Phase

Similar to the S.D phase, the “As-is” BIM workflow for the Design Development phase has issues for both the Process and Technology domains. In the following section we will discuss how to improve BIM implementation during the Design Development phase by developing a new “To-be” BIM workflow that helps to come over these issues.

8.4.2.1 Resolving Process Domain related issues- Lack of Contractor involvement

As previously mentioned, it is important in the new process to include the contractor earlier in BIM workflow. Their input during the early stages of the BIM model development can reduce risks, lower cost and improve scheduling. Figure (8-3) presents the development in the workflow after adding the “Contractor” to the “To-be” model.

The “To-be” model suggests that the contractor should be involved in three processes in the Design Development; this creates three process map nodes (Figure 8-3). The first node comes after developing the project “Design Development” documents, so the team can benefit from the contractor reviewing the project details. At this time, the team can make any changes needed to fit the construction/manufacturing process, or add any missing details to the project that could affect the project budget and/or its schedule. With this workflow, we can minimize the number of RFI's and requests for "extras".

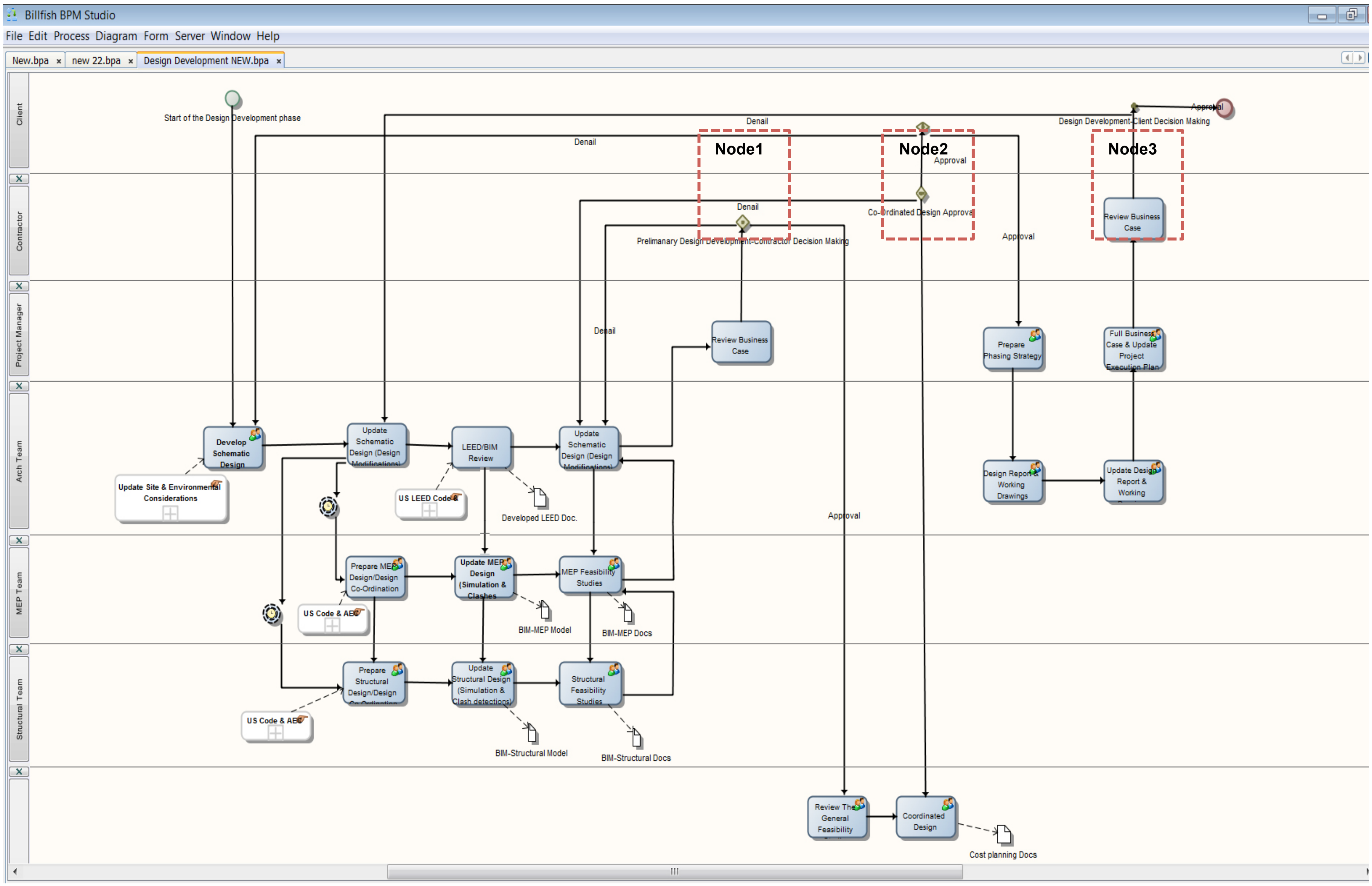


Figure 8-3 Involvement of Contractor in the Design Development Phase- New “To-be” Workflow

Node 2 comes after the project cost estimate. At this phase, reviewing the cash flow, and the cost of the different construction components, while evaluating the cash flow impact of payment terms and retention release provisions, and reviewing the contract's cash flow to ensure "positive money" are included in the earlier stages of the job, which are important issues. At this stage, involving the contractor to resolve all these concerns before signing the construction contract is the best opportunity to negotiate all these terms.

Node 3 is added to review the whole process again in case there are any required changes or modifications before signing the construction contract.

8.4.2.2 Resolving Process Domain related issues- Sequence of activities

As previously mentioned in the “As-is” BIM related process model, the sequence of activities that were revealed to the researcher in the Design Development phase is linear, where the appointed BIM manager sends the BIM model to the MEP team so they start MEP and HVAC design. Later, the structural team starts to work on the model after the MEP team finishes. Sometimes the structural team comes into the workflow before the MEP team. The order of BIM users’ involvement depends on the project type, but in most cases, only one team is invited to work with the architect.

To resolve the problem of the inefficient sequence of activities the researcher suggests that some activities should be done in parallel in the new ”To be” model (this can be done with the aid of a “central BIM model”) we will examine the different methods of synchronizing multi-tasks on the business process flow in the next few pages.

8.4.2.3 Compressing/ Accelerating the Design Process and Synchronizing Multi tasks (Parallel tasks).

Compressing the design process is a strategy that was adapted in the new “To-be” related BIM model that allows individuals to conduct activities simultaneously. This strategy is usually implemented when we have different activities/tasks can be performed at the same instant, which in our workflow are MEP, Structural, Cost Engineer and Architect involvements/activities. This strategy might be required to save time and avoid redundancy if the undesired results are accumulated, which already exists in the "As-is" workflow. Obviously, the project completion time is reduced or shortened by compressing the workflow, focusing on decision-making, maintaining cost control into a single phase, which consequently affects the expenditure and the project scope directly. According to the Project Management Institute (PMI), there are three constraints, which can affect the project quality, these include: risk, resources and external factors. However, reducing the project timeframe during any stage of the Design/Construction process will have an effect on at least one of the other key constraints of the project.

8.4.2.3.1 Different Mechanisms of Compressing and Accelerating the Design Process

A BPMN business process modeling approach provides three mechanisms for parallel activities. The next section will discuss the various strategies of compressing and accelerating the workflow

A. **Uncontrolled Flow-:** In the first mechanism, the workflow can be divided into two or more outgoing sequence flows, which are conducted in parallel (see Figure 8-4); there is no flow control object (event, behavior, etc.) before the division. Thus, the flow continues through these paths without any dependencies or conditions—i.e.(White 2008)

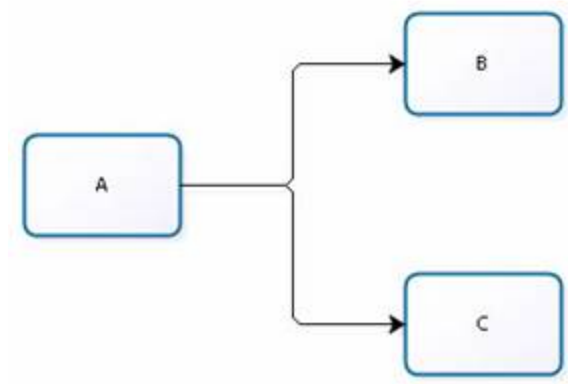


Figure 8-4 Uncontrolled Flow - Source: White 2008

B. **Controlled Flow (Gateway controlled):** In the second mechanism, which is implemented in the "To-be" model in this study, the workflow uses a gateway (event, behavior, etc.) for situations that can be created through multiple sequence workflows. For some workflow planners, this workflow can be the "best practice" once the decision/actions immediately reaches the Gateway, the information will be sent at the same time to each of the outgoing Sequences (White 2008). Later, both flows may interact with each other to verify the results or to exchange information.

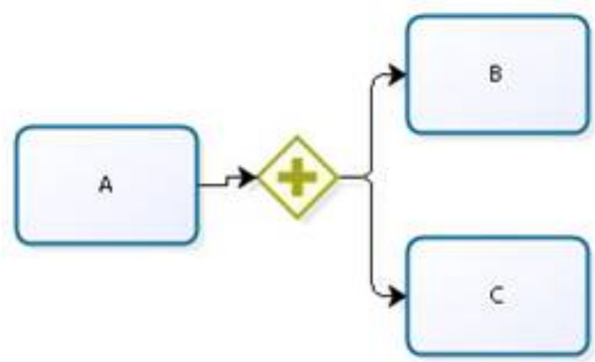


Figure 8-5 Controlled Flow (Gateway controlled) - Source: White 2008

C. **Controlled Flow (Parallel Box):** in the third mechanism, the workflow is split into two or more patterns that start when the Sub-Process starts. If the process does not have a gateway (start event), then these processes simultaneously start in parallel. This is presented by creating a "parallel box," and a parallel situation with visually different appearance (White 2008).

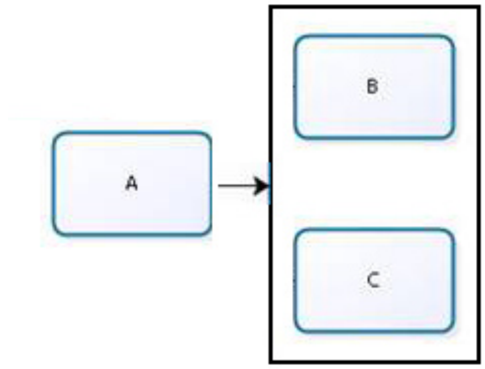


Figure 8-6 Controlled Flow (Parallel Box) - Source: White 2008

By including one or more of the techniques, the new "To-be" model is expected to compress the design process. It is proposed that the second technique, Controlled Flow (Gateway controlled), can best improve the workflow, since information can be processed to each of the outgoing Sequence Flows using the central BIM model (White 2008). The sequence flow in this case may represent a group of BIM users such as Architect, MEP or Structural Engineering teams. Later, these flows/groups may interact with each other to verify the results or to exchange information (figure 8-7 & 8-8).

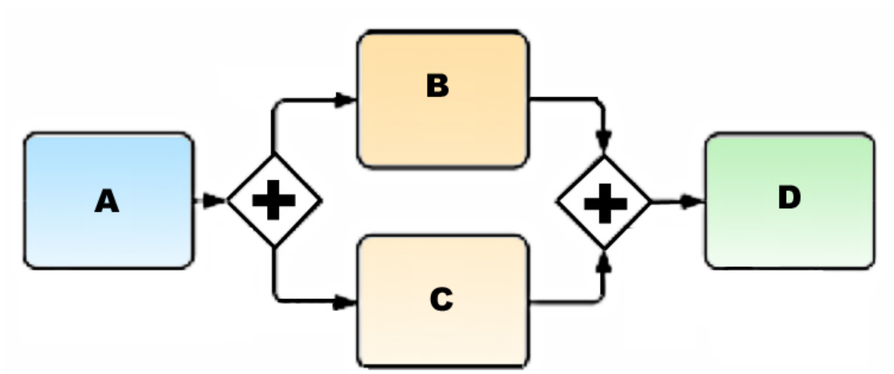


Figure 8-7 Simple Merge Of Multi Tasks-Business Process Diagram Source: (White 2008)

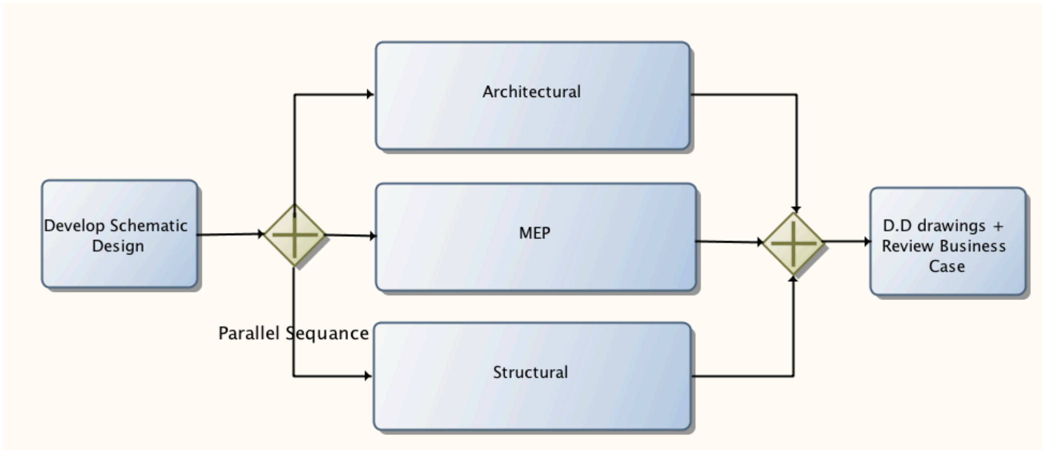


Figure 8-8 Managing of Multi Tasks – Design Development phase.

Thus, the new scenario is expected to accelerate the design process like the following, once the schematic drawings are approved from the client and then reviewed by the architectural team and the project manager, the consultants (MEP, Structural, Cost Engineers, Etc.) simultaneously get involved in the outgoing parallel Sequence Flow. Also, they can exchange information using the "BIM Central Model" or one of the IT developed approaches that will be explained in the next chapter, which could reduce time loss that occurs as a result of the linear flow of tasks. White describes this flow as "best practice" whereas the model creates single or multiple gateways that act as discriminators to distribute tasks between different members simultaneously (White 2008).

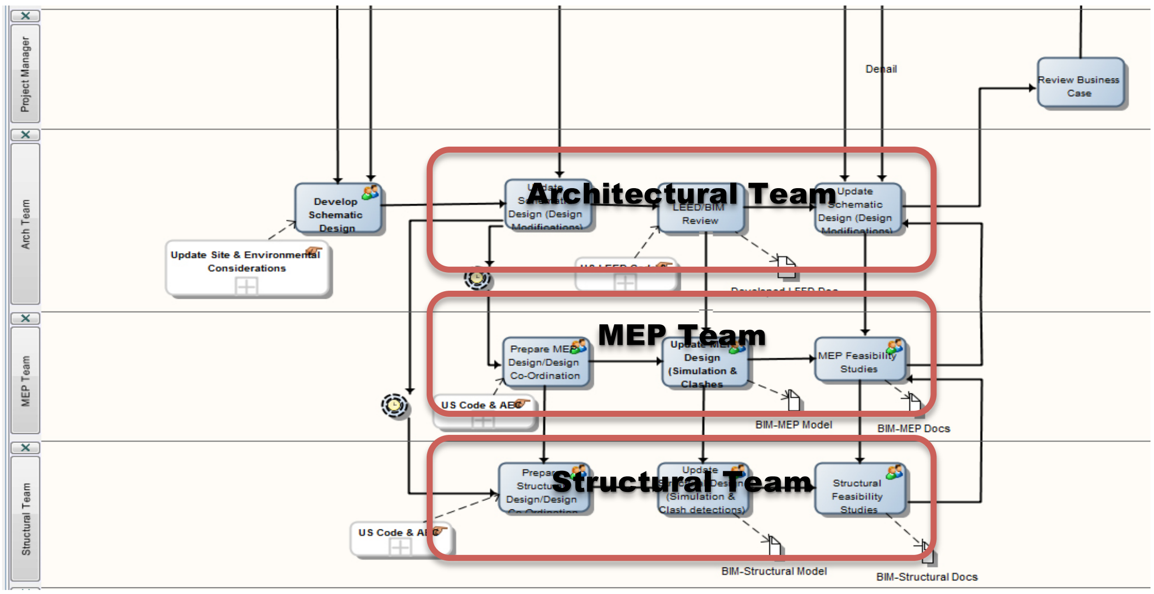


Figure 8-9 Managing of Multiple Tasks - Design Development phase

8.4.2.4 Resolving Process Domain related issues- Routing of information and lack of the Central model

It is clear that exchanging information in the proper timeframe between BIM members and how the availability of information impact decision-making during the building lifecycle. It is, however, important to know that decision-making depends on the amount of available information to BIM users, and based on this information, either to move forward to the next phase or to review the existing one.

As previously mentioned, typically there is no direct communication between BIM users because of the lack of a central BIM model, which subsequently affects the flow of information by increasing the communication route. On the other hand, BIM mangers have control of everything regarding BIM data and documents. All types of information have to go through an FTP server to be verified and approved by BIM mangers before sending it to other BIM users, or they may contact the BIM managers if they need help with any missing information.

8.5 Developing BIM central Model

The New "To-Be" BIM related process model is aimed at delivering support for the collection and aggregation of information from various BIM users simultaneously through the "BIM Central Model". The central model supports exchanging and extracting the relevant information between BIM members during task preparation, instead of waiting till the end of each stage to review this information with other members. To share the model and synchronize information flow, the researcher suggested some strategies to help to enhance the BIM Technology domain. These strategies will be discussed in detail in the next chapter.

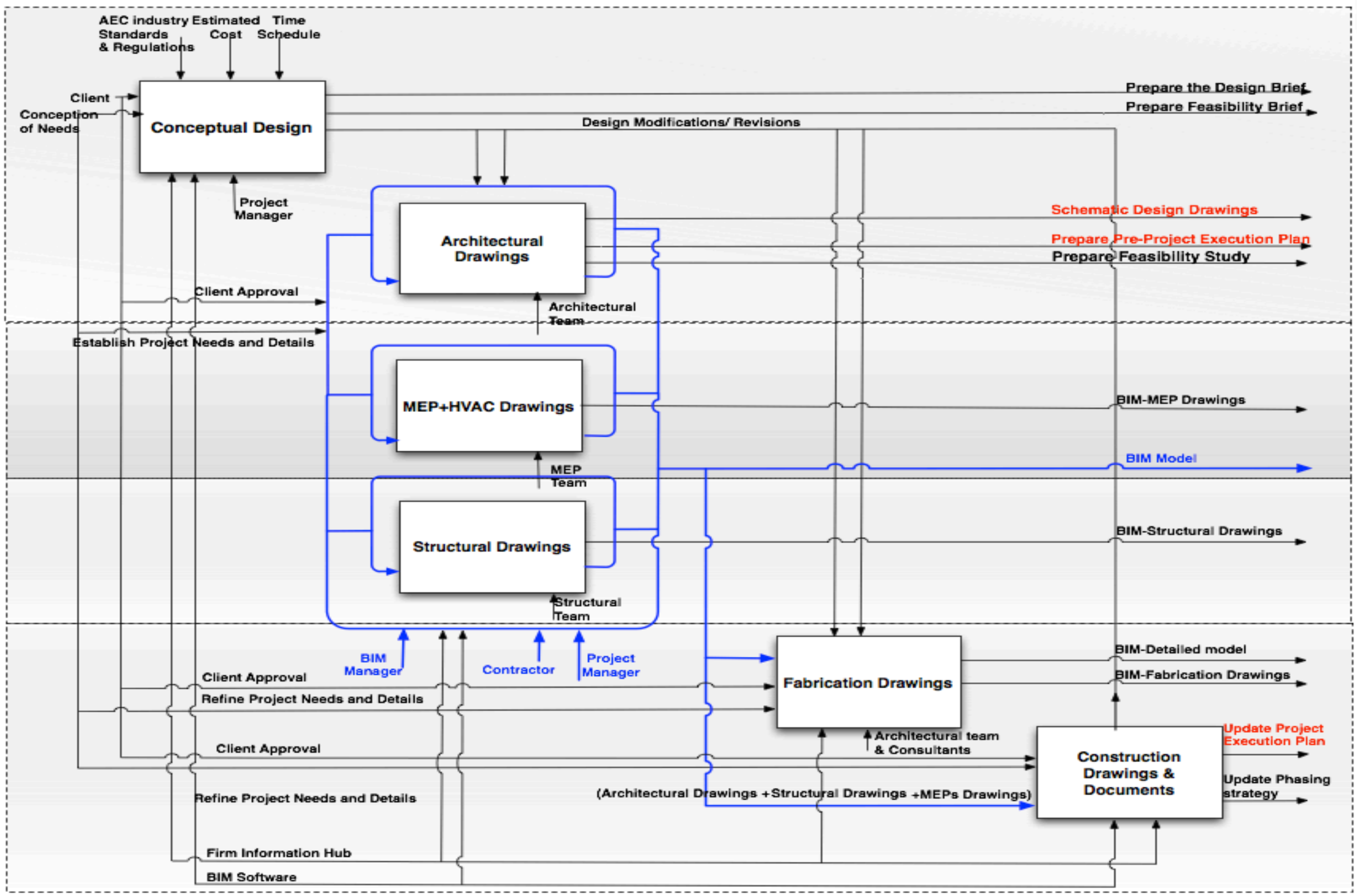


Figure 8-10 IDEF Model – New “To-Be” model

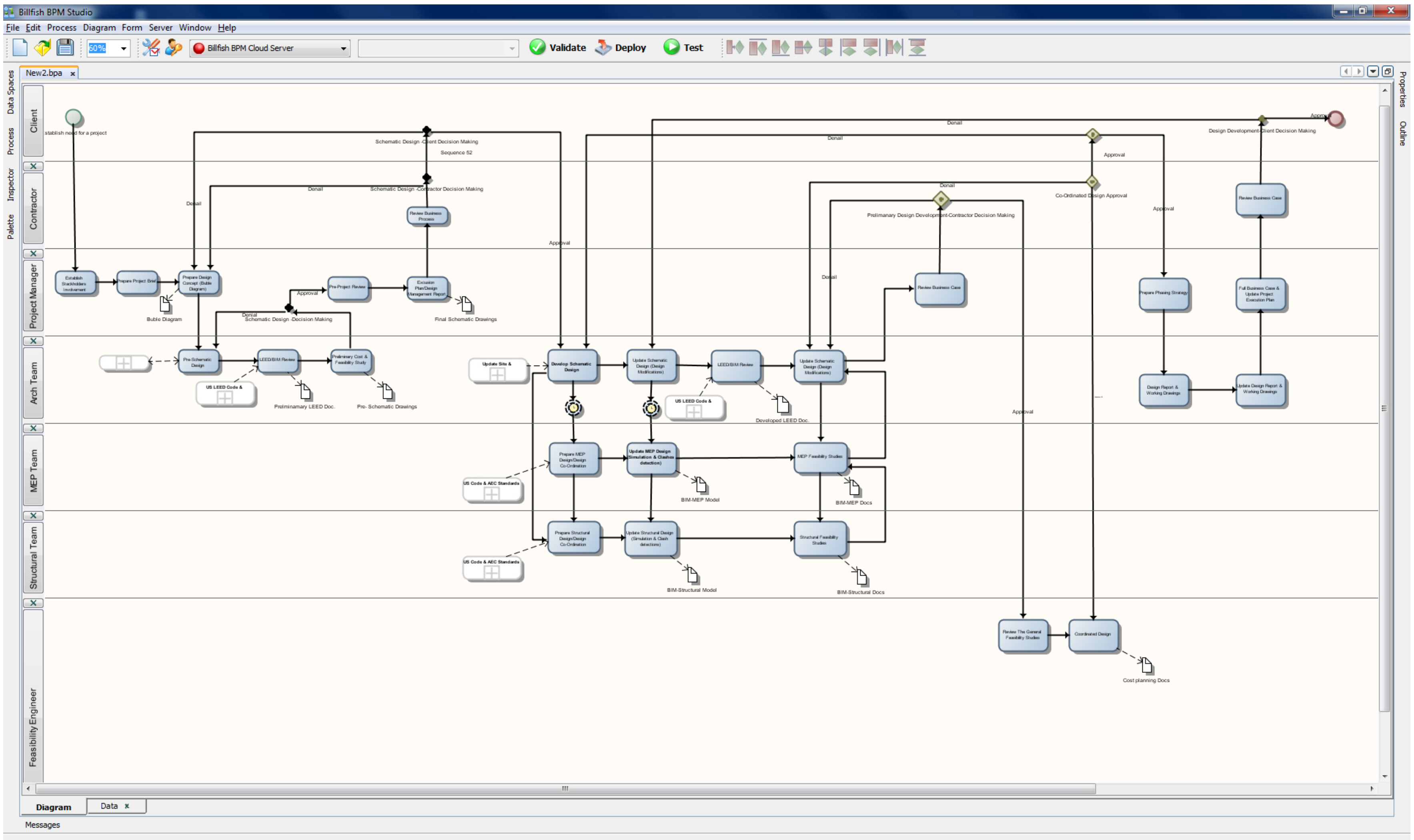


Figure 8-11 BPMN Model – New “To-Be” model

Table 8-1 The new “To-Be” model process components

No	Task type	BIM members	Input	Activity/task	Output	Notes
1	Start Event - Initial action	Client			Client requirements	
2	Starting of Process	Project Manager	Client requirements	Establish Stakeholders Involvement		
3	Sub- Process			Prepare Project Brief		
4	End of Process			Prepare Design Concept (Bubble Diagram)	Bubble Diagram	Beginning of architectural team involvement
5	Starting of Process	Architectural team	Site & Environmental Analysis	Pre-Schematic Design		
6	Sub- Process		US LEED Code & Environmental Considerations	LEED/BIM Review	Preliminary LEED Doc.	
7	End of Process		Material enquires + Previous project Databases	Initial Cost & Feasibility Study	Pre- Schematic Drawings or alternative designs + quantities + design-specific advices and method statement	Drawings and project documents returned to Project Manager (Pre- Schematic Drawings)

Table 8-1 The new "To-Be" model process components (continued)

No	Task type	BIM members	Input	Activity/task	Output	Notes
8	Decision Making	Project Manager Planning engineer + Estimator + Engineering consultant + Operation engineer	Pre-Schematic Drawings	Denied	Returned to step 5	Revision of Schematic design phase
				Approved	Pre-Project Review	Forwarded to Contractor
9	Decision Making	Contractor	Pre-Schematic Drawings	Denied	Returned to step 5	Revision of Schematic design phase
				Approved	Pre-Project Review	Forwarded to Client
10	End- Process	Project Manager Planning engineer + Estimator + Engineering consultant + Operation engineer	Pre-Schematic Drawings	Execution Plan/Design Management Report	Final Schematic Drawings	Forwarded to client
11	Decision Making	Client	Schematic Design and other documents	Denied	Returned to step 5	Revision of Schematic design phase
				Approved	Signing Contract- Move to Next Project Phase (Design Document)	Move to the design Development Phase
	End of Schematic Design Phase- Beginning of Design Development Phase					

Table 8-1 The new "To-Be" model process components (continued)

No	Task type	BIM members	Input	Activity/task	Output	Notes
12	Start Process	Architectural team	Pre-Schematic Drawings & Update Site & Environmental Considerations	Review Schematic Design	Reviewed strategies in planning, program, design, material and subcontract procurement	
13	Sub Process			Update Schematic Design (Design Modifications)		Beginning of MEP and Structural team involvement
15	Sub Process		US LEED Code & Environmental Considerations	LEED/BIM Review	Developed LEED Doc.	
12	Sub Process		US Code & AEC Standards For MEP	Prepare MEP Design/Design Co-ordination	Material enquires + Previous project databases	Initiating communication from step 14
13	Sub Process	Architectural team	US Code & AEC Standards For Structural Design	Prepare Structural Design/Design Co-ordination	Material enquires + Previous project databases	Initiating communication from step 17

Table 8-1 The new "To-Be" model process components (continued)

No	Task type	BIM members	Input	Activity/task	Output	Notes
14	Start process (parallel process)	MEP Team		Update MEP Design (Simulation & Clashes detection)		BIM-MEP Model
15	Sub-Process		Approved MEP + Schematic Drawing	MEP Feasibility Studies	BIM-MEP Drawings + MEP Cost analysis report with material list + enquires issued+ list of suppliers invited to quote, etc.	Drawings and documents returned to Project Manager for approval
16	Sub Process	Structural Team		Update Structural Design (Simulation & Clash detections)	BIM-Structural Model	Drawings returned to Project Manager for approval
17	Sub Process			Prepare Structural Design/Design Co-Ordination		
18				Update Structural Design (Simulation & Clash detections)	BIM-Structural Model	Drawings returned to Project Manager for approval

Table 8-1 The new "To-Be" model process components (continued)

No	Task type	BIM members	Input	Activity/task	Output	Notes
19	End Process	Structural Team		Structural Feasibility Studies	BIM-Structural Docs + Structural Cost analysis report with material list + enquires issued+ list of suppliers invited to quote, etc.	Drawings and documents returned to Project Manager for approval
20	Decision Making	Contractor + Project Manager+ Engineering consultant + MEP + Structural + Schematic Drawing	Review the Business Case	Denied	Returned to step 13	Revision of Design Development phase
21				Approved	Move to Structural Feasibility	Approved
22	Decision Making	Client+ Contractor + Project Manager+	Review the Business Case	Denied	Returned to step 13	Revision of Design Development phase
				Approved	Move to Structural Feasibility	Approved
23	Start Process	Planning engineer + Estimator + Engineering consultant + Operation engineer	MEP + Structural + Schematic Drawing	Review The General Feasibility Studies & Other Documents		
24	End Process			Coordinated Design	Overall Cost	Drawings

Table 8-1 The new “To-Be” model process components (continued)

		Planning engineer + Estimator + Engineering consultant + Operation engineer			estimation (including Direct cost + Staff cost + Financing cost + Insurance+ Site indirect cost + works cost + other cost + Markup & Overheads + Tax, etc.)	returned to Project Manager for approval
25	Decision Making	Project Manager	Overall project documents	Denied	Returned to step 13	Revision of Design Development phase
26				Approved	Prepare Phasing Strategy	
27	Start Process	` Project Manager	Overall project documents	Prepare Phasing Strategy		
28	Start Process	Architectural team	Overall project documents	Design Report & Working Drawings		
29	End Process		Overall project documents (with required amount of copies)	Update Design Report & Working Drawings	Project Review Report + Qualifications	

Table 8(1 The new “To(Be” model process components (continued)

No	Task type	BIM members	Input	Activity/task	Output	Notes
30	End Process	Project Manager	Overall project documents (with required amount of copies)	Full Business Case & Update Project Execution Plan	Reviewed strategies in planning, program, design, material and subcontract procurement + Controlled work directions and progress	
31	Decision Making	Contractor+ Project Manager	Overall project documents	Denied	Returned to step 13	Revision of Design Development phase
32				Approved	Prepare Construction Documents (Next Phase)	
33	Decision Making	Client+ Contractor+ Project Manager	Overall project documents	Denied	Returned to step 13	Revision of Design Development phase
34				Approved	Prepare Construction Documents (Next Phase)	

8.6 Consensus of the new "To-Be" BIM Related Workflow Model

As previously mentioned, the main objective of this phase is to collect feedback from interviewees to evaluate the applicability of the new BIM business process model and the "To-be" scenarios. Thus, similar to the research protocols that were performed in the first two rounds of interviews, the researcher sent out a report that included the research findings attached to the proposed BIM model ("As-is" model and process components) using both the IDEF and Business Process Modeling Notation (BPMN) methods. Then, the report was followed by a phone call and interview to get their feedback.

8.6.1 Methods of Consensus for new business process models

The objective of determining consensus for the "To-Be" process model was to identify key issues that may need to be changed before execution of the model, which would then improve the reliability of the new model. Usually, there are three methods that can be used to gain consensus for any new business process model; we will briefly outline these methods in the next section.

8.6.1.1 Simulation of the New Business Model

Business simulations are computer programs and business simulation games that are used to simulate the development of resources and new business processes' flow to enhance decision-making. Typically, the researcher inputs data into a computer program and receives back a series of optional or conditional data based upon his initial input. The software typically flows through several interactive and iterative alternatives to redesign the process.

Although these software can be used to enhance decision-making, they can't provide reliable results on developing the process nor to evaluate new models.

Because the development of these simulations requires numerical data inputs (quantitative data) in addition to detailed business rules/policies, which cannot be provided through this research. On the other hand, the process does not only include certain business policies but also different human reaction that varies according to existing situations.

8.6.1.2 Implementation of the New Business Model

In the approach, the model is implemented to test, observe and then evaluate the new business process. One reason that we cannot implement this method in the research is due to time constraints and the required support from the targeted firms. Yet, it is not guaranteed that if implementation is pursued, it will gain members satisfaction in a short period of time so they are convinced with the results and continue supporting the model, in addition to the efforts needed to control the environment and observe the implementation.

8.6.1.3 Interviewees Feedback and Consensus

This approach is the one that is used in this study, as it is more accurate than the other two methods and provides advanced consensus, also because it represents the implementation results from the point of view of BIM experts.

Using this method, the researcher invites selected members of the BIM users' community to provide their feedback on the new model and other research results. Based on the interviewees' perspectives and experiences, the new proposed business process could be redesigned and reviewed by the researcher for process improvement.

8.7 Consensus and Updating of the new model

Neither the immediate implementation nor simulation of the new business model is feasible in architectural mid-size firms because of the reasons that have been mentioned earlier. Thus, the method of "interviewees' feedback and consensus" is employed.

In order to obtain BIM users' feedback, an attachment contains BIM "As-is", BIM "To-Be" model and BIM related issues was initially emailed to selected BIM users (Appendix C). Then, an interview with various BIM members has been conducted over the phone to evaluate whether the new business processes can improve BIM implementation in their offices (Appendix 4). The interview consisted of the following questions:

Do you think the new BIM model can improve BIM implementation in mid-size firms in terms of?

1- Schematic Design Phase:

- Improve Information exchange by resolving interoperability issue in the schematic design phase? (Save time, Information exchange, Enhance BIM Implementation, Handling of design changes and updating, Increase BIM members' efficiency, etc.)
- Enhance BIM Implementation by involving the contractor earlier in the design process

1- Design Development Phase:

- Improve Information exchange by resolving interoperability issues in the design development phase? (Save time, Information exchange, Enhance BIM Implementation, Handling of design changes and updating, Increase BIM members' efficiency, etc.)
- Enhance BIM Implementation by involving the contractor earlier in the design development phase?
- Enhance the flow of information?
- Save time and Increase BIM members' efficiency by using the parallel mechanism of communication?

8.8 Feedback on "To Be" BIM related process model

It is important to mention that the researcher requested the interviewees' feedback of the envisioned BIM related "To be" workflow from two groups; the first contained some BIM users who contributed to the study from the start. In addition, the new "To-be" BIM related workflow was presented to a second group of interviewees, which included not part of the model development.

The new model was sent out in both IDEAF (to summarize the process) and BPMN formats (to provide interviewees with the capability of understanding BIM business procedures in a more detailed graphical notation, in addition to facilitate the understanding of the performance collaborations and business transactions between the different process components). Similar to the "As-is:" BIM related model it was found that interviewees are not very interested in an IDEF model but were more interactive with BPMN model, citing that BPMN was easier to understand. More details about BIM user's feedback are presented in the next section.

8.8.1 Feedback From the First Group (BIM users who participated earlier in the research)

Following the interviews that were conducted with BIM users, it was revealed that the majority of interviewees of the first group (4 out of 4 participants) agreed that the ”As-is” workflow, which was previously presented in chapter six, generally exhibits the common practice of BIM in the US market. They also agreed that the model could be changed according to the structural conditions that were previously mentioned in chapter seven. Furthermore, they agreed that the new “To-Be” BIM related process model would enhance BIM workflow in mid-sized firms. Table 8-2 summarizes feedback from the first group.

Table 8-2 Summary of Feedback from the First Group of BIM Interviewees.

	Participant 1			Participant 2			Participant 3			Participant 4		
	Agree	Not Sure	Don't Agree	Agree	Not Sure	Don't Agree	Agree	Not Sure	Don't Agree	Agree	Not Sure	Don't Agree
	"As-is" Model											
Represents the Market	✓			✓			✓			✓		
	"To-be" Model											
Schematic Design												
Resolving interoperability issue	✓			✓			✓			✓		
Involving the contractor in SD phase	✓			✓			✓			✓		
Design Development												
Resolving interoperability issue	✓			✓			✓			✓		
Involving the contractor in SD phase	✓			✓			✓			✓		
Enhance the flow of information?	✓			✓				✓		✓		
Compressing Design/ Parallel mechanism	✓			✓				✓			✓	

Interviewees of the first group have feedback on the new "To-be" BIM related process model; the following section summarizes this feedback:

1. The majority of the interviewees agree that the new "To-be" model would enhance BIM implementation in the mid-size firms.
2. Most interviewees agreed that sharing information between the architectural firm, consultants, contractors, owners and other BIM members earlier in the Design Development phase will give more accuracy and accessibility to information.
3. It is expected that the new "To-be" model will save time since everyone is involved earlier and they can change or add more details and extract precise information from the BIM model when it is needed, in addition to maximize the owner's expectations and provide an increased value to the overall project.

In the following section, we will discuss Interviewees feedback in more details.

8.8.1.1 Feedback on the Schematic Design phase

8.8.1.1.1 Interoperability on the Schematic Design phase

The interviewees agreed that working in the Schematic Design phase using the same software package would save time and effort, but this may need some software development or user training. Most of the users agreed that the flexibility of Sketch-up modeling cannot be compared to Revit, but the researcher's proposal of using 3DS Max may solve many interoperability issues.

> *"We have tried modeling in Revit, which is not as fluid as the tools inside Sketch Up. I'm not sure about 3D Max, but I'm pretty sure that working with the same software package allow us to accelerate parts of the design process"*

The researcher suggested the 3DS Max as a 3D application is compatible with Revit, some interviewees thought that its more complicated than Sketch-up, but it is also important to mention that at the time of this study, the researcher found that software vendors are competing to resolve this issue. For example, Autodesk released a new 3D modeling software similar to Sketch-up called " Autodesk FormIt" that could help in the early phases of the project and also supports BIM workflow. This application was released in April 9, 2013, so there was no chance to test it, but the following is the product description from the Autodesk website.

> *"Autodesk® FormIt mobile app helps you capture building design concepts digitally anytime, anywhere ideas strike. Use real-world site information to help create forms in context and support early design decisions with real building data. Experience a continuous Building Information Modeling (BIM) workflow by synchronizing designs in the cloud for further refinement using Autodesk® Revit® software products and other applications."*

Figure 8-12 Autodesk® FormIt – Source: iTunes Online Store

8.8.1.1.2 Contractor involvement: Involving the contractor earlier in the Schematic Design phase would solve many project issues, but this requires client's knowledge of how BIM works. One of the interviewees, who is a contractor, mentioned that the number of RFI's in the projects that he gets involved with tends to be less with early involvement.

> ***Participant1:*** *I think the best method to implement BIM is the CMGC delivery method, where the owner hires the architect and separately hires*

the contractor and we work together in the pre-construction.

Researcher: *What is the difference between the CMGC and the Design Bid Build delivery method?*

Participant1: *The different between this method and the Design Bid Build Method that in the CMGC, the owner will hire the contractor before the design is complete, then the contractor works with the architect and designers until preparing the preconstruction drawings, and the design is complete but the contractor is already on board, in the traditional design bid build the contract documents are complete and then the contractor bids on completed drawings"*

8.8.1.2 Feedback on the Design Development phase:

8.8.1.2.1 Information Flow – BIM Central Model: Interviewees agree that working simultaneously on a BIM "Central Model" is a good idea that could help accelerate the Design Development phase, but this concept of BIM "Central Model" concept might need more development and further research, this will be discussed more in chapter 9.

> *"It is my experience that the central shared model works best, however it is dependent on the available bandwidth for data, which can be expensive. My experience with the decentralized model is that independent models are shared at a minimum of every week for updating into the combined model. Although not an ideal arrangement, it did work." Participant2*

> *"Sharing BIM files in a server so everyone in the project will access to updates in real time. This could be a great improvement." Participant3*

8.8.1.2.2 Parallel Mechanism – Compressing the Design Development phase: The design team must work out the overall strategy for how the model will be shared. In order to avoid duplication of effort and conflicts, each team member must have a clear understanding of the sharing strategy. At this point, the BIM manager will hold the responsibility for managing the simultaneous information flow between different design and construction disciplines while controlling the changes to that model.

To compress and accelerate the design process in the proper format, one of the interviewees proposed a change to the suggested “To-be” BIM related model; this change will be discussed in the following section.

8.8.1.3 Changes to the ”To be” Model that were suggested by the Participants of the First group

One of the interviewees from the previous group, who is a BIM manager, requested a modification to the “To-be” model.

Although the model supports the involvement of the contractor and other consultants earlier in the process, it seems that some consultants cannot start working unless there is a “Preparation period” before sharing the central model (Figure 8-15). Thus, these consultants have to wait for the BIM manager to develop the model before sharing it, by embedding information, suggesting information workflow, and identify who will control the changes to that model. Figure 8-13 shows the parallel workflow of the various consultants during the Design Development phase in the purposed model.

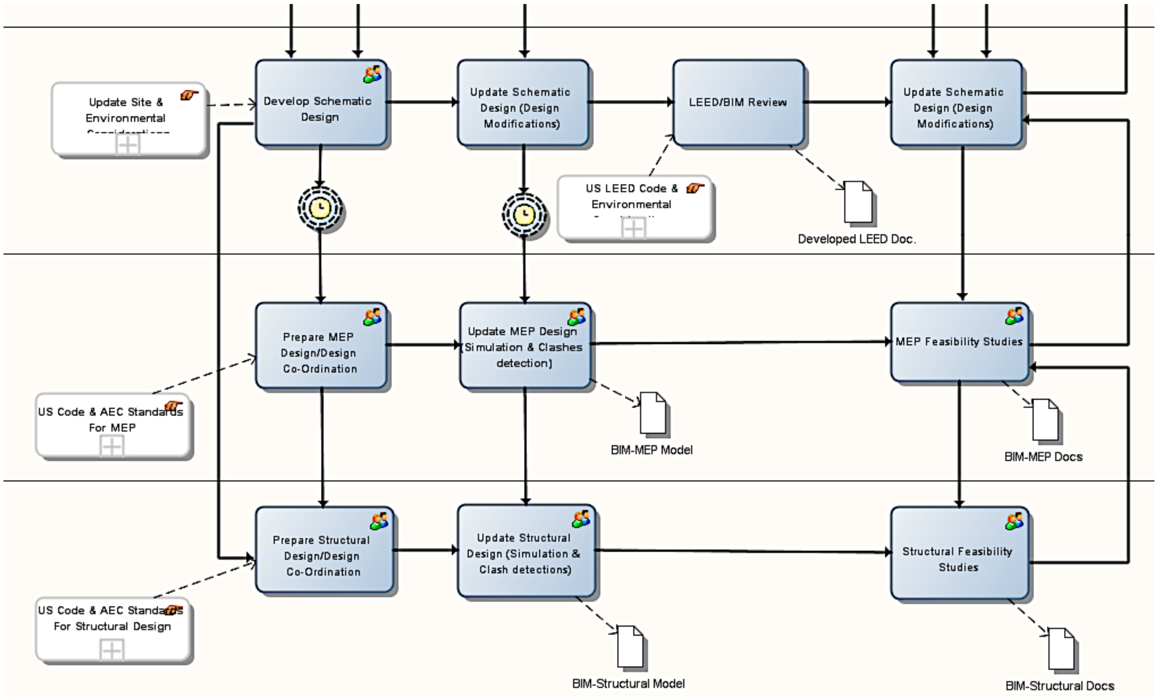


Figure 8-13 Parallel collaboration between the various consultants during the Design Development phase

> *"When considering the development of BIM workflow, it is important to have a preparation period before sharing the model to understand the different needs and roles of each of the users, the designer, the construction manager, and the owner. Each party has very different needs. My example of this is the designer is not interested in the ability of BIM to track costs because this would require an immense amount of work on their part, but this is the BIM manager's responsibility (As a designer, I track overall cost during early design by keeping the building sized appropriately and understanding if I am making it more complex than the budget allows)". Participant 2*

From this feedback, some changes were made to the "To-be" model, whereas the architecture team and BIM manager should have some time in the beginning of the Design Development phase to reach the state of a "ready for sharing" model, then consultants should have a "Kick off meeting", so they can discuss their roles, understand information flow, and identify responsibilities. Before the kick off meeting, it is expected that the Architecture team would develop the model to the point that other BIM users can find their basic requirements with enough information to start their tasks. It is not necessary that the architecture team prepare a full detailed description of the objects into the BIM model, but we should reach the stage of balance where consultants can start work and later they can add more information, such as crucial details and embedding performance data that will help in the analysis and decisions. On the other hand, it is highly recommended for the architecture team to embed this information early as the model develops. Figure 8-14 reflects this change.

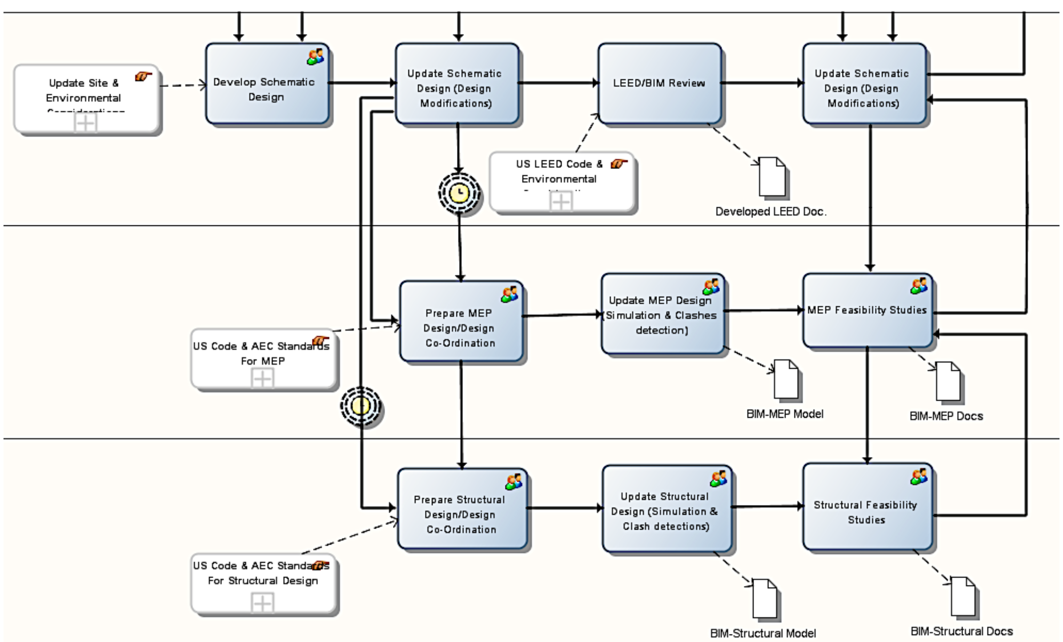


Figure 8-14 Suggested changes to the new "To-be" Model

No changes were made to the IDEF0 model as it only summarizes the process. The BPMN model was updated according to these suggested changes. Figure reflects the updated ”To-be” model.

8.8.2 Feedback from the New Participants (Second Group)

As previously mentioned, the researcher requested feedback from a new group of participants to the study in order to gain consensus that the research results can be generalized to a wide number of mid-size firms in the USA. The interviewees agreed that the existing “As-is” BIM workflow represents the general BIM workflow in most mid-size firms in the USA depending on the structural conditions that were previously presented in chapter 7.

> *“This (As-is model) looks consistent with the market place“*
> *Participant 5*

> *“I think in the next five years, clients will become more sophisticated, especially as they look at ways to incorporate BIM in their facility management, and this will help define some of the processes of using BIM. I think now if the client is knowledgeable it would affect the workflow and the deliverables” Participant 7*

Table 8-3 Summary of Feedback from the New Participants.

	Participant 5			Participant 6			Participant 7		
	Agree	Not Sure	Don't Agree	Agree	Not Sure	Don't Agree	Agree	Not Sure	Don't Agree
"As-is" Model									
Represents the Market	✓			✓			✓		
"To-be" Model									
Schematic Design									
Resolving interoperability issue	✓			✓			✓		
Involving the contractor in SD phase	✓			✓			✓		
Design Development									
Resolving interoperability issue	✓			✓			✓		
Involving the contractor in SD phase	✓			✓			✓		
Enhance the flow of information?		✓		✓				✓	
Compressing Design/ Parallel mechanism	✓				✓			✓	

Moreover, the second group agreed that the new model could enhance BIM implementation in their offices. In the following pages, we will discuss the results of these interviews.

8.8.2.1 Feedback on the Schematic Design phase

Below are selected comments and suggestions from the participants of the second group related to the Schematic Design phase changes.

8.8.2.1.1 Interoperability on the Schematic Design phase: As previously mentioned, some software vendors recently acknowledged the need for software that directly delivers the proprietary file format to the BIM application. Thus, there is effort underway to facilitate information exchange among the myriad of AEC software programs employed by different BIM users during the design and construction process.

> *"In the Schematic Design Phase, our company is using Revit, AutoCAD and Sketch-up, but we decided to use Revit from the first day of our project, not to lose information, but unfortunately it consumes a lot of time" Participant 5*

> *"As a contractor, we use Sketch-up later in the project to model curtain walls, systems and use it for training. So, I'm not familiar with using it early in the process, but for me it makes sense to try standardized and avoid doing things twice with different software" Participant 6*

Generally, the interviewees agreed that using the same software package is rapidly gaining acceptance nowadays in their offices. The interviewees confirmed that they are trying to implement this strategy in their firms in order to enable information interchange between the software programs commonly employed during both the Schematic Design and Design Development phases.

8.8.2.1.2 Contractor involvement: The interviewees in the second group agreed that involving the contractor in the workflow is desirable to alleviate design errors and subsequently enhance BIM implementation. The interviewees explained that contractors usually have their teams that can handle cost estimating and early project planning as well as a construction team that handles detailed project planning and implementation. The interviewees agreed that the maximum benefit of BIM is achieved when it is used as a vehicle for increasing inter-company teamwork and collaboration.

> *"I like this, because we do study different design alternatives and we provide cost analysis and schedule analysis for different design alternatives. So, the early feedback is important" Participant 6*

8.8.2.2 Feedback on the Design Development phase:

Below are the comments from the participants of the second group on the design development phase on the new "To-be" model.

8.8.2.2.1 Contractor Involvement: As previously mentioned, the researcher suggested that the contractor gets involved in the Design Development phase in three process map nodes; The first node is after developing the project "Design Development" documents, the second node comes after coordinating the design and extracting the project cost estimate, and the third node is to review all the Design Development documents before getting the client approval and proceeding with the Construction Document phase. The interviewees agreed that involving contractor in these nodes of the workflow would enhance the project quality.

> *"This looks like a little more involvement than what I typically see in the market, but I like to get involved early with the project, so I would highly recommend that" Participant 6*

> *" I would say this is the optimum scenario, and one way that could be accomplished if the team co-locates a stator, and we were doing that more and more in larger projects, where the entire team moves together, essentially work side by side for design development and cost estimation" Participant 7*

8.8.2.2.2 Parallel Mechanism – Compressing the Development phase:

Most of the interviewees explained that compressing the design process is expected to enhance BIM implementation and to help multidiscipline BIM teams improve the project, but this requires more effort from the BIM manager to organize work between BIM users.

> *"Working simultaneously needs more efforts from the BIM manager in coordinating the project. Coordination is a universal problem on any project that involves a team and can be problematic whether the person is 50 feet away or 50 miles away. A significant aspect of teamwork is the ability of each individual to understand how their work impacts the other team members and in laboratory design this is critical due to the complexity of the building and its services, here comes the role of BIM manager." Participant 6*

One of the interviewees mentioned that this is an important issue that increases the responsibilities of BIM managers. He explained that in cases where we implemented the "BIM central model", it is the BIM manager's responsibility to organize the proper access rights of each BIM member to the central model, where he may need to restrict this right to certain users on the team, thus reducing the possibility of accidental changes to the model. This is part of the project coordination responsibility

8.8.2.2.3 Information Flow – BIM Central Model

The researcher discussed with the new participants the possibility of adding a layer of process logic and decision-making support to the workflow model, which will be explained in detail in the next chapter. Some members of this group commented that this additional layer might consume time to track changes. To address this, there may be designated a specific BIM user who would be responsible for this task. It was suggested that to save time the notification system only be activated at the end of each design stage.

> *"I think part of this notification system could be similar to clash detection, which is a very time consuming task, and if you had this tool on every day you were working, you would never get anything done. Lab buildings when properly designed, each trade is assigned volumes in the building for placing and running their work. This zoning allows the majority of the work to be done without having to be concerned with interferences. Beginning at the midpoint of design development, and onward, clash detection is done as a separate task and as a group in that the resolution of a clash impacts everyone also." Participant 6*

8.9 General recommendations on the suggested workflow and compressed design process:

It is likely that the workflow could become more complicated when BIM users', consultants, and contractors work on one model. The concept of a BIM Central Model would result in storing all project information in a single, continuously updated model. From the interviews with -BIM users' it was mentioned that coordinating a BIM central model across several BIM users is significantly more challenging to manage, and that for this live streaming of BIM files the following aspects should be considered. Some of these recommendations focus on the Process domain, while others are concerned with the Technology Domain. Below are some of these recommendations.

8.9.1 Process Domain Recommendations:

1- **Preparing Design Coordination and Backup Plan:** As previously mentioned, after getting the client's approval on the schematic design drawings and before starting work on a "BIM Central Model", the BIM manager should prepare a "Co-ordination Plan", which describes the information exchange mechanisms, and how to maintain these evolving data throughout the building life cycle.

2- **Negotiating the Workflow and Data Flow Mechanisms:** From the structural conditions for BIM workflow that were previously discussed in chapter 7, it is clear that each project will have its own specific variation for the process workflow. Thus, the BIM Manager will be responsible for negotiating and planning the process workflow, and also responsible for establishing standards for BIM process workflow that provide efficient and effective planning, coordination, clash detection, and correction and procurement. Furthermore, he is responsible for overseeing the general functional BIM capabilities instantly between all BIM users.

8.9.2 Technology Domain Recommendations:

Below are recommendations to develop the technology domain to better accelerate the design process, when using the BIM Central Model.

1- The Central model approach should include the ability to track changes and record who is responsible for these changes: Typically, in the existing "As-is" BIM related workflow, the exchange of data simultaneously occurs between two teams (Architecture/Structural or Architectural/MEP). Thus, if there is a problem in the structural design then the BIM manager will resolve the issue with the structural team. While if there is a MEP problem, the BIM manager will resolve the issue with the MEP team. Thus, it seems important that when sharing a BIM Central Model to be able to track changes. More details about this feature will be discussed in the next chapter.

> *"I believe when implementing a shared BIM model, one important issue is the ability to track the changes and who did what! Currently there is no intelligence in finding changes, the only criteria is element id, but the generated report shows numbers only, nothing graphical at all, in other words: you need to manually get element id's, and find objects by yourself. We tried it once couple of years ago, and the last review was few Weeks ago, still disappointing" Participant 7*

“Recently, a section cut on the building has been deleted and no one knows who deleted it, it was gone and it has to be recreated, no trace and no way to find out who deleted it. I wanted to know who deleted it, not to get this person into trouble, but to advise them not to delete other peoples work. I told them in the past if you didn’t place it don’t erase it, but there is no way to trace it, there is no way to trace changes or issues” Participant 8

It is important that when changes are made to the model, the BIM manager should follow up with these changes and when needed inform the other BIM users. Changes to the budget and schedule should also be updated automatically.

2- **Levels of authorization to change the BIM model:** BIM managers may be able to control changes made to the Central model by applying different levels of authorization to the model. He may give a read only, limited, or full authorization to BIM users who access the model.

3- **Backup of the Central Model:** Maintaining BIM data integrity requires explicit management and oversight; this is because of the high-value of the BIM model. Thus, backups have to be saved at least once a day, in order to avoid model corruption and loss of information. It should also be the responsibility of the BIM manager to discuss this plan with all participants early in the Design Development phase in the “Kick off” meeting.

4- **Development of a group chat system:** The development of a chatting system embedded in the BIM application is also recommended, where BIM users can chat with the whole team or privately with any other BIM user. This would make it quick and easy to centralize, discuss, and prioritize tasks. This chat system, or the Meeting Room as it is widely known, should be featured with history access, offline messages and seamless sync with the other network devices.

8.8.2.2.4 Final BIM "To-Be" Related Business Process Model

Based on the suggested changes and feedback from the interviewees, the final "To-Be" Related Business Process has been developed as the following.

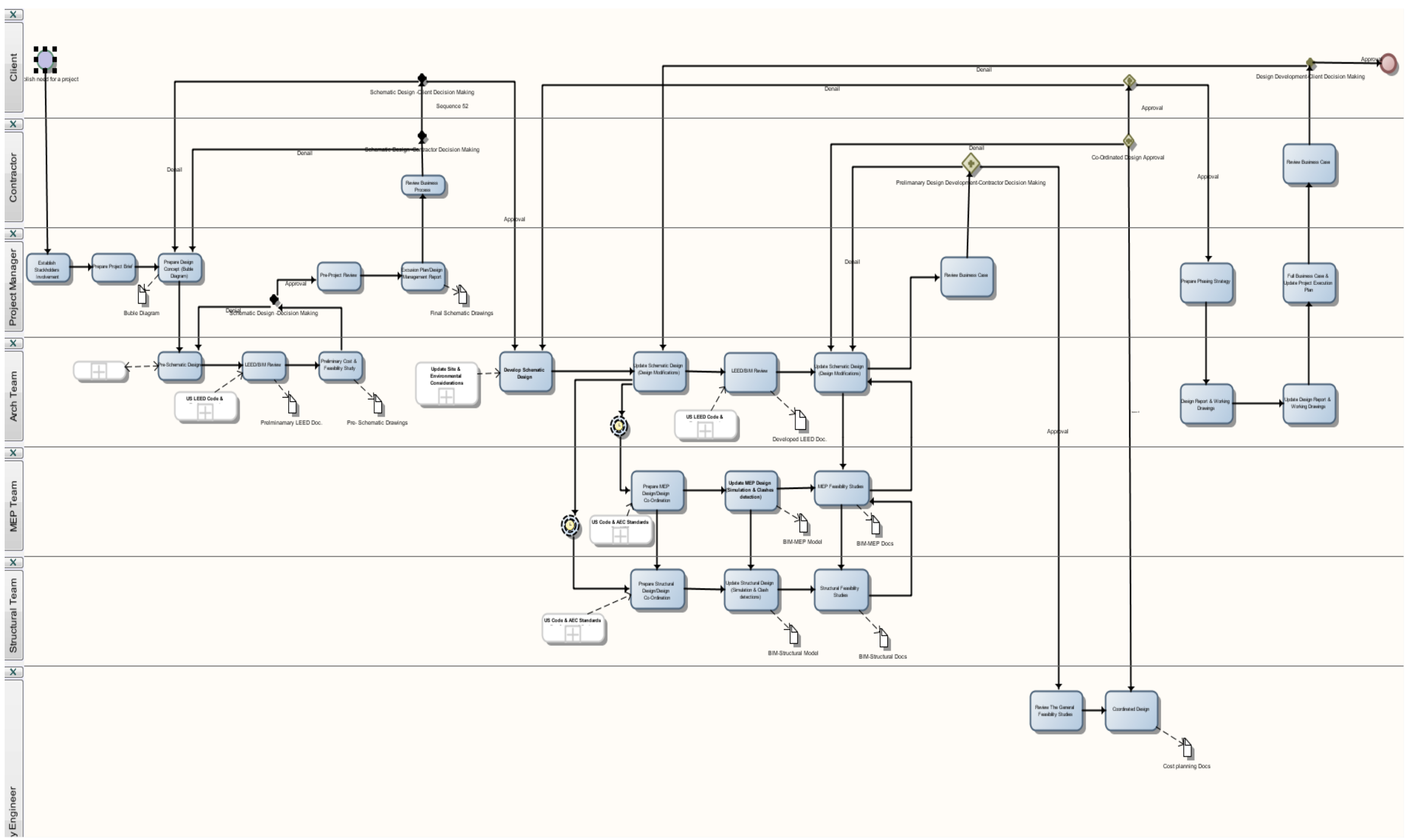


Figure 8-16 the final “To-be” BIM related workflow

8.10 Summary

This chapter focuses on the fourth objective of this study, which is developing a new "To-be" BIM related business process related model. The researcher redesigned activities within the "As-is" BIM related process model; this could be achieved through rearranging the process components. Also, BIM related issues that were discussed in chapter 6 were presented and solutions to resolve these issues have been discussed. The chapter also explores the criteria for redesigning the new "To-be" BIM related process model, what are the best methods to resolve BIM issues that were previously discussed in chapter 6, and the response to the new model.

The chapter also presents feedback from interviewees on the new BIM "To-be" model. The researcher requested the interviewees' feedback concerning the proposed BIM related "To be" workflow from two groups, in order to accept that the research results can be generalized to a wide group of mid-size firms in the USA. The first group contained some BIM users who contributed to the study from the beginning. The second group of interviewees were new BIM users who were interviewed to obtain their feedback and to evaluate whether the new model can be improved.

Chapter 9

Developing the Technology Domain

9.1 Introduction

As mentioned in chapter 2, the primary focus of this work has been on two domains, Process and Technology as they relate to BIM related workflow. While the previous chapter mainly focused on the process domain, this chapter will discuss the strategies to develop and improve workflow in the Technology Domain. The Technology Domain primarily involves computer systems and other related devices, telecommunications equipment, information, platforms, applications, databases, and the networks they comprise. According to A. Sharp and P. McDermott Information Technology is one of two important enablers (domains) that help support the better implementation of any "To-Be" business process model. The Technology Domain is important as it enables the execution, monitoring, and management of business processes as they flow through multiple systems. What is more, they do this at a very reasonable cost, which is very important in a competitive building industry (Sharp and McDermott 2009).

This chapter presents the Technology Domain aspects that should be developed in parallel to support the new process model. The focus is limited to platforms, applications, and database management, which adds more capabilities and provides support to the implementation of a new business process model. The chapter discusses three suggested strategies that were interpreted from the data. First, is the adding of a Relational Database Management System that supports decision-making, second is developing the BIM Central Model concept, and the third is developing the BIM Polling Network.

9.2 Importance of Technology Domain Enhancement

The value of BIM is dependent upon the accuracy of information input and the ease of using, transferring, and sharing of this information throughout the life cycle of a building. However, BIM, which is continually engaged in a cycle of data collection and information analysis, is sometimes quite inadequate, and the accuracy and reliability of information may degrade rapidly (Smith and Tardif 2009). The importance of improving the handling of information is suggested by Dana Smith, who states that *"The chain of custody of building information breaks down even before construction of the building begins. Because it is so rarely compiled, preserved, and maintained in a consistent and methodical manner, the validity of most building information becomes suspect almost immediately after it is created"* (103, Smith and Tardif 2009). No doubt software companies are responsible for some of the issues related to poor information exchange, yet it is the responsibility of BIM users to define their business requirements. For example, what information needs to be exchanged? When and how should it be organized?

Furthermore, Dana Smith describes the importance of developing the Technology Domain (IT Systems) in architectural firms while implementing a new process model, *"If your firm's existing IT infrastructure cannot support the BIM-related business processes and workflow that you wish to implement in your firm, then you need to ensure that your IT department has the financial, personnel, and technical resources it needs to provide your firm with the IT infrastructure that it requires, because your competitors surely will".*

To articulate information exchange requirements, and support the business process redesigning (BPR), this chapter is devoted to describing the scope of information exchange techniques suggested by the researcher to resolve BIM Technology Domain issues. The researcher suggests some strategies to software providers and architectural firms that support the seamless and reliable exchange of information. In addition, certain problematic issues concerning information exchange that were mentioned earlier- in chapter 6 are discussed.

9.3 Developing Process Logic and Decision-Making Support

While conducting this study, there was a question that came up fairly often, "what happens, or should happen, when an architect wants to change the placement and/or properties of MEP equipment?" This equipment is 'owned' by the MEP engineer who is responsible for it. Also, "what is the best way to let the MEP engineer know about this change to review it". In addition, there is a need to support the concept of "Compress/Accelerate Design process", which will be based on having a "Central BIM File" that helps BIM users to share and develop BIM information simultaneously. As the project progresses, the amount of information grows, and subsequently data becomes difficult to manage. Moreover, the timing of critical decisions is important. Often these critical decisions can have a direct impact on the success or failure of the project. Knowing how to analyze the situation and identify the conflicting constraints can greatly increase the likelihood of making the right decisions that allow the project to finish on time and within budget. Thus, the researcher suggests a strategy to better find and retrieve the information quickly. One of the available tools is Metadata, which can be understood as data about data.

For Metadata, the strategy is to deploy layers of process logic and decision-making support to BIM applications. This is defined as application logic, business logic, business rules, and modules. Adapting this strategy is important for the following reasons:

- **1-** Identify who makes changes to the model
- **2-** Identify the impact of this change on the other aspects of the project, for example, increasing/decreasing the project budget, changes to the level of LEED accreditation, changes to project timeframe, etc.

Usually, IT systems and data management layers rely on computations they perform, in addition to data storage and retrieving. Any data management application has the ability to store and process data records and so on, which are necessary for an enterprise to operate. Yet once the Relational Database Management Systems (DBMS or RDBMS) are adopted, number logic can be employed. The concept of number logic is extensively used in business applications by programming modules that contain logic to enforce the rules of the business and subsequently update files and databases. These logics rely on both business and IT perspectives, for the business, every action or task represents a unit of work that has business value, while IT represents functions that must be employed in parallel with these business processes (Sharp and McDermott 2009).

Sharp and McDermott give an example of the relational database management system with the process of withdrawing funds from a bank account using your card-

> *The bank service receives a message from the presentation layer and then checks that the personal identification number (PIN) is valid for the account number, verifies that the account has adequate funds, determines applicable service charges, and so on. It also coordinates updates to the data management layer, updating the account balance and logging details of the transaction. Depending on the technology, the programmer might implement the logic in programs called stored procedures, methods, components, modules, transactions, or (this year!) services. The same business service might be invoked by different presentation mechanisms. For instance, the same transfer cash functionality may be accessible via an ATM, via a terminal at a teller's workstation, over the telephone via an IVR system, or over the Internet via a Web browser. This gives us the flexibility to add or modify user interfaces without reprogramming business services or to change the rules of a service without having to change all of the user interfaces.* (Sharp and McDermott 2009).

Another simple example of RDBMS software is a small third-party application called "TripIt." According to the application's website, the application is inspired by five words, "Customize, Share, Collaborate, Connect, and Integrate", which are analogous to what, the researcher plans to achieve in BIM development. The application is used by travelers, as it authorizes their corporate travel agent to automatically place business itineraries into their TripIt account, and keep them synchronized with forward booking confirmation to automatically create a master itinerary for a trip. TripIt will then “**Customize”** itineraries with additional plans, photos and notes. It can even be used as a guide to pick up your luggage from the baggage claim area once the flight has landed. You can “**Share”** travel plans with family, colleagues, and friends on TripIt network, LinkedIn, Facebook, and Twitter. It also “**Collaborate(s)”** on trips with travel planners and other travelers, “**Connect(s)”** with other travelers using "Who's Close" updates and TripIt Groups, and then “**Integrate(s)”** with helpful third-party apps.

In the previous two cases, there are obvious examples of relational data management. For instance, the case of withdrawing funds, where the system first checks the validity of inputs (using PIN), verifies process validation (checking available funds), and then updates system information instantly (Updating available funds amount). Adopting this strategy to BIM and using a form of relational database management and structured information provides sophisticated algorithms of information and sequence of actions which helps to overcome much of the messy information created by retrieval and compilation of relevant information. Imagine a reality where similar concepts are worked into BIM. If one were to consider a major design change, such as changing the ceiling height, the BIM application would identify the person who is permitted to make this change through an identification code. This step is important because every piece of information generated at any stage of any business process should be tracked, as it matures and a continuous record of when and how it has changed should be available at any stage of building life cycle. Some but not all BIM applications already have tracking features and change-management that can help BIM members to obtain a record of the evolution of information.

The next step is to check whether a change is following some pre-defined inputs, logic or rules. These inputs are typically developed at earlier stages between project members and may vary from one to another, based on the project nature and requirements. These inputs include objectives such as; LEED accreditation, US Building Standards, Cost and Time constraints, information provided by equipment manufacturers, etc.

This step is very important to support decision-making during the different project phases and transforms BIM into a strategic decision-making tool, rather than being only an information modeling tool- useful only in the late stages of project development (Smith and Tardif 2009). For example, BIM could provide some information at the earlier stages of the design such as if this change will be within the budget constraints or not, or if it will have an impact on the required level of LEED accreditation or not, etc. And if not, BIM may suggest some alternatives that could be adapted into the changes.

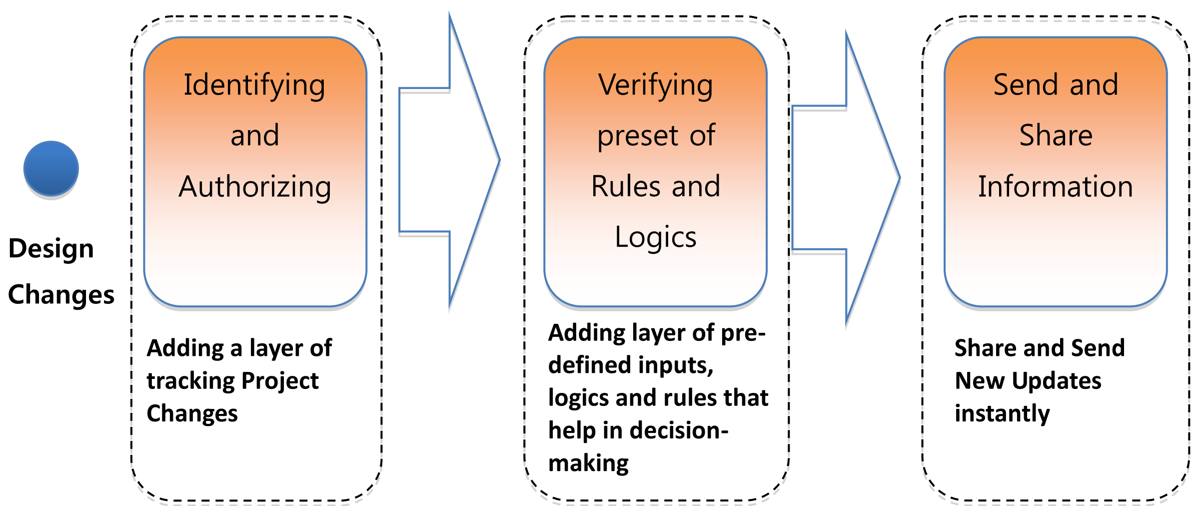


Figure 9-1 Embedding RDBMS logics into BIM application

The last step is to confirm these changes, update the BIM model, and then share these changes with other BIM partners through an instant messaging system. These instant messages should be sent to members who may be concerned with the specified changes. BIM applications should be able to collect and compile only the information they need perform a task. According to the implementation of the algorithmic logic, BIM applications should go through a set of "If/Then" sequential steps and logical algorithms. Then, based on the type of changes that are made and approved, BIM should coordinate these updates to the data management layer and instantly detect the extent that the new design change would impact the other BIM members. Following this, it should notify these members of the changes. For example, if the changes in the height of the ceiling have been approved from the authorized BIM member, the application should detect the types of the equipment that were moved and then share these modifications with related BIM members-MEP and structural engineers in this case. If the design change is related to selecting a new material, the BIM application should send an instant message to the cost estimator and project manager to review and keep them updated concerning the changes. This will save time in transferring large BIM files, and will also keep the teamwork updated. Figure 10-1 presents the process.

9.4 Developing the BIM Central Model concept

Since the early stages of data collection, the researcher felt the importance of working with one central BIM model. While the study evolved, the researcher found that the concept of a central model became increasingly popular. As previously mentioned in chapter 6, the existing flow of information has to go through the FTP server and then the BIM manager, which then directs the information to whom it concerns. This long route of information flow usually takes more time to notify other BIM users of any update or change, which causes the loss of time and effort.

On the other hand, the IFC data model was meant to be the central model, but the researcher found the improper implementation of the IFC import/export function in current software tools. The so-called 'round tripping' of an IFC model cannot be performed without data loss, making the merging of data into one central data repository impractical.

> *"IFC's is a common ground between programs but it reduces data, it doesn't maintain all data, the conversion process is not clean and interoperable as it should be. It is similar to DXF as a trans-format to other programs in old CAD systems, but you lose a lot of things, this similar to IFCs, you may get the geometry, but you lose a lot of data."* ***Participant 3 Interview 3***

As the research progressed, it was found that many software vendors were trying to implement the "Central Model" concept through cloud servers. For example, Autodesk introduced "BIM 360", a fairly new service that allows BIM users to access BIM files through a broad range of cloud-based services. Although the "Central model concept was introduced years ago in various forms such as, 'shared data model' and 'IFC', both failed to support all project partners working simultaneously.

Does the "Central model" solve all of the BIM issues? To answer this question TNO and other Dutch AEC companies conducted a study in 2010 to gain practical insights in working with a "Central BIM Model". The objective of the study was to test different workflows for BIM collaboration and to measure the efficiency of BIM workflow using a Central Model, where all actors used the same software tools. (L.A.H.M. van Berlo 2012). Contrary to the researcher's expectations, the result of the study showed that BIM users turned off the real-time capabilities of the software systems, and rather than real time synchronization, files were checked once a day, or even once a week. This may be for two reasons; the first is that BIM users only need a specific set of information to perform a given task, but working with a Central Model provides more information than what is needed, where this information overload may reduce performance of the specific task to be completed (L.A.H.M. van Berlo 2012). The second reason is associated with the hardware limitations where they cannot handle real-time synchronization.

This brings us back to the first process flow recommendation that was previously discussed in this chapter; the Process Logic and Decision-Making Support. For this

BIM users can work independently while the BIM application sends information concerning any changes to specified users informing them of the updates. In addition, the application can help to make decisions and understand the impact of these decisions on the other BIM users.

9.5 Developing a BIM Polling Network

Another recommendation is to adopt "BIM polling". This strategy is currently implemented in some large firms with satellite offices. Here, different BIM users share information through a computer network with a server or network hub that polls each computer for data. The network manager (who could be the project manager) periodically sends queries to the other devices on the network, one at a time, asking if it has anything to communicate. With this, information can only be shared when a particular computer is polled- if the computer has data to send but is not polled, the data will need to be stored on the network until it can be retrieved.

Bart Sinclair defines this network polling as "A computer communications network that uses polling to control access to the network. Each node or station on the network is given exclusive access to it in a predetermined order. Permission to transmit on the network is passed from station to station using a special message called a poll. Polling may be centralized (often called hub polling) or decentralized (distributed). In hub polling, the polling order is maintained by a single central station or hub. When a station finishes its turn in transmitting, it sends a message to the hub, which then forwards the poll to the next station in the polling sequence. In a decentralized polling scheme, each station knows its successor in the polling sequence and sends the poll directly to that station." (Sinclair Jun 9, 2005)

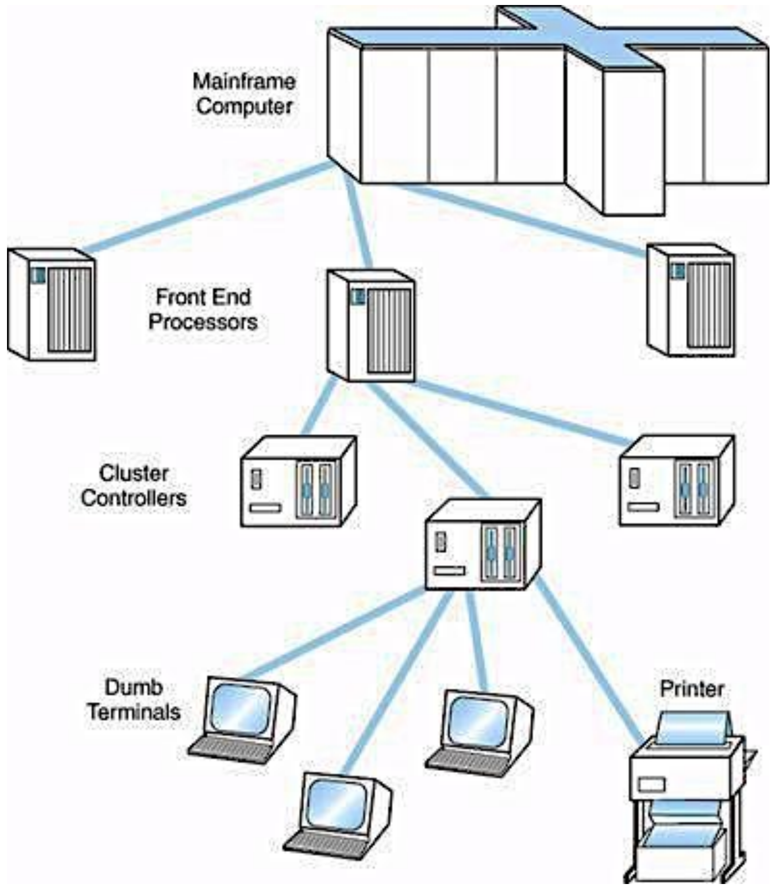


Figure 9-2 Hierarchical, Polled Network - Source: Sinclair Jun 9, 2005

9.6 Expected Outcomes of Technology Domain Enhancement

According to Davenport & Short, Technology and Business Process Redesigning (BPR) have a strong relationship. Davenport & Short state "each redesigning process requires taking a broader view of both IT and business activities, and of the relationships between them. IT should be viewed as more than an automating or mechanizing force: to fundamentally reshape the way business is done." Thus, the new BIM process should be developed in a way which is more than redesigning users activities and/or re-coordinating roles and tasks across architectural firms- by recognizing that neither processes nor IT exist in isolation. IT capabilities should be considered as the most powerful tool for reducing the costs of coordination and as strong enablers supporting business processes. (8, Sloan Management Review Association, Industrial Management Review Association. et al. 1970)

The Technology Domain can have a large impact on the BIM process, and the use of both BIM software development and network polling strategies between BIM users in mid-size firms. In addition to redesigning the workflow that has been described in chapter 9, it has various advantages. First, it shares any design modifications instantly between BIM users, and it keeps all modifications updated instantly, by sending periodical messages to other BIM users. This saves time when compared to waiting for the end of the weekly meetings to be informed of the project modifications and updates. Also, this strategy helps to avoid transferring large BIM files over the Internet, which is uncommon in mid-size firms due to the slow Internet speed and the cost of this technology. Davenport & Short outline more advantages that reflect the roles that IT can play in BPR,

1. **Time management**: time management analysis is a process that can suggest strategies for the redesigning the process. Usually, making changes to the business process workflow should start simultaneously, not sequentially, with development of an IT enabler. According to Thomas Davenport and James Short, “this approach has been followed in the design of computers, telephone equipment, automobiles, and copiers (by Digital Equipment, AT&T Bell Labs, Ford, and Xerox, respectively)”. (7, Sloan Management Review Association., Industrial Management Review Association. et al. 1970)

2. **Enhanced Output quality:** Every process has products or outputs, either physical or informational. An important factor that may suggest a process enhancement is when output quality can be improved. The measurement of output quality may vary, but usually it depends on reviews from customers and team members. Thomas Davenport and James Short explain how Otis Elevator redesigned its elevator service dispatching process around an information system, radically improving service quality and consistency. (7, Sloan Management Review Association., Industrial Management Review Association. et al. 1970)

3. **Cost reduction:** Cost is an important factor in redesigning the process, although optimizing other enablers seems to bring about cost improvements, minimizing cost does not seem to bring about other objectives.

4. **Quality of work life (QWL)/learning/empowerment:** another objective is the enhancement of work life-quality of the individuals involved in the process. Thomas Davenport and James Short explain that IT can either lead to quality control or greater empowerment of individuals. "Zuboff has pointed out that IT-intensive processes are often simply automated, and that the **"informating"** or learning potential of IT in processes is often ignored. Moreover, Schein has pointed out that organizations often do not provide a supportive context for individuals to introduce or innovate with IT."

9.7 Summary

This chapter sheds light on the importance of using IT when adopting the new workflow model, discussed earlier in chapter 9. The researcher suggests two main IT strategies to enhance BIM implementation in mid-size firms.

The first strategy depends on developing BIM applications by embedding layers of RDBMS logics and algorithms into these applications. By adopting this strategy, it is expected that BIM should be able to track design modifications and provide a record of them over the life cycle of the building. Then, the embedded algorithms and logical routines will be able to help BIM users in decision-making and indicates the areas that will be affected with these modifications, instantly. Finally, once these modifications are implemented, the process will include sharing the design modifications and exchanging this information between BIM users. The application should be developed in such a way so as to contact only those users who are concerned with these modifications.

The other suggested strategy is to adopt BIM network polling. This network strategy depends on exchanging information over a local office network and doesn't depend on the Internet for sharing information. The network sends queries to the other devices on the same network, asking if it has anything to communicate, then transfers the new information instantly between the network members. This strategy is already implemented in big architectural firms that have satellite offices, and has been widely accepted.

Chapter 10

Conclusion

10.1 Introduction:

This chapter generally offers interpretive overview for the research objectives, process, and findings. It also summarizes the BIM challenges that were identified in both the Schematic and Design development phase, the existing workflow of BIM and how the "As-is" related business process model was developed, and the new "To-be" BIM workflow that was developed to enhance BIM implementation and to help overcome the current limitations associated with BIM.

Explicitness of the "As-is" BIM related business process model developed in this research allows mid-size firms in the USA to have a clear overview of BIM challenges in both the Schematic and Design development phase, the interdependencies of roles, key activities or tasks, activity sequences and information flow in the business processes. On the other hand, the new "To-be" BIM related business process model suggests some strategies to overcome these challenges and some changes to activity sequences and workflow.

The chapter also discusses the research contributions, and suggests possible future research that may further enhance BIM implementation in these firms, plus some strategies that may help to overcome BIM issues in mid-size firms in the USA.

10.2 Research Summary

The study is qualitative in nature and focuses on revealing the BIM challenges that limits getting the best use out of BIM in both the Schematic Design and Design Development phase. The researcher attempted to map the workflow of BIM in mid-size firms using two methods of data collection, case studies and interviews. Furthermore, the researcher developed the existing “As-is” model and linked the identified challenges to this workflow. Then, a new “To-be” business process model is purposed to help mid-size firms, to better implement BIM.

The following particular research objectives and tasks are addressed throughout the study:

1. Mapping the existing challenges that limit BIM implementation.

The researcher conducted two case studies and several interviews in order to identify BIM challenges in both the Schematic Design and Design Development phases in mid-size firms.

2. Mapping the As-is business process model for mid-size architectural firms.

The researcher also attempted to map the flow of information in order to be used in the future as a reference for further research in different business processes within the architectural/construction filed.

3. Identifying the model structural conditions:

Although the generated “As-is” model should be generic to reflect the popular BIM-related workflow in a broad number of mid-size firms, the researcher found that it is also important to identify the model structural conditions, where these conditions may influence the As-is model and change the workflow. Thus, a qualitative approach has been used to identify these structural conditions (the different business contexts).

4. Developing a new model that supports communication improvement in mid-size architectural firms: Feedback from stakeholders and BIM managers on the developed model was gathered. The model was updated and redeveloped based on this feedback.

These research objectives and tasks are addressed throughout nine chapters, in the following section we will present an overview of these chapters.

Chapter Two presents an overview of BIM basic concepts and definitions, also discusses some important features of BIM. This chapter explores the three BIM domains; Technology, Policy and Process, and based on these domains, the researcher classify BIM challenges under each domain.

Chapter three of this study discusses the business process modeling methods that were used in this research. It also gives reasons for the rise of process modeling in the AEC industry and discusses the criteria for using two modeling approaches. The researcher presents two methods of process modeling that will be presented in this research, IDEF and BPMN, the researcher used both of these methods to generate the existing BIM related process model (As-is model), and then to develop a new business process model (To-be model).

Chapter four focuses on the research methodology applied in this study. The chapter also delineates why qualitative research methods were chosen for this dissertation, and discusses the sequential flow of the qualitative research methods, which has different data collection strategies. The researcher used case studies (two case studies has been conducted in two mid sized architectural firms), and interviews as data collection tactics, the researcher interviewed different BIM stakeholders to map the existing BIM related workflow process model, and to develop a new flexible business process model. Chapter five is more focused on data collection strategies adopted in the dissertation and discusses in details both interviews and case studies approaches.

Chapter six summarizes the outcome of data collection; the researcher presented the existing “As-is” BIM related workflow and discusses BIM challenges that were revealed through the interviews and case studies. The researcher found different issues that were subsequently classified according to the three BIM domains; these issues were also linked to the existing BIM workflow to identify when and how they occur.

Chapter seven focuses on the third objective on this study, which is identifying the structural conditions that may affect or change the “As-is” BIM related process workflow. The researcher found that because the workflow that had been presented in chapter six is popular and may represents the common BIM workflow in mid-size architectural firms, so it is also important to discuss when and why this workflow should be changed. To identify these conditions, the researcher interpreted the data from the interviews using a qualitative analysis tool, Atlas.ti, through three rounds of coding. Then, it was revealed to the researcher that the client is the central category that may change the BIM workflow according to his/her needs.

Chapter eight focuses on developing a new BIM “To-be” related workflow that could help in overcoming BIM issues that were previously discussed in chapter 6. This chapter presented solutions to resolve these issues and explored the redesigning criteria of the new ”To-be” BIM related process model. The chapter also presents feedback from BIM interviewees on the envisioned BIM related “To be” workflow from two groups, in order to verify that the research results can be generalized to a wide number of mid-size firms in the USA. Most of the interviewees agreed that the new BIM “To-be” model could improve BIM implementation in mid-size firms. Interviewees also requested some changes to the new “To-Be” workflow and made recommendations, which were presented in the same chapter.

Finally, chapter nine, focuses on the second BIM domain; the Technology domain. The researcher suggests some technology related strategies to enhance BIM implementation. The first strategy depends on developing BIM applications by embedding layers of RDBMS logics and algorithms into these applications. The second strategy focuses on developing the BIM Central Model concept and how software vendors are trying to implement the "Central Model" concept through cloud servers. While the third strategy discusses BIM network polling, which depends on exchanging information over a local office network and doesn't depend on the Internet for sharing information.

10.3 Study Limitations:

This study is a comprehensive study of BIM related issues and process workflow. It covers many areas including exchange of information, BIM related issues, approaches to process modeling. However, this study has the following limitations:

1. **Limitations related to the research timeframe:** One important issue to this study is the limited duration of case studies. Obviously, each architectural/construction project is limited by the time and the contribution of the project experts, in addition to other variables that are beyond the direct control of the researcher. Thus, using of case study as a data collection tool is not enough to map all issues related to BIM implementation during any phase of the project. On the other hand, architectural projects are each unique and therefore two case studies were not able to capture all of the subtitles of BIM implementation.

2. **Limitations related to the existing old management system:** The BIM phenomena started many years ago, since then it has reached a certain level of maturity. However, according to the National Building Information Model Standard Project Committee (NBIMS-Committee 2010) , current BIM applications are still in an early stage of development whereas many software vendors are pushing BIM development (NBIMS-Committee 2010). Of course BIM is in use today, but many problems of the old CAD management system are still involved in BIM process workflow.

3. **Limitations related to participants intentions:** it was found that some members of the project sought to maximum profit, which affected the amount of information that was exchanged between BIM users, and subsequently increased time and effort. For example, a contractor could depend on some missing information so he can request more clarification and RFI's later after the bid. This leads to additional cost over the original bid, or even changing orders during the project.

4. **Limitations related to human nature:** the variance of race, cultural background and overall personal character can result in miscommunication between the office team members. Due to competition, some team members might be concerned with the achievements that individuals could gain for their planned task. Moreover, subcontractors might not cooperate efficiently. Such issues can be in the form of, improper cleanup, timely removal of equipment and materials, etc. Generally in a project, construction teams might not work collaboratively, but in competition.

10.4 Major Research findings:

In the following section we will summarize the research findings.

10.4.1 Use of BPMN vs IDEF:

Having used both the IDEF and BPMN modeling techniques for the "As-is" BIM related process workflow, it was discovered that the IDEF modeling technique had little or no advantages to interviewees and BIM users. It seems that interviewees are not very interested in an IDEF model to represent workflow but were more interactive with the BPMN model, citing that BPMN was easier to understand. In addition, it provides greater detail about the BIM related workflow, inputs, outputs, actions, tasks and who is doing what, which is vital for the overall comprehension of the workflow.

10.4.2 As-is model and major implementation issues that were found:

In the following section, the researcher summarizes research findings from issues that limit the implementation of BIM during the Schematic Design phase and Design Development Phase.

10.4.2.1 Schematic Design phase:

BIM related issues for the Schematic Design phase were classified into two domains, the first being the “Technology domain”; the second the “Process domain”. Here we will summarize these issues.

10.4.2.1.1 Technology domain issues - BIM Interoperability

Although the researcher was not expecting to find any Technology related domain issues in the Schematic Design phase, because BIM is less frequently used in this phase, but contrary to expectation, the researcher found that using two software packages in the Schematic Design phase would slow the workflow, because drawings have to be initially presented using design software such as Sketch-up, and then redrawn using BIM software, this usually causes a redundancy in workflow, in addition to loss of time.

10.4.2.1.2 Process Domain issue- Lack of Contractor Involvement

Through the first case study it was shown that the contractor had little, if any, involvement in the Schematic Design phase. The reason might be due to the Design-Bid-Build method that was used for this project. Although there are a number of construction project delivery methods in addition to the traditional and most common Design-Bid-Build (DBB).

10.4.2.2 BIM related issues- Design Development Phase

Similar to the Schematic Design phase, issues for the Design Development phase were classified according to the two BIM domains “Process domain issues” and “Technology domain issues”.

10.4.2.2.1 Process domain issues- Design Development Phase

The process domain issues in the Design Development phase can be classified as follows:

1- **Lack of contractor involvement:** Similar to the Schematic design phase, mapping the workflow as it relates to the use of BIM in the Design Development phase revealed the lack of the contractor involvement.
2- **Routing of information and lack of a central model:** The second case study showed that because there wasn't a central BIM model to act as a central communication/information hub, information routing was difficult. It was also found that there is no direct communication between BIM users, which subsequently affects the flow of information by increasing the communication route.
3- **Sequence of activities:** It was found that many BIM related activities are linear, rather than parallel activities, which causes redundancy in the "As-is" workflow, because once a new BIM group of activities is added, the new BIM users, who are responsible for this new group of activities (MEP, Structural, Cost estimation, etc.), have to rebuild/modify/update the BIM model to fulfill their needs.

10.4.2.2.2 Technology domain issues- Design Development Phase

Only one issue was identified for the technology domain for the Design Development phase: the lack of interoperability. Participants in the interviews indicated that the lack of interoperability is a significant constraint to achieving an efficient workflow between architectural, structural, MEP and other building services design disciplines. This issue requires that any new BIM user incorporate his/her own BIM data into his/her model, and consequent should expect to deal with interoperability issues by redrawing or editing the model, which consumes time for updating the model.

10.4.3 “To-be” Model Major Changes from “As-is” model:

10.4.3.1 Resolving Process Domain related issues- Lack of Contractor Involvement: The new “To-be” model suggests including the contractor earlier in BIM workflow. Contractor input during the early stages of the BIM model development can reduce risks, lower cost and improve scheduling. The “To-be” model suggests that the contractor should be involved in three processes during Design Development; this creates three process map nodes. The first node comes after developing the project “Design Development” documents, so the team can benefit from the contractor reviewing the project details. Node 2 comes after the project cost estimate. At this phase, reviewing the cash flow, and the cost of the different construction components. Node 3 is added to review the whole process again in case there are any required changes or modifications before signing the construction contract (Figure 8-3).

10.4.3.2 Resolving Technology domain related issues – Lack of Interoperability:

Although not the ideal solution this suggests that architectural firms should try to work with software in the same family. For example; starting the Schematic Design phase using AutoCAD, 3D Studio Max and later in the Schematic Design phase switch to Revit, which may help resolve many of the interoperability issues.

Furthermore, it is also important to mention that at the time of this study the researcher found that software vendors are progressing to resolve this issue.

10.4.3.3 Resolving Process Domain related issues- Sequence of activities:

To resolve the problem of the inefficient sequence of activities the researcher suggests that some activities should be done in parallel in the new ”To be” model, this can be done with the aid of a “central BIM model”. Different methods of synchronizing multi-tasks on the business process flow are presented.

10.4.3.4 Resolving Process Domain related issues- Routing of information and lack of the Central model:

a. The New "To-Be" BIM related process model is aimed at delivering support for the collection and aggregation of information from various BIM users simultaneously through the "BIM Central Model". The central model supports exchanging and extracting the relevant information between BIM members during task preparation, instead of waiting till the end of each stage to review this information with other members. To share the model and synchronize information flow, the researcher suggested some strategies to help to enhance the BIM Technology domain.

10.4.3.5 Compressing/ Accelerating the Design Process and Synchronizing Multi tasks (Parallel tasks).

Compressing the design process is a strategy that was adapted in the new "To-be" BIM process model that allows individuals to conduct activities simultaneously. This strategy is usually implemented when we have different activities/tasks to be performed simultaneously, which in our workflow are MEP, Structural, Cost Engineer and Architect involvements/activities.

10.5 Challenges for implementing the new "To-be" Business Process Model

Although there have been different attempts to implement new business process models in the field of AEC industry, many did not work all that well. Dana Smith refers this failure to two main reasons, the first is that the leaders in the building industry are often willing to lead with "my way or the highway" attitude, which leads to the flawed implementation. Also, most likely the important decisions are executed as strong suggestions, with no back up plans in case of failure (Smith and Tardif 2009). Also, it is very important to know that the top-down leadership approach, which is the common model in most architecture/construction firms, is more likely to fail because most business leaders work on reforming their organization without the support of their people.

A second possible reason for the failure is that most business leaders are missing the ideological steps that are needed for transforming their firms, which is a particularly difficult challenge. It is well known that many business process models have been developed through trial and error, which means they are undocumented, and rely on the assumption that "everyone knows how it's done." In AEC industry, still firms do not think about business processes in a methodical way (Smith and Tardif 2009). To summarize, there are a few published explicit models developed for the AEC industry, but these models are not robust enough to be implemented and to support improving the workflow in architecture/construction firms.

10.6 Academic and Practical Implications:

This study offers the research field, BIM users and professions, as well as other community members in the area of business process modeling, a participatory process with contributions and significant academic and practical implications as discussed below.

10.6.1 Academic Implications

1. **Providing a reference model for BIM practice in mid-size firms for further research or enhancements:** The research presents a workflow for the existing BIM activities in mid-size firms, which provides a reference model for researchers and practitioners who plan to conduct future research in the same area of study. Although this study covers only the Schematic Design and Design Development phases, the modeling approach and data collection methods that were used in this study can be applied to other stages of design/construction projects.

2. **Identifying BIM issues in both the Schematic Design and Design Development phases:** identifying BIM challenges in both the Schematic Design and Design Development phases in mid-size firms is an important contribution from this study, which can be used as a reference for further research in order to develop different strategies that could also focus on BIM processes within the architectural/construction field.

3. **Providing structural conditions that impact BIM workflow:** this study presents another important aspect for academia, which is identifying the major factors that impact BIM workflow. This could help other researchers in developing BIM implementation strategies to understand where and how to start once we decide to develop a BIM business process.

10.6.2 Practical Implications:

1. **The study presents an "As-is" BIM related process workflow that can be used as a reference for effective process improvement in the AEC industry:** This research provides a model of the existing BIM related workflow, in order to identify BIM related business-process-improvements in the AEC industry.

2. **The study offers a description of the current BIM issues in both S.D and D.D phases represented in the data that was gathered from BIM users and their practicing environments.** In this study the researcher attempted to map BIM related issues in both the Schematic Design and Design Development phases. Furthermore, the researcher identified when and how these issues occur. This identification and classification could be important for Industry developers.

3. **The study proposed some techniques to develop the BIM technology domain:** The researcher suggested some technics and strategies to enhance BIM software as well as networking between BIM users, in order to increase

efficiency and enhance communication between them.

4. **The study offers a description of the "To-be" BIM scenarios in both S.D and D.D phases in mid-size firms:** The study offers some potential business process techniques that help to improve BIM implementation in mid-size firms. These techniques would support redesigning the workflow in these firms to meet the needs and challenges of the competitive AEC market.

5. **The study improves the collaboration between BIM members:** The new "To-be" business process model focuses on managing the collaboration between BIM users which is in high demand in the AEC industry. The business process of the subject firms sheds light on other mid-size firms' BIM related business processes, through information sharing and integration, which could improve a wide sector of BIM implementation in the AEC industry, whereas the value to the client and design quality will be much greater.

10.7 Further Research

This study is a beginning to numerous future research opportunities in a number of fields such as the following areas:

1. **Conduct research focused on the Policy Domain**: As previously mentioned, this study mainly focuses on the Policy and Technology domains, but new research focused on the Policy domain could help improve the current state of BIM Standards/Guidelines. Currently, it is well known that BIM contracts are missing vital agreements, such as who is legally responsible for maintaining data and models; copyrights of the model, what the models must include; and managing the accessibility and the use of the model before, during, and after construction.

2. **Conduct research focused on the other phases on the project life**

cycle to map the business process flow: Future studies may be devoted to other project phases or other types of firms, such as mapping the business processes of BIM in large-size companies during the construction documents phase.

3. **Increase the validity of the business process model structural conditions through multiple case studies.** The validity of the structural conditions developed in this research could be increased if there is cross-research with multiple cases that could test these structural conditions and measure the impact of each.

4. **Management of the BIM Central Model concept:** setting up the criteria for managing the BIM shared model for a project that would enable the effective sharing of the model with a multidisciplinary team working over one network. Cross-research may create a strategic framework that focuses on both the Process Domain and the Technology Domain.

5. **Embedding the Process Logic and Decision-Making Support in BIM application:** Possible studies may be devoted to deploying some layers of process logic and decision-making support to BIM applications. As previously mentioned, this strategy could be defined as application logic, business logic, business rules, and modules.

10.8 Research Recommendations:

The following research recommendations are classified according to two BIM domains, Process Domain and Technology Domain.

10.8.1 Process Domain Recommendations:

1- **Roadmap for the transition:** Before implementing the new "To-be" model, BIM managers should be required to objectively conduct an internal assessment to review their existing "As-is" process model. Also, they should also be required to evaluate their current position and capabilities and distinguish what are the proper steps for this transition. It is also important to identify a development strategy for the existing "As-is" BIM workflow. Thus, a planned BIM workflow transition should be developed. Also, BIM users have to define roles, responsibilities, deliverables, determine how a model is developed, and ways that the information will be shared, such as the form, when will it be provided, by whom, and to whom.

2- **Measuring Quality:** Understanding your objectives as well as the desired quality of the "To-be" model deliverables is an important factor that ensures maximum effectiveness for the new process model implementation. Having quality measurement indicators to monitor the success of the new process model implementation as well as developing a risk management plan, in case of failure, is an important aspect.

3- **The BIM users' level of determination has direct impact on the success of the new "To-be" model implementation**: Identify the "Heroes of Change" who will lead the implementation of the new "To-be" model, and ensure that upper management is fully supportive of the transition process and know what to expect from BIM and when to expect it are important factors.

4- **Developing BIM resources:** Through case studies, the researcher found some existing issues related to the quality of BIM resources and who has access to the shared office resources, including object libraries. Thus, when implementing the new "To-be" model, it is important to develop the existing BIM resources, such as in an object library management system, BIM knowledge portal, and creating a BIM manual with standard procedures that can help ensure that the new “To-be” model is used at its maximum potential.

5- **The existing Delivery Method:** BIM managers have to consider their firms’ ability to engage in different forms of project delivery and the tolerance for this change. As previously mentioned, the current delivery methods don’t support higher levels of communication between different BIM users and consultants.

10.8.2 Technology Domain Recommendations

1. **Higher Levels of Communication are needed to improve the New “To-be” Model Outcomes:** Implementing the new “To-be” model requires changing the existing communication system between BIM users. As previously mentioned, the current communication mechanism in the present mid-size firms represents a crucial issue for the successful adoption of BIM, while the new “To-be” BIM workflow requires the smooth exchange of information between all project participants. Thus, the development of an instant communication mechanism between BIM users is highly recommended, where the users can communicate and share their screens instantly with the whole team or privately with any other BIM user. This would make it faster and easy to centralize, discuss, and prioritize tasks.

2. **Upfront Investments:** Thus, the implementation of the new “To-be” process model requires a considerable amount of upfront investment in software, hardware, a high level of information technology support and buy-in. Also, it is important to ensure that the IT manager is involved in the transition process to support the implementation of the new “To-be” model.

3. **Interoperability:** Interoperability is the ability to exchange data between different platforms/users and applications, allowing multiple types of users to share the project information. Although the researcher presented some strategies to avoid related interoperability issues, developing a long term strategy should be considered while implementing the new "To-be" model.

4. **The Ability to Track Changes and Record who is Responsible for These Changes:** BIM "Central Model" supports exchanging and extracting the relevant information between BIM members during task preparation, instead of waiting to the end of each stage to review this information with other members. The "Central Model" should be updated by its respective creators and requires that all model components to exist in one shared model, with one entity responsible for maintaining the BIM model. Thus, it is important that when changes are made to the model, the BIM manager should follow them up and when needed inform the other BIM users. Changes to the budget and schedule should also be updated automatically.

5. **BIM Visualization and Sharing Format:** the form of sharing BIM data is one of the major issues that the researcher found. BIM users typically share BIM information in a form of 2D drawing files instead of sharing intelligent BIM objects. Also, if the project parties are to view the model on a single desktop computer, they may miss identifying some of the geometric elements as clearly and quickly as they can when using a large projection display. Thus, it is highly recommended to develop a management strategy to share BIM information, not to lose the embedded data and BIM features. For example, the Immersive Construction Lab started to experiment with an effective visualization mechanism by using a 3-screens projection system to view the whole BIM model (Otto, Messner et al. 2005).

10.9 Sharing the research Findings with the AEC industry:

My research findings will be implemented within the AEC industry on two separate forefronts; BIM offices and BIM conferences.

1. **Sharing the research findings with mid-size firms:** The researcher plans to share the research findings with a number of mid-size firms to get their feedback for future study. It is expected that these firms will gain great benefit from the research's description of all BIM issues such as when they occur and how to prevent them. Feedback from BIM stakeholders and BIM managers of the effectiveness of the "To-be" model will be gathered to evaluate the new business process for future studies.

2. **Sharing the Research Findings in Conferences and Journals:** Conference presentations and journal publications are traditional means of sharing research findings with engineers and architects from both the practice and academia, hence my research results are expected reach out to a large and varied type of audience.

Appendix A

IRB Protocols, Participants' Initial Communication Email and Verbal Consent Script

Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24061
540/231-4991 Fax 540/231-0959
e-mail moored@vt.edu
www.irb.vt.edu
FWA00000572 (expires 6/13/2011)
IRB # is IRB00000667

DATE: February 26, 2010

MEMORANDUM

TO: James R. Jones
Ibrahim Abdelhady

Approval date: 2/26/2010
Continuing Review Due Date: 2/11/2011
Expiration Date: 2/25/2011

FROM: David M. Moore

SUBJECT: **IRB Expedited Approval:** "A New Operational Structure and Process Model for Enhancing BIM Implementation in Architectural Design", IRB # 10-143

This memo is regarding the above-mentioned protocol. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. As Chair of the Virginia Tech Institutional Review Board, I have granted approval to the study for a period of 12 months, effective February 26, 2010.

As an investigator of human subjects, your responsibilities include the following:

1. Report promptly proposed changes in previously approved human subject research activities to the IRB, including changes to your study forms, procedures and investigators, regardless of how minor. The proposed changes must not be initiated without IRB review and approval, except where necessary to eliminate apparent immediate hazards to the subjects.
2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.
3. Report promptly to the IRB of the study's closing (i.e., data collecting and data analysis complete at Virginia Tech). If the study is to continue past the expiration date (listed above), investigators must submit a request for continuing review prior to the continuing review due date (listed above). It is the researcher's responsibility to obtain re-approval from the IRB before the study's expiration date.
4. If re-approval is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately, except where necessary to eliminate apparent immediate hazards to the subjects.

Important:

If you are conducting **federally funded non-exempt research**, please send the applicable OSP/grant proposal to the IRB office, once available. OSP funds may not be released until the IRB has compared and found consistent the proposal and related IRB applicaton.

cc: File

Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24060
540/231-406 Fax 540/231-059
e-mail irb@vt.edu
Website: www.irb.vt.edu

MEMORANDUM

DATE: January 28, 2011

TO: James R. Jones, Ibrahim Abdelhady

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires October 26, 2013)

PROTOCOL TITLE: A New Operational Structure and Process Model for Enhancing BIM Implementation in Architectural Design

IRB NUMBER: 40-13

Effective February 26, 2011, the Virginia Tech IRB Chair, Dr. David M. Moore, approved the continuation request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at http://www.irb.vt.edu/pages/responsibilities.htm (please review before the commencement of your research).

PROTOCOL INFORMATION:
Approved as: **Expedited, under 45 CFR 46.110 category(ies) 5**
Protocol Approval Date: **2/26/2011 (protocol's initial approval date: 2/26/2010)**
Protocol Expiration Date: **2/25/2012**
Continuing Review Due Date*: **2/11/2012**
*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:
Per federally regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Office of Research Compliance
Institutational Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, VA 24060
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: April 10, 2013

TO: James R Jones, Ibrahim A I Abdelhady

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)

PROTOCOL TITLE: A new operational structure and process model for enhancing BIM implementation in architectural design

IRB NUMBER: **10-143**

Effective April 9, 2013, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Continuing Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 5**
Protocol Approval Date:	**April 9, 2013**
Protocol Expiration Date:	**April 8, 2014**
Continuing Review Due Date*:	**March 25, 2014**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Virginia Polytechnic Institute and
State University
School of Architecture + Design
Architecture and Design Research

Dear Sir/Madam,

My Name is Ibrahim Abdelhady and I'm PhD candidate at the Collage of Architecture and Urban Studies, Virginia Tech. Currently I'm conducting a research focusing on mapping BIM challenges on architectural firms, precisely on the Schematic Design (S.D) and Design Development (D.D) phases.
The objective of this work is to identify these challenges, organize the findings in terms of themes and categories, and then develop the existing process model for BIM. The research outcome is expected to be a new business process model that helps to overcome these challenges.

The research includes "Case Study" where I have to monitor BIM activities in your office and also different types of interviews. Thus, I would like to invite you to be part of this research, and share your experience through those discussions and interviews, in order to find out the management strategies that can help to overcome BIM challenges and to help reaching a conclusion of what are the most important BIM challenges that facing BIM in the office and what are best strategies to overcome these challenges.

Waiting to hear back from you

Respectfully

Ibrahim Abdelhady

Virginia Polytechnic Institute and
State University
School of Architecture + Design
Architecture and Design Research

Verbal Consent Script

"A NEW BUSSINES PROCESS MODEL FOR ENHANCING BIM IMPLEMENTATION IN ARCHITECTURAL DESIGN"

HELLO, my name is Ibrahim Abdelhady, a PhD candidate in School of Architecture + Design, Virginia Polytechnic Institute and State University. I'm conducting research to identify the existing BIM challenges to the enhanced implementation of BIM during the Schematic design and design development phases. The objective of this research is to identify these challenges, organize the findings in terms of themes and categories, and then develop the existing process model for BIM.

The research outcome is expected to be a new business process model that helps to overcome these challenges. You are being contacted because I would like to ask you questions about Building Information Modeling (BIM). If you agree to be part of this study, I would like to ask you some questions about BIM issues and Information workflow in your office. The survey should take [45min to 1:15min]. Our discussion will be audio taped to help me accurately capture your insights in your own words. The tapes will only be heard by me for the purpose of this study. If you feel uncomfortable with the recorder, you may ask to stop or that it should be turned off at any time.

You are encouraged to ask questions or raise concerns at any time about the nature of the study or the methods I am using. Also, you also have the right to withdraw from the study at any time. In the event you choose to withdraw from the study all information you provide (including tapes) will be destroyed and omitted from the final paper.

Do you have any questions about the research project? I will be documenting your consent to participate. May I proceed with the first question?

Appendix B

Interview Questions

Virginia Polytechnic Institute and
State University
School of Architecture + Design
Architecture and Design Research

"A NEW BUSSINES PROCESS MODEL FOR ENHANCING BIM IMPLEMENTATION IN ARCHITECTURAL DESIGN"

This questionnaire is a part of a doctoral research at Virginia Polytechnic Institute and State University aims to identify the existing BIM challenges to the enhanced implementation of BIM during the Schematic design and design development phases. The objective of this work is to identify these challenges, organize the findings in terms of themes and categories, and then develop the existing process model for BIM. The research outcome is expected to be a new business process model that helps to overcome these challenges. The research proposal is grounded in the proposition that these challenges currently limit BIM implementation.

1- Personal Information:

Name: ....
E-mail: ....
Tel: ....

2. Company Information:

Name: ....

Web Site: ....

3. General Question:

1. How long have you been with the organization?
2. What is your current position title?
3. How long have you been in your current position?
4. What is your role within the organization?
5. What are your responsibilities within the organization?
6. What is the most important activity in your area of responsibility/expertise?

How many employees do you have in your firm?

5-15	16-50	51-100	100-200	>200

Which of the following construction disciplines does your company belong? Describe the type services being offered by your firm.

Architecture	Engineering	Contracting	Other *(specify)*

At which phase of the project will you get involved?

Project Planning	Schematic Design	Design Development	Bid	Construction Document	Facility Management	Maintenance

BIM Process Information:

- Since when have you been using BIM?
- Please describe the CAD process inside your firm from project planning to completion before using BIM?
- How did your CAD process change with the adoption of BIM?
- Did you anticipate changes in organizational structure of your firm?
- What are the organizational changes that you made to implement BIM? (Training, Practice, standardization of application)?
- Has it been difficult to convince project partners to shift from their CAD systems to the BIM collaboration and document exchange environment? (i.e. cultural resistance?)
- In order to accomplish future business change, what do you anticipate requiring from other internal groups in order to achieve success?

Controlling Data Feed

- Are you able to identify whom usually feed/modify BIM model with information at any stage of the project?
- What is the validation method of this information?
- Do you have an assigned staff that will manage and update the data?
- How do you track data in your area of responsibility and keep it current?

Method of collaboration

- How do you usually start the project (sketching bubble diagram, or direct computer modeling)
- How do you usually share the project information/documents between you and other project parties/ consultants? (2D drawing files vs. sharing the intelligent BIM object)
- Rate your team members in their ability to provide comprehensive reporting of BIM information at any stage of the project.
- Hypothetically speaking, if an array of support departments within your organization came to you to competitively bid to deliver BIM services and enable more effective information exchanges to your area of the organization, what would be the best delivery method to meet your needs?
- When does the contractor usually get involved into your project?

Frequent design changes

- Please describe in details the procedures that are usually followed to resolve a design problem (Design alternations/conflicts)?
- How do people usually communicate once there is a need for design changes? (For example; they exchange emails, sharing the model, sending PDF's, etc.)
- How long does it usually take to resolve the design modifications and conflict issues?

Software Information

- What is your BIM software? How did you choose your BIM software Package?
- Please *rate the following* areas of your BIM software with (1 = poor; 3 =average; 5 = excellent)
  - A. Ease of software setup, Ease of learning, Ease of use and reading GUI (Graphical User Interface).
  - B. Quality of Resources: Customer Support, Online Help, Tutorials, and Other Learning Resources.
  - C. Availability of Resources: Availability of object Families, Blocks and Standard Objects.
- Which of the following analysis do you see as the benefits of using BIM for your firm business needs? Please explain why?
  - A. Direct integration with structural analysis applications
  - B. Direct integration with energy analysis applications
  - C. Direct integration with cost estimating applications
  - D. Direct integration with project management applications

Interoperability

- Do you encounter any issues once you transfer your BIM files from an old BIM application version to a new version
- How do you rate the impact of interoperability on BIM quality (Ability to import/export files within different BIM environments, Compatibility between different BIM applications)
- If the issue of interoperability exists in your firm, what are the procedures that you follow to avoid this issue.
- How do you evaluate IFC Interoperability/ Support?

Shared Model

- Do you share BIM model between the different project disciplines in real time Networking (associative file sharing and distributed work process across WAN/Internet)?
- If not, what does prevent you from sharing the model in real-time? How do you usually catch up with the model updates/changes?

Forms of visualization & Method of exchanging information

- In which form do you usually share the project documents and information between you and the other project disciplines (2D drawing files vs. the 3D BIM object.)
- How do you prepare and obtain BIM Families?
- How easy is it to access the specific information from BIM model?
- How is BIM and information exchange value quantified when reviewing project progress and success?
- Do you feel that you possess the awareness and insight regarding BIM processes and technology to be able to fully leverage the capabilities it offers the organization?

File size

- How do you evaluate BIM ability to handle large files?
- How frequently do BIM Files crash?

Any other questions or concerns that you may need to address?

Appendix C

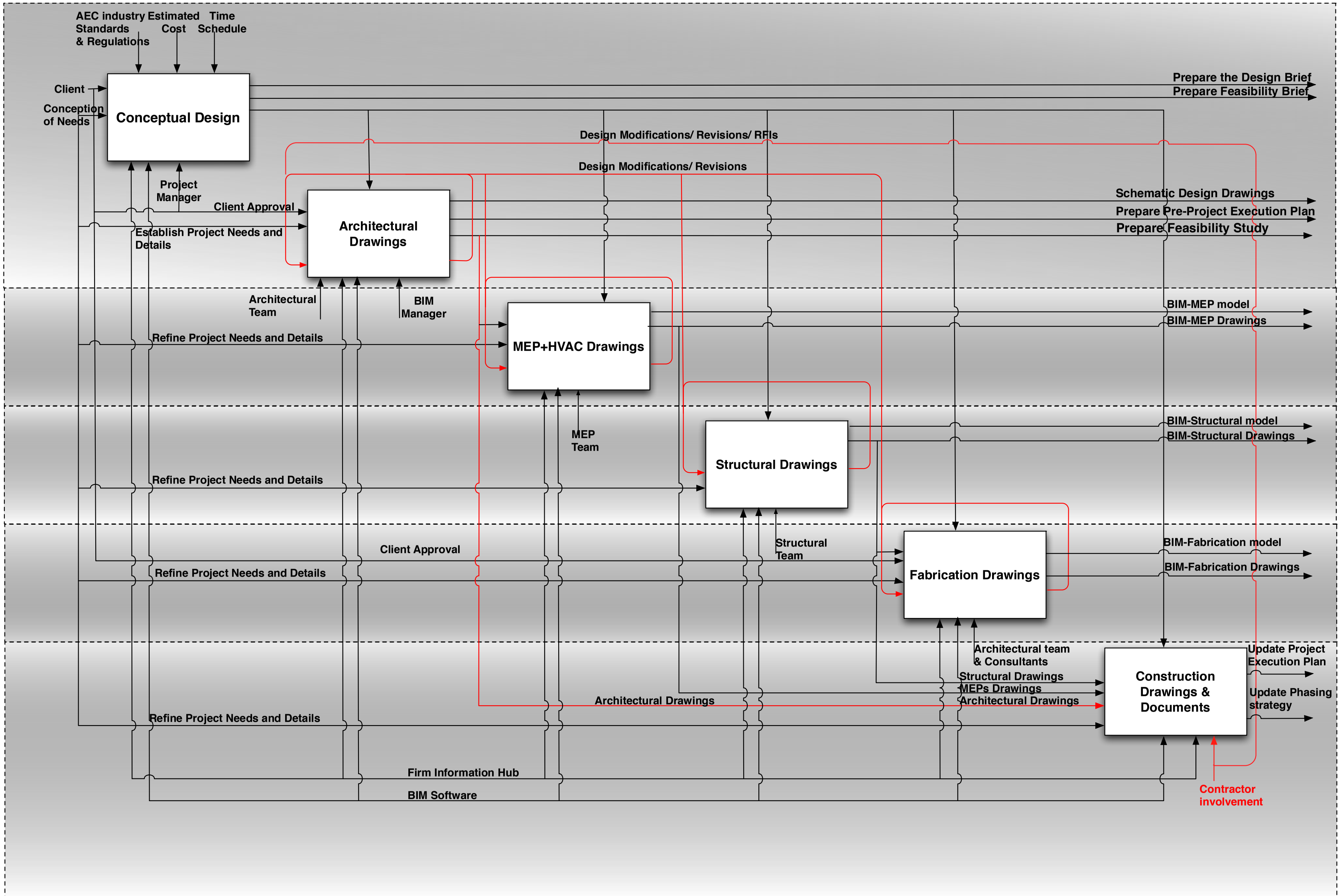
Feedback Interview

Virginia Polytechnic Institute and State University
School of Architecture + Design
Architecture and Design Research

“A NEW BUSSINES PROCESS MODEL FOR ENHANCING BIM IMPLEMENTATION IN ARCHITECTURAL DESIGN”

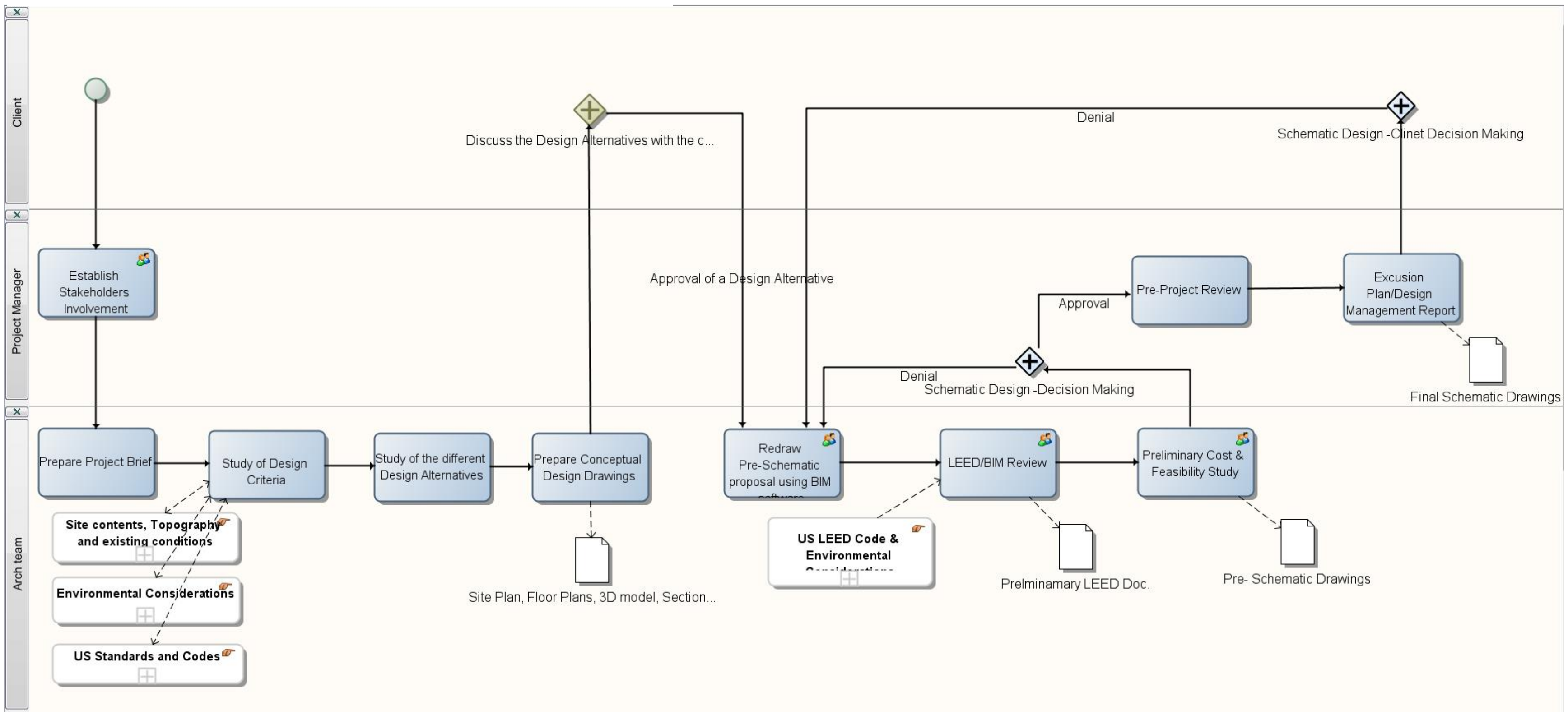
This questionnaire is a part of a doctoral research at Virginia Polytechnic Institute and State University aims to identify the existing BIM challenges to the enhanced implementation of BIM during the Schematic design and design development phases. The objective of this work is to identify these challenges, organize the findings in terms of themes and categories, and then develop the existing process model for BIM. The research outcome is expected to be a new business process model that helps to overcome these challenges. The research proposal is grounded in the proposition that these challenges currently limit BIM implementation.

Mapping “ As-is” BIM Related Process Model

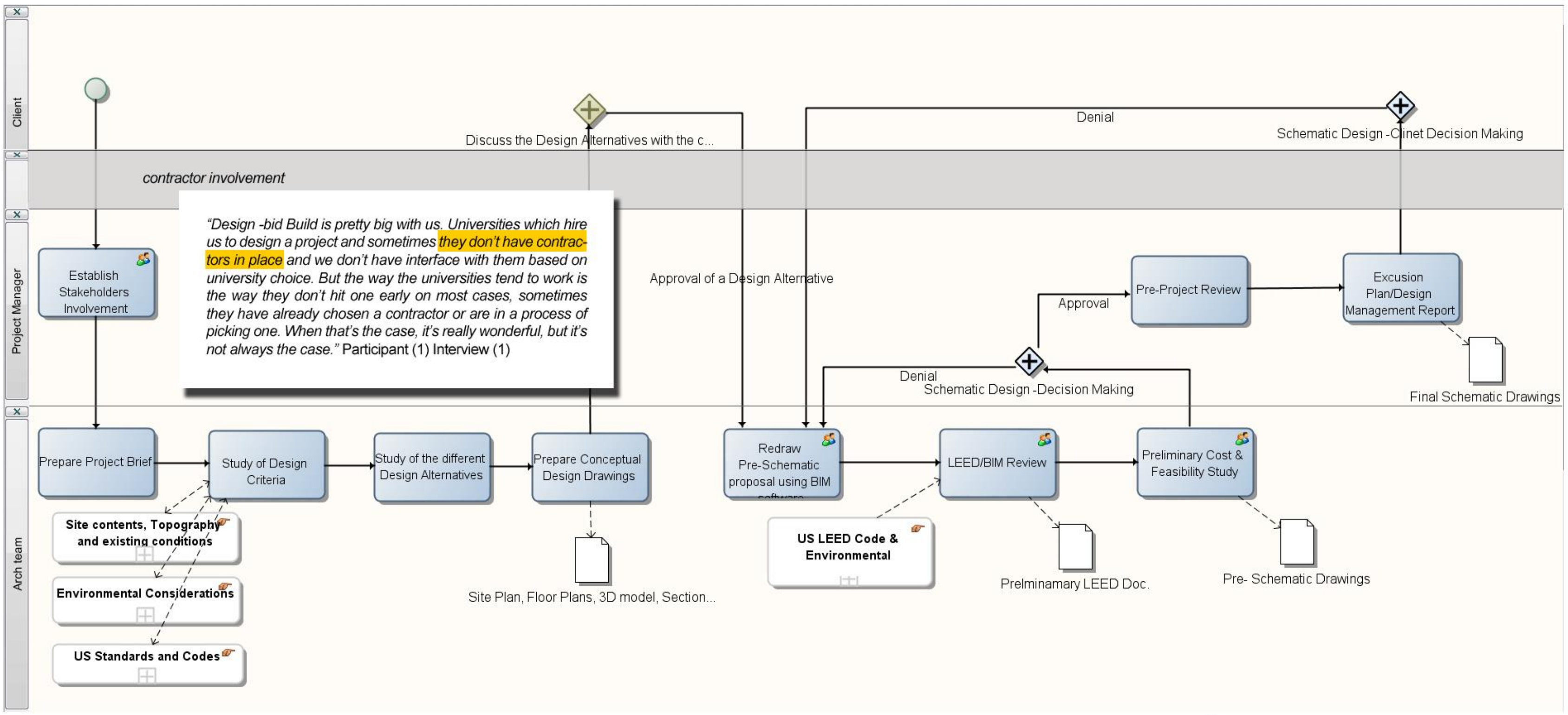


The existing BIM process model using IDEF technique

Exiting Workflow Schematic Design Phase:

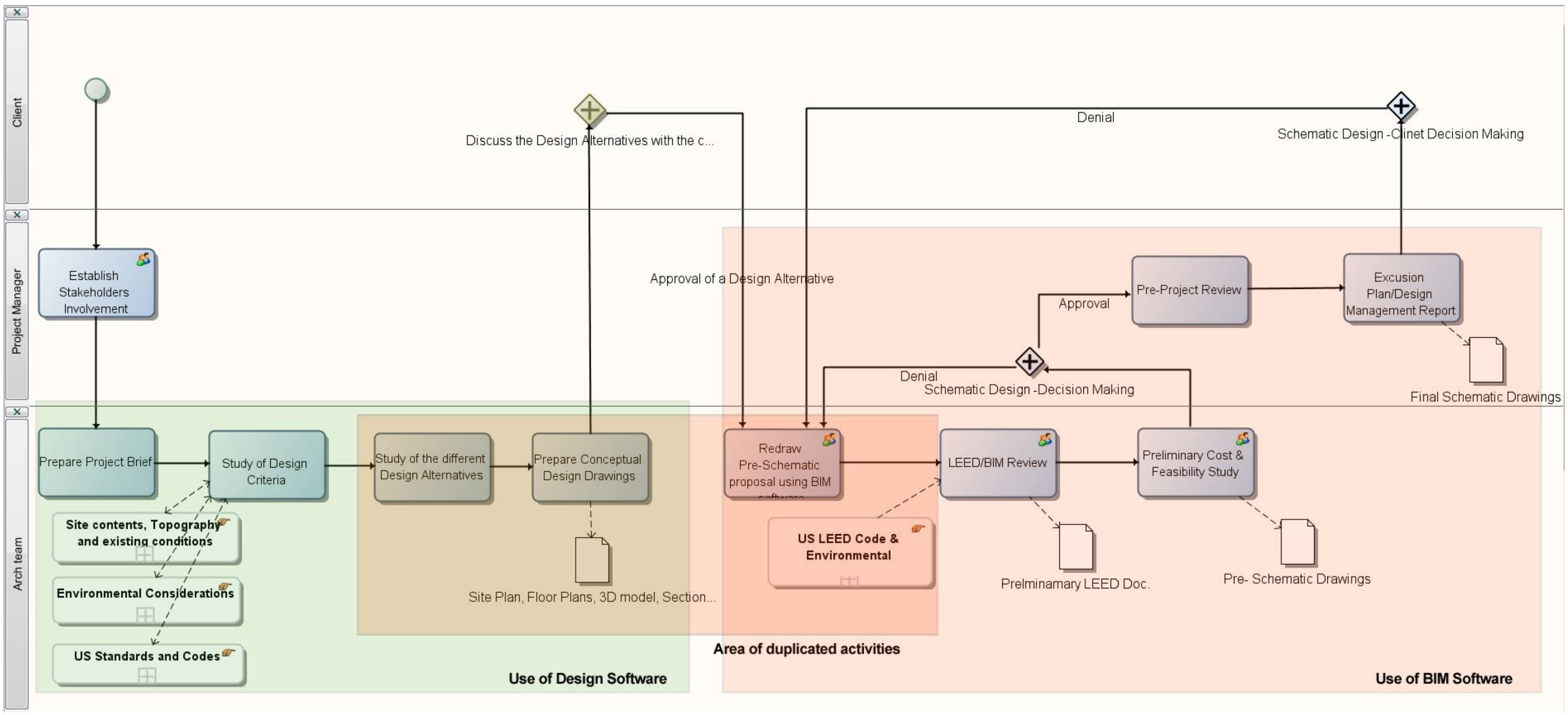


Lack of Contractor involvement- Schematic Design Phase:



Process Domain Issues: Missing of Contractor Involvement
Schematic Design Phase
BIM "As-is" related process model

Interoperability- Schematic Design Phase:



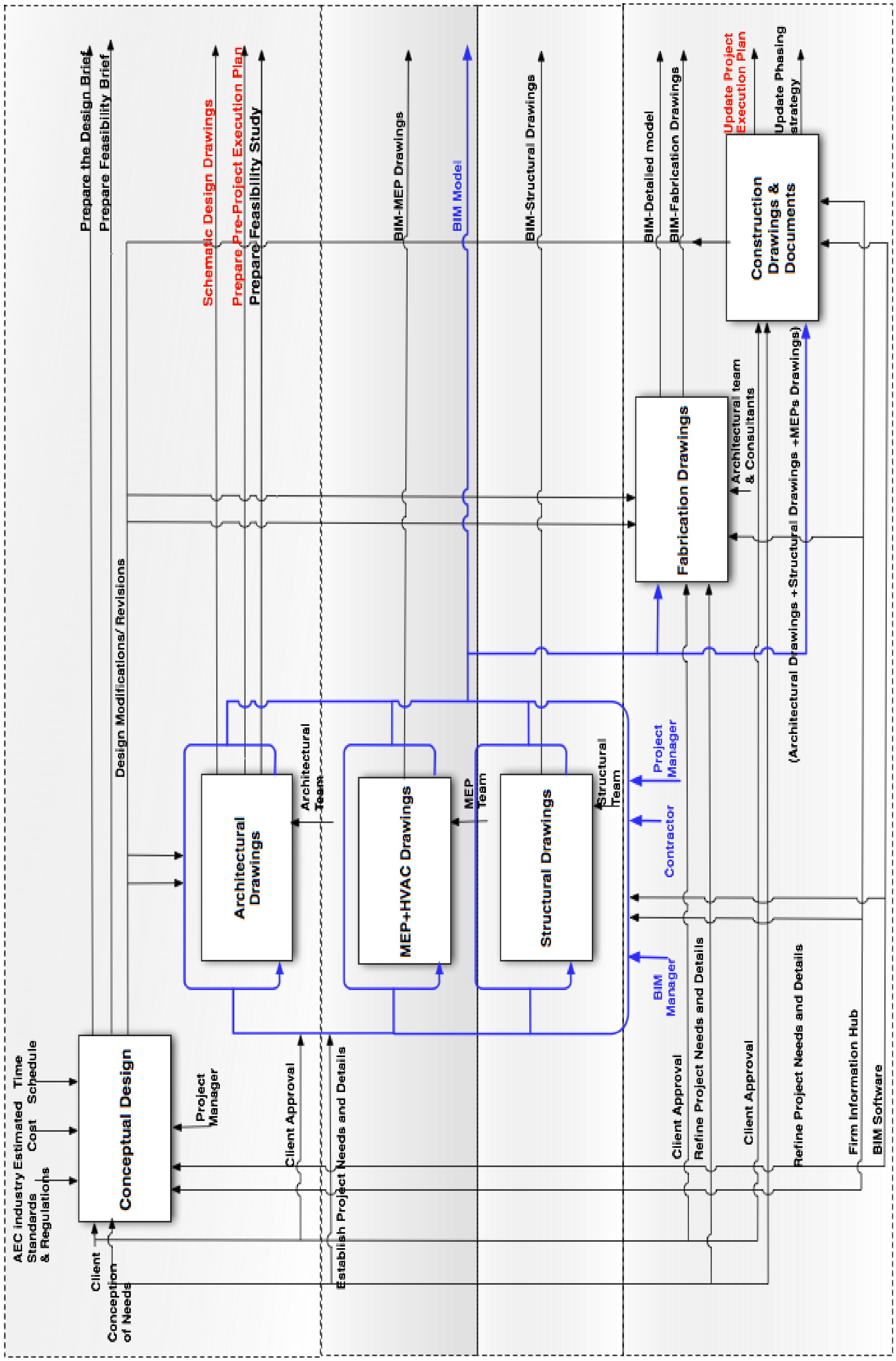
Technology Domain Issues: Interoperability and duplicated activities Schematic Design Phase

BIM "As-is" related process model

Feedback on the Existing BIM model

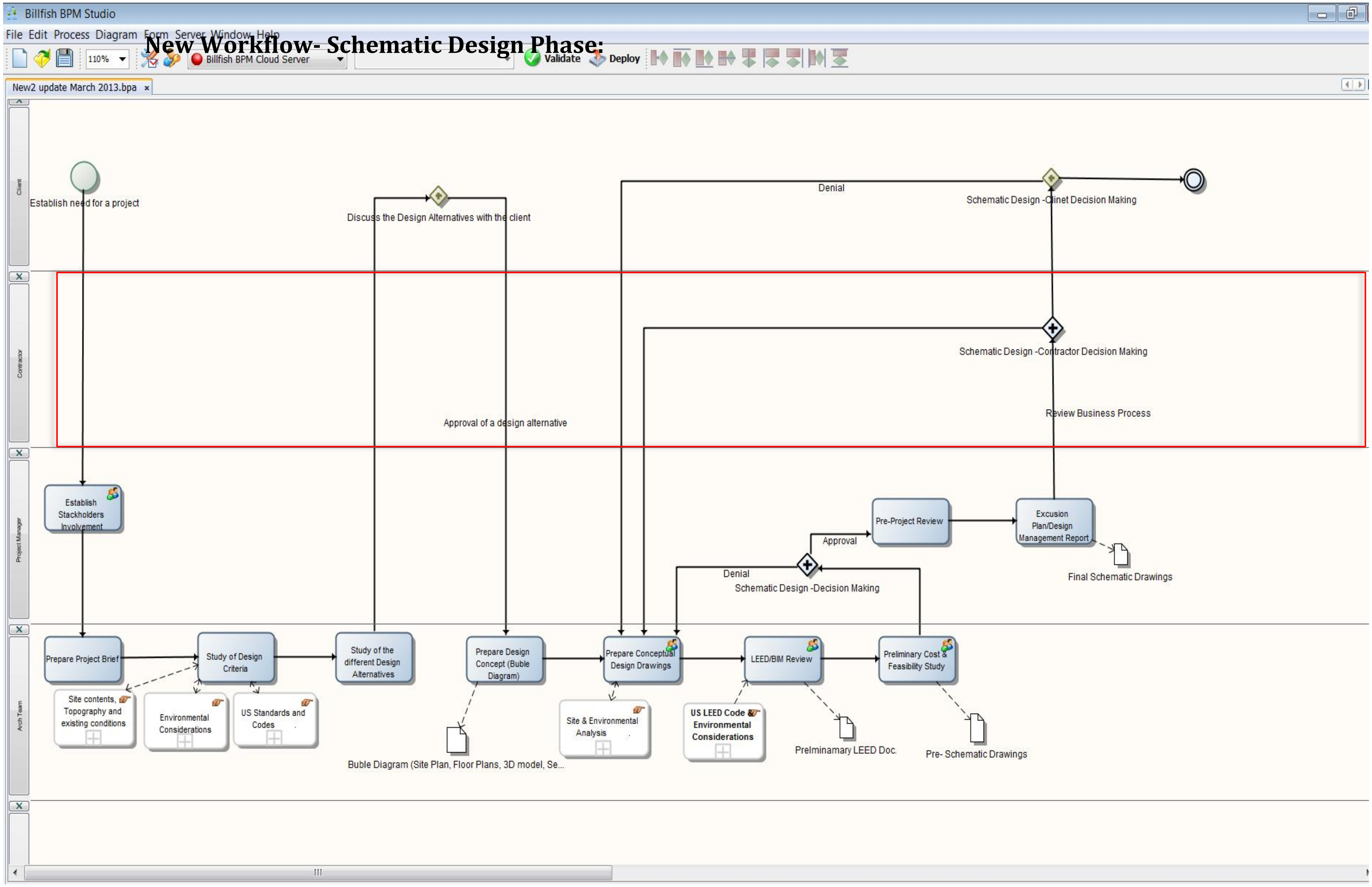
1. **Do you think the Existing BIM model that is presented here reflects the existing BIM workflow in your firm in both the Schematic and Design Development phase?**
2. **If not, what are the required changes to this model to present your office workflow?**

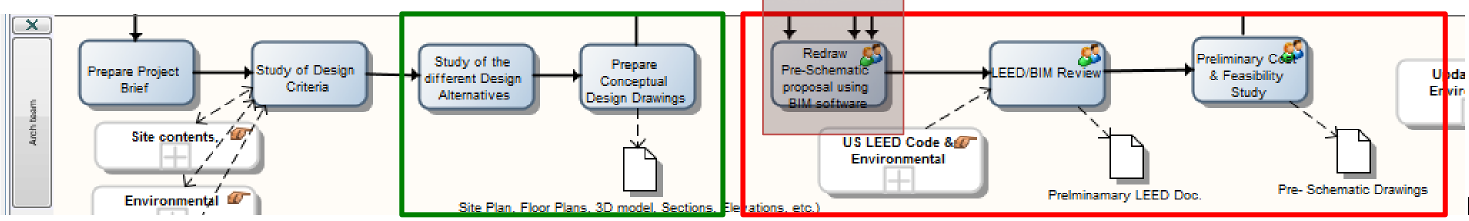
New “ To Be” BIM Model



IDEF Model – New "To-Be" model

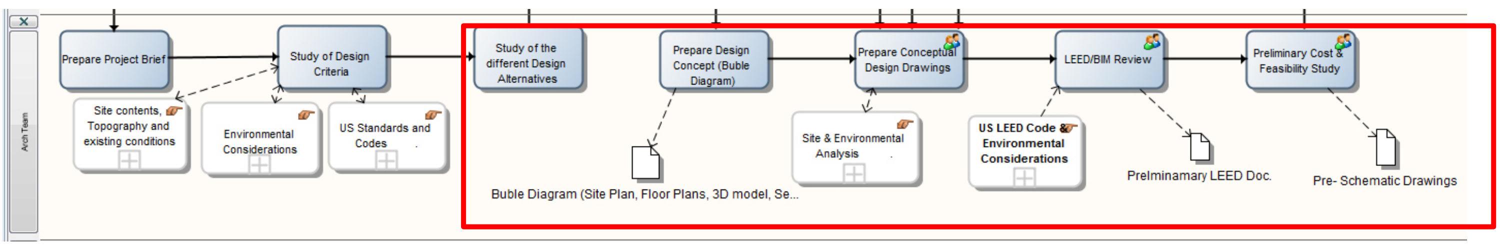
New Workflow- Schematic Design Phase:





3D Sketch-Up BIM Software

A) The "As-is" BIM related model - Interoperability Issue and Using of two different Software Families

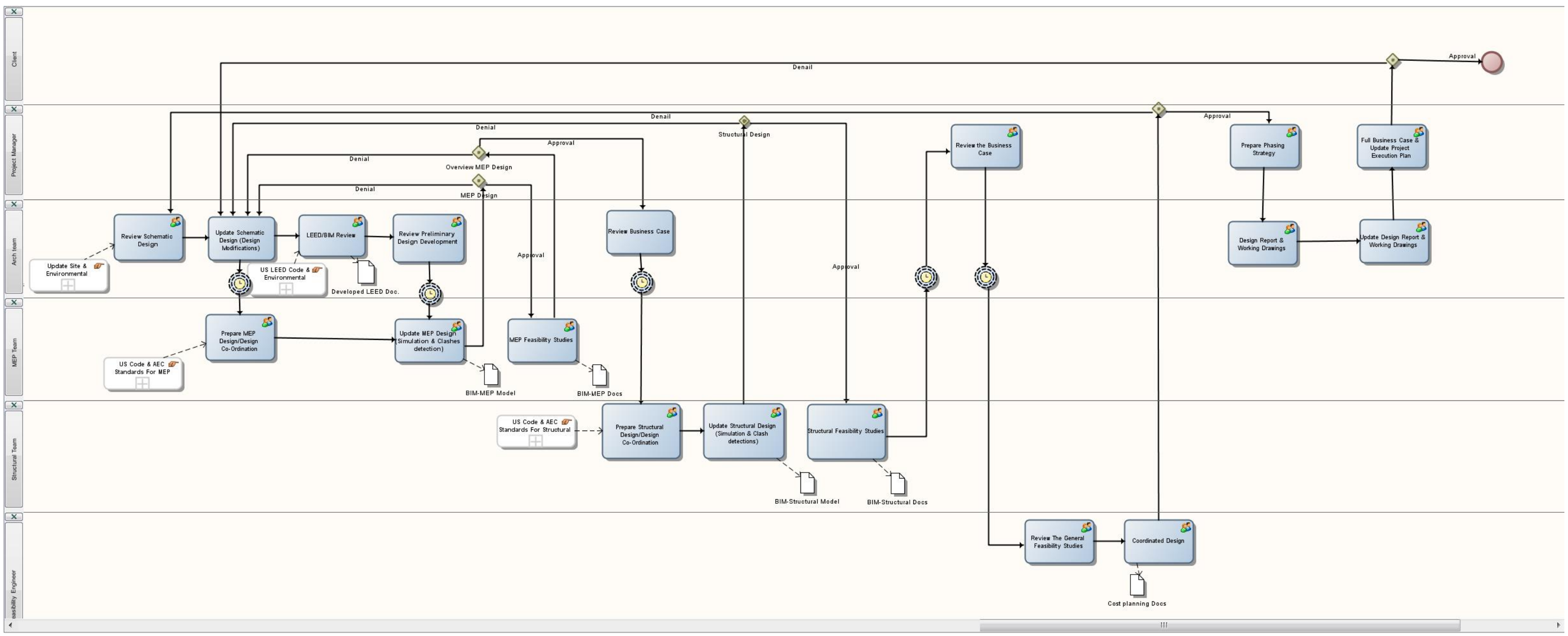


Autodesk Package

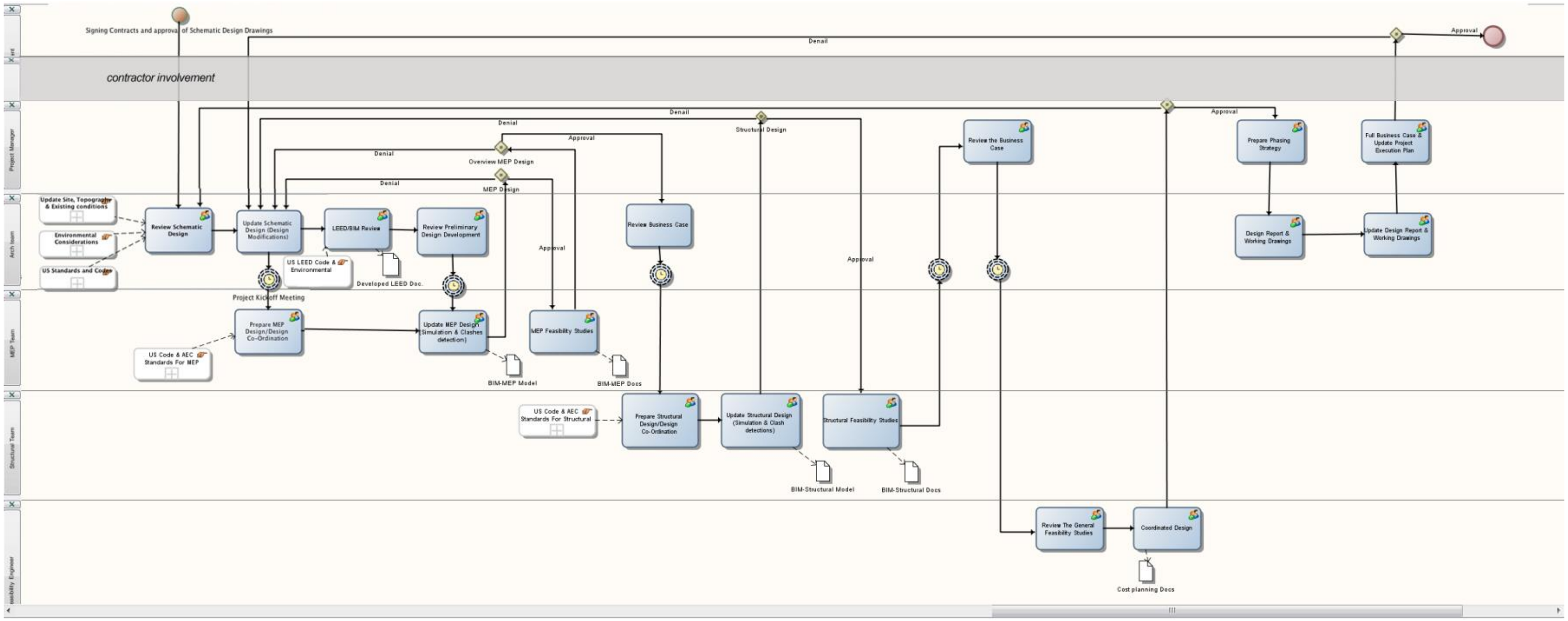
B) The new "To-be" BIM related model - Resolving Interoperability Issue

Mapping " As-is" BIM Related Process Model - Design Development Phase

Exiting Workflow Design Development Phase:

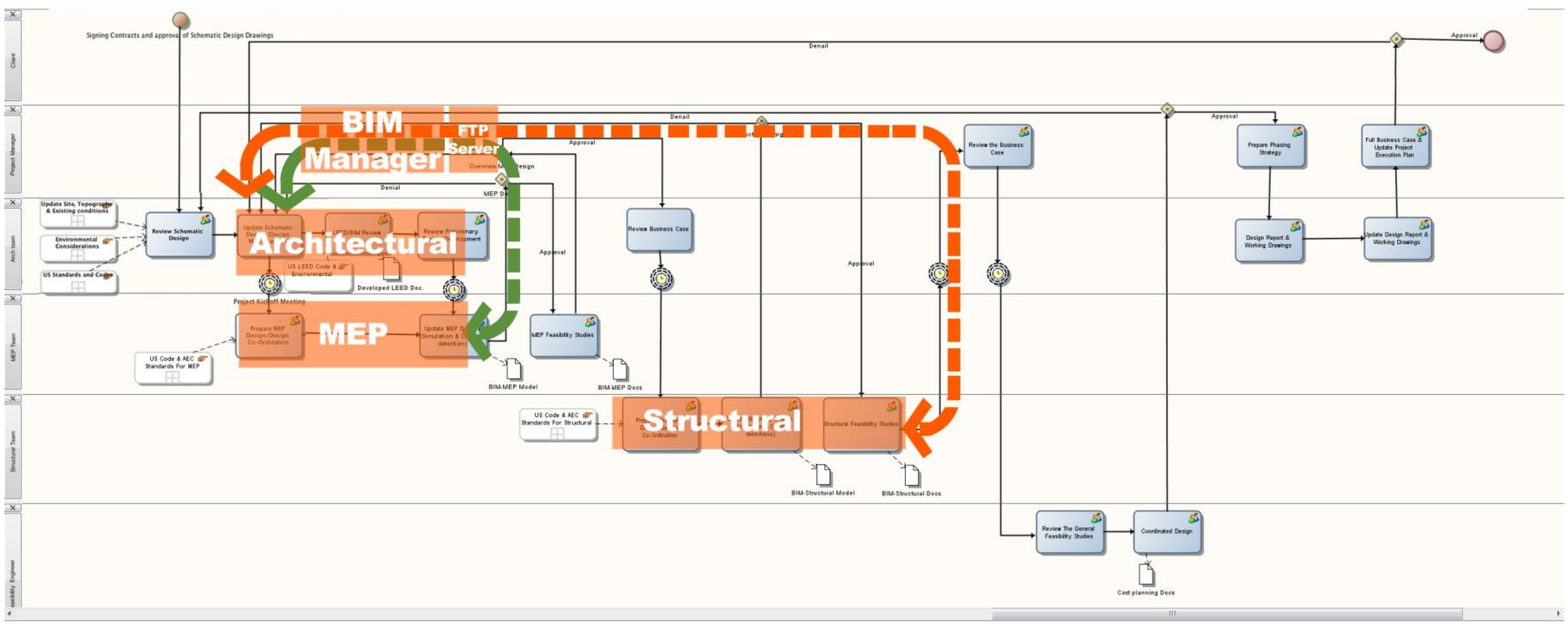


Lack of Contractor involvement- Design Development Phase:



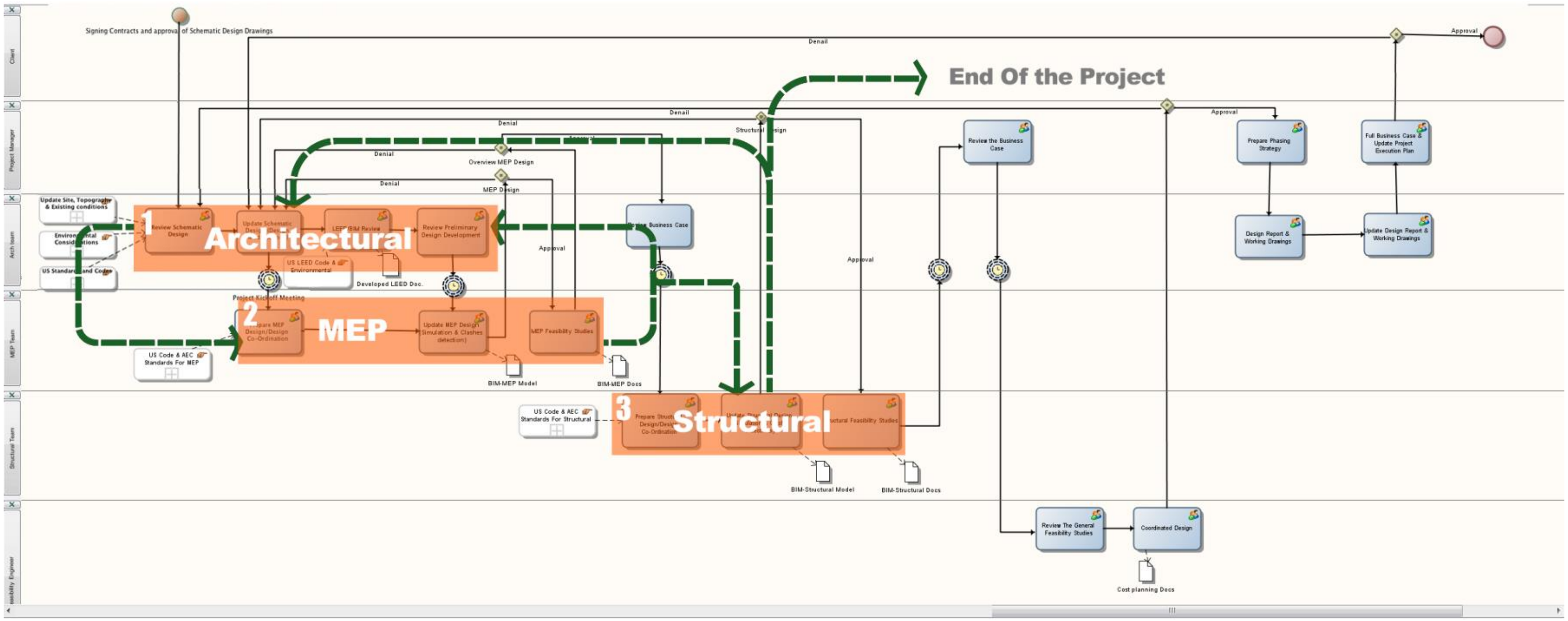
Design Development Phase
BIM "As-is" related process model

Information Flow- Design Development Phase:



Information Route & Communication Mechanism
Design Development Phase
BIM "As-is" related process model

Sequence of Activities- Design Development Phase:

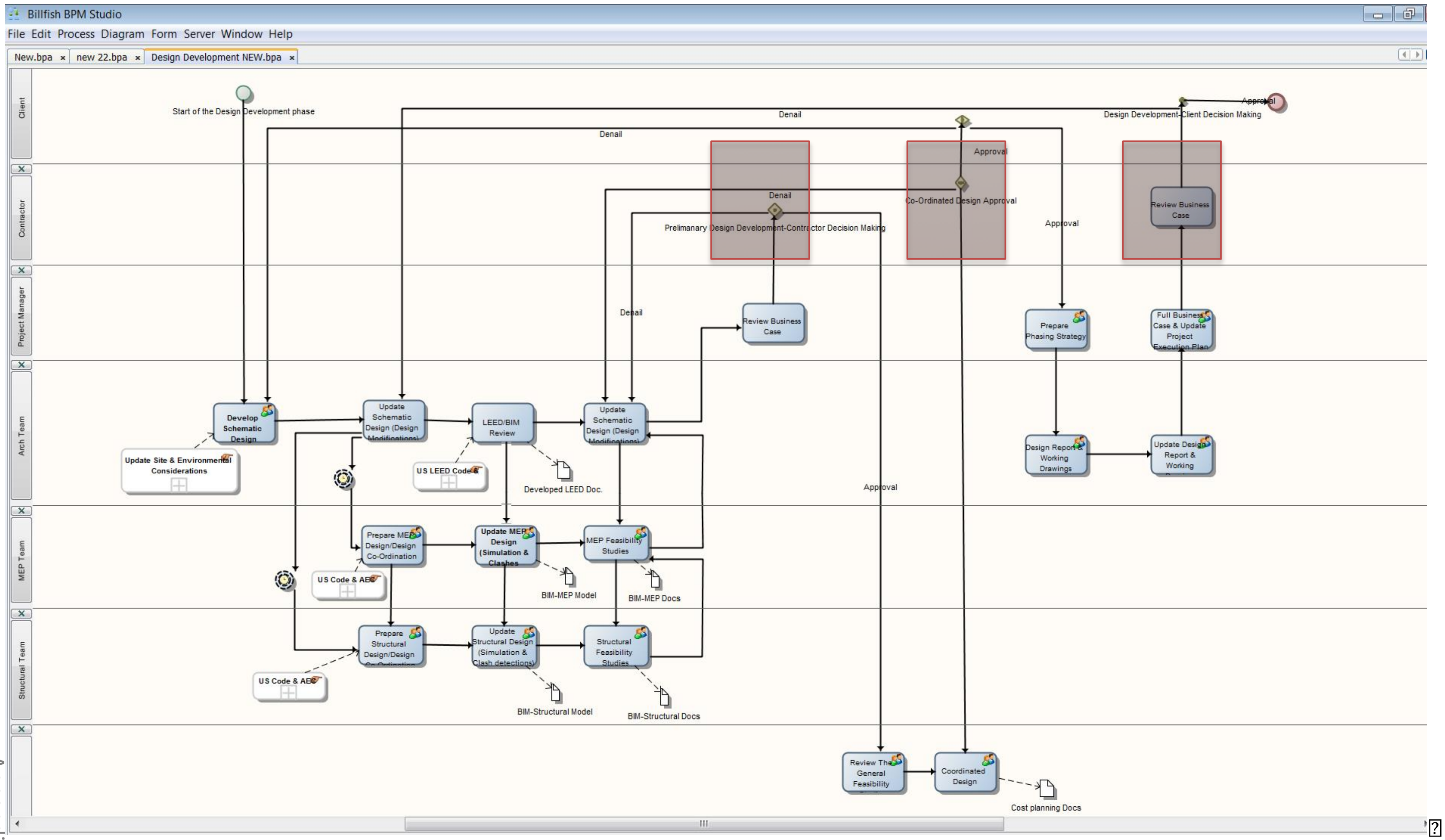


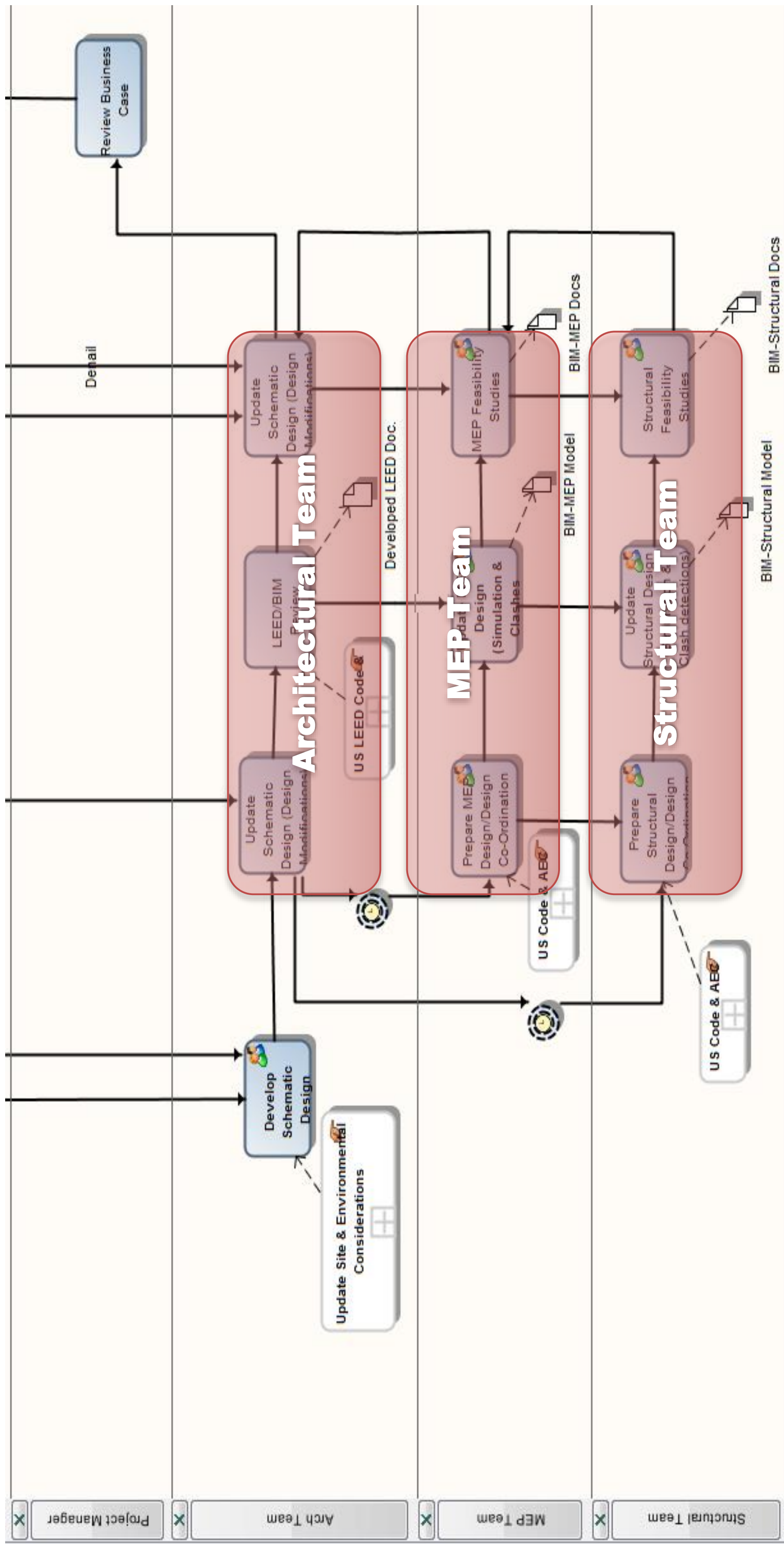
Design Development Phase

BIM "As-is" related process model

New “ To Be” BIM Model – Design Development Phase

Contractor involvement- Design Development Phase:





Project Manager
Arch Team
MEP Team
Structural Team
Review Business Case
Detail
Develop Schematic Design
Update Site & Environmental Considerations
Update Schematic Design (Design Modifications)
LEED/BIM Review
US LEED Code &
Developed LEED Doc.
Update Schematic Design (Design Modifications)
Architectural Team
MEP Feasibility Studies
Design (Simulation & Clashes)
Prepare MEP Design/Design Co-Ordination
US Code & AEC
BIM-MEP Model
BIM-MEP Docs
MEP Team
Structural Feasibility Studies
Update Structural Design (Clash detections)
Prepare Structural Design/Design Co-Ordination
US Code & AEC
BIM-Structural Model
BIM-Structural Docs
Structural Team

Feedback on the Existing BIM model

Do you think the new BIM model can improve BIM implementation in mid-size firms in terms of?

1- Schematic Design Phase:

- Improve Information exchange by resolving interoperability issue in the schematic design phase? (Save time, Information exchange, Enhance BIM Implementation, Handling of design changes and updating, Increase BIM members' efficiency, etc.)
- Enhance BIM Implementation by involving the contractor earlier in the design process

1- Design Development Phase:

- Improve Information exchange by resolving interoperability issue in the design development phase? (Save time, Information exchange, Enhance BIM Implementation, Handling of design changes and updating, Increase BIM members' efficiency, etc.)
- Enhance BIM Implementation by involving the contractor earlier in the design development phase?
- Enhance the flow of information?
- Save time and Increase BIM members' efficiency by using the parallel mechanism of communication?

References:

(CEMCA), C. E. M. C. f. A. (2010). Manual For Educational Media Researchers: Know Your Audience. CEMCA. Sarv Priya Vihar, New Delhi.

A.I.A (2008) E202™–2008 Building Information Modeling Protocol Exhibit.

A.I.A (2008) Integrated Project Delivery.

Adler, P. A. and P. Adler (1987). Membership roles in field research. Newbury Park, Calif., Sage Publications.

AGC, A. G. C. o. A. (2005). The Contractor’s Guide to BIM. R. Foundation. Las Vegas, NV. **1st ed**.

AGC, T. A. G. C. o. A. (2007). The Contractor's Guide to BIM.

AIA (2009). Negotiating and structuring construction contracts : leading lawyers on protecting client interests, managing risk, and understanding recent trends and developments. Boston, MA?, Aspatore.

AISC (2008). "The Role of Specialty Contractor." from http://www.aisc.org/content.aspx?id=3814.

AIT (1995). "“Activity Analysis: Process Management”, Business Process Improvement (Reengineering)." Handbook of Standards and Guidelines, Office of Information Technology Version 1.0. Retrieved January, 2009, from http://www.faa.gov/ait/bpi/handbook/chap3.htm.

American Institute of Architects. (2009). "The architecture student's handbook of professional practice." 14th. from http://www.loc.gov/catdir/toc/ecip0817/2008018988.html http://www.loc.gov/catdir/enhancements/fy0833/2008018988-d.html.

Anumba, C. J. a. E. (1999). “A Taxonomy for Communication Facets in Concurrent Life-Cycle Design and Construction”, Computer-Aided Civil and Infrastructure Engineering 14.

Autodesk (2008). Autodesk Revit Systems: BIM for MEP Engineering. A. R. SYSTEMS.

Bartunek, J. and M. R. Louis (1996). Insider/outsider team research. Thousand Oaks, Sage Publications.

Bernard, H. R. (1994). Research methods in anthropology : qualitative and quantitative approaches. Thousand Oaks, CA, Sage Publications.

Bickman, L. and D. J. Rog (1998). Handbook of applied social research methods. Thousand Oaks, CA, Sage Publications.

Bitsch, V. (Spring 2005). "Qualitative Research: A Grounded Theory Example and Evaluation Criteria." Journal of Agribusiness-Agricultural Economics Association of Georgia **23**(1): 78.

Bob Hunt, M. M. a. H. S. (July 21, 2008). County of Marin's Emergency Operations Facility: An Analysis of Project Delivery Methods and Financing Strategies. T. S. Company**:** 7.

Bogdan, R. and S. K. Biklen (2007). Qualitative research for education: an introduction to theory and methods, Pearson/Allyn and Bacon.

Borzage, M. (2006). Construction Simulation Lab-BIM workshops. C. S. Lab.

BrainStorm Group. BPM strategies. Northboro, MA, BrainStorm Group**:** v.

Bryman, A. (2001). Social research methods. Oxford ; New York, Oxford University Press.

BTEC (2008). Structure of the construction industry. P. Schools. UK. **5**.

Cai, Q., Kiki; 蔡棋瑛 (2007). Business process model for process improvement : an investigation of the tendering process in a construction company. Architecture. Hong Kong, University of Hong Kong. **Doctor of Philosophy**

Cardoso, J. and W. v. d. Aalst (2009). Handbook of research on business process modeling. Hershey, PA, Information Science Reference.

Copeland, A. P. and K. M. White (1991). Studying families. Newbury Park, Calif., Sage Publications.

Corbin, J. M. and A. L. Strauss (1988). Unending work and care : managing chronic illness at home. San Francisco, Jossey-Bass Publishers.

Corbin, J. M. and A. L. Strauss (2008). Basics of qualitative research : techniques and procedures for developing grounded theory. Los Angeles, Calif., Sage Publications, Inc.

Coulon, A. (1995). Ethnomethodology. Thousand Oaks, Sage Publications.

Creswell, J. W. (2012). Educational research : planning, conducting, and evaluating quantitative and qualitative research. Boston, Pearson.

De Munck, V. C. and E. J. Sobo (1998). Using methods in the field : a practical introduction and casebook. Walnut Creek, CA, AltaMira Press.

Defense.Acquisition.University (2001). Systems Engineering Fundamentals.

Demkin, J. A. (2008). The Architect's Handbook of Professional Practice American Institute of Architects.

Demkin, J. A. and American Institute of Architects. (2008). The architect's handbook of professional practice. Hoboken, Wiley.

Denzin, N. K. and Y. S. Lincoln (1994). Handbook of qualitative research. Thousand Oaks, Sage Publications.

Denzin, N. K. and Y. S. Lincoln (2011). The Sage handbook of qualitative research. Thousand Oaks, Sage.

Desai, D. (Summer, 2002). "The Ethnographic Move in Contemporary Art: What Does It Mean for Art Education?" Studies in Art Education **Vol. 43, No. 4** (Published by: National Art Education Association): 307-323.

DeWalt, K. M. D., Billie R. (1998). "Participant observation. In H. Russell Bernard (Ed.)." Handbook of methods in cultural anthropology **Walnut Creek: AltaMira Press**: 259-300.

Eastman, C. (2011). "What is BIM? ." from http://bim.arch.gatech.edu/?id=402.

Eastman, C. M. (2008). BIM handbook : a guide to building information modeling for owners, managers, designers, engineers, and contractors. Hoboken, N.J., Wiley.

Fine, G. A. and K. L. Sandstrom (1988). Knowing children : participant observation with minors. Newbury Park, Calif., Sage Publications.

Gephart, R. P. (1988). Ethnostatistics : qualitative foundations for quantitative research. Newbury Park, Sage Publications.

Glaser, B. G. and A. L. Strauss (1968). The discovery of grounded theory: strategies for qualitative research. London,, Weidenfeld and Nicolson.

Groat, L. N. and D. Wang (2002). Architectural research methods. New York, J. Wiley.

Grover, V. and W. J. Kettinger (2000). Process think : winning perspectives for business change in the information age. Hershey, Pa., Idea Group Pub.

GSA (2009). from http://www.gsa.gov/portal/category/100000.

GSA, U. G. S. A. (2007). US General Services Administration Washington, U.S. G.P.O. : For sale by the U.S. G.P.O., Supt. of Docs., Congressional Sales Office.

Hammersley, M. (1983). The Ethnography of schooling : methodological issues. Driffield, N. Humberside, Nafferton.

Hancock, B. (1998). Trent Focus for Research and Development in Primary Health Care: An Introduction to Qualitative Research. T. Focus.

Harrison, M. I. (1987). Diagnosing organizations : methods, models, and processes. Newbury Park, Sage Publications.

Heckscher, C. C. and A. Donnellon (1994). The Post-bureaucratic organization : new perspectives on organizational change. Thousand Oaks, Calif., Sage Publications.

Howell, I. B., Bob (2006). " "Building Information Modeling Two Years Later –Huge Potential, Some Success and Several Limitations"." International Journal Of Architectural Computing **04**(04).

Hsiu-Fang Hsieh, S. E. S. (2005). Three approaches to qualitative content analysis. Qualitative Health Research. Qualitative Health Research. **9**

: 1277-1288

J.I., L. R. M. a. M. (2007). ""Comparing traditional schematic design documentation to a schematic building information model."." 24th International Conference on Information Technology in Construction **June 26-29, 2007**.

Jernigan, F. E. (2008). Big BIM, little bim : the practical approach to building information modeling : integrated practice done the right way! Salisbury, MD, 4Site Press.

Jessor, R., et al. (1996). Ethnography and human development : context and meaning in social inquiry. Chicago, University of Chicago Press.

Khandkar, S. H. (2009). Qualitative Method- Open Coding. http://pages.cpsc.ucalgary.ca/~saul/wiki/uploads/CPSC681/open-coding.pdf, Department of Computer Science- University Of Caligary.

Khemlan, L. (2008). "DProfiler: A "Macro" BIM Solution." AECbytes Product Review. Retrieved October, 2011, 2011, from http://www.aecbytes.com/review/2008/DProfiler.html.

Krygiel, E. and B. Nies (2008). Green BIM : successful sustainable design with building information modeling. Indianapolis, Ind., Wiley Technology Pub.

Kymmell, W. (2008). “Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations”.

L.A.H.M. van Berlo, J. B., P. Bos, H. Hendriks, R.C.J. van Tongeren (2012). "Collaborative engineering with IFC: new insights and technology." Proceeding of the 9th European Conference on Product and Process Modelling: 811-818.

Lee, R. M. (1995). Dangerous fieldwork. Thousand Oaks, Calif., Sage Publications.

Lindlof, T. R. and B. C. Taylor (2011). Qualitative communication research methods. Thousand Oaks, Calif., SAGE.

Lineberger, R. and KPMG Peat Marwick. (1993). The Art of business process management : a guidebook. Houston, Tex. (2525 Bay Area Blvd., Suite 660, Houston 77058), KPMG Peat Marwick.

Lottaz, C., Stouffs, R., and Smith, I. (2000). "Increasing Understanding During Collaboration Through Advanced Representations." Electronic Journal on Information Technology in Construction **5**: 1-24.

Majchrzak, A. (1984). Methods for policy research. Beverly Hills, Sage.

Mangione, T. W. (1995). Mail surveys : improving the quality. Thousand Oaks, Calif., Sage Publications.

McGraw-Hill (2008). Smart Market Report, Building Information Modeling (BIM)

McGraw-Hill (2008). "Smart Market Report, Building Information Modeling (BIM) " Building Information Modeling Trends SmartMarket Report.

Miller, S. I. and M. A. Fredericks (1994). Qualitative research methods : social epistemology and practical inquiry. New York, P. Lang.

Mitchell, R. G. (1993). Secrecy and fieldwork. Newbury Park, Sage.

Myers, M. D. (2004). "‘Qualitative Research in Information Systems’." Retrieved 18th December 2011, from http://www.qual.auckland.ac.nz//.

Natasha Mack, C. W., Kathleen M. MacQueen, Greg Guest, and Emily Namey (2005). Qualitative Research Methods: A Data Collector's Field Guide. North Carolina, Family Health International.

NBIMS-Committee (2010). 2010, from http://www.buildingsmartalliance.org/index.php/nbims/.

Neuckermans, S. B. a. H. (2005). "Improving Design Workflow in Architectural Design Applications." International Journal Of Architectural Computing **04**(04).

Neuman, W. L. (1991). Social research methods : qualitative and quantitative approaches. Boston, Allyn and Bacon.

NIBS, N. I. o. B. S. (December 2007). The National Building Information Model Standard (NBIMS), National Institute of Building Sciences.

Patrick C. Suermann, R. R. A. I. (2007). "EVALUATING THE IMPACT OF BUILDING INFORMATION
MODELING (BIM) ON CONSTRUCTION." 7th International Conference on Construction Applications of Virtual Reality(October 2007).

Patton, M. Q. (1990). Qualitative evaluation and research methods. Newbury Park, Calif., Sage Publications.

Rafael, S. (2010) “Process Plant Design” Autodesk White Paper

Raj, M. O. a. J. (2003). BPMN and Business Process Management : Introduction to the New Business Process Modeling Standard, Popkin Software.

Retz, K. J. (2009). Negotiating and structuring construction contracts : leading lawyers on protecting client interests, managing risk, and understanding recent trends and developments. Boston, MA?, Aspatore Books.

Richard Cull, T. E. (2004). "A hybrid approach to workflow modelling." Journal of Enterprise Information Management **23**(3): pp.268 - 281.

Rossman, G. B. and S. F. Rallis (2003). Learning in the field : an introduction to qualitative research. Thousand Oaks, Calif., Sage Publications.

Rossman, J. R. (2003). Recreation programming : designing leisure experiences. Champaign, IL, Sagamore Pub.

Rossman, M. L. (2003). Fighting cancer from within : how to use the power of your mind for healing. New York, Henry Holt and Company.

Ruikar, K. (2004). BUSINESS PROCESS IMPLICATIONS OF E-COMMERCE IN CONSTRUCTION ORGANISATIONS. Department of Civil & Building Engineering Loughborough, Loughborough University. **PhD:** 210.

Ruikar, K., Anumba, C.J., and Carrillo, P.M. (2003). 'Reengineering Construction Business Process through Electronic Commerce'. The TQM Magazine, Special issue: Managing Quality in E- Operations, Emerald Press. **15**.

Rushkoff, D. (2005). Get back in the box : innovation from the inside out. New York, Collins.

Sabol, L. (2007). Challenges in Cost Estimating with Building Information Modeling. D. C. Strategies, http://www.dcstrategies.net.

Salman Azhar, A. N., Johnny Y. N. Mok and Brian H. Y. Leung (2008). Building Information Modeling (BIM): A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects. First International Conference on Construction in Developing Countries (ICCIDC–I)"Advancing and Integrating Construction Education, Research & Practice". **2008, Karachi, Pakistan**.

Saunders, M., et al. (2012). Research methods for business students. Harlow, England ; New York, Pearson.

Savage, C. M. (1996). Fifth Generation Management : Co-creating Through Virtual Enterprising, Dynamic Teaming, and Knowledge Networking Butterworth-Heinemann.

Schooley, A. (1995) Playing with qualitative research: Designing a research project with diamonds and venns. . The Qualitative Report **3**,

Seale, C. (2004). Social research methods : a reader. London ; New York, Routledge.

Sevigny, M. (1976). A descriptive study of instructional interaction and performance appraisal in a university studio art setting: A multiple perspective., The Ohio State University. **Doctoral dissertation.** .

Sharp, A. and P. McDermott (2009). Workflow modeling : tools for process improvement and applications development. Boston, Artech House.

Sinclair, B. (Jun 9, 2005). "Polling Network Analysis." UEH Network. Retrieved August 2nd, 2012, from http://cnx.org/content/m10818/latest/.

Sloan Management Review Association., et al. (1970). Sloan management review. Cambridge, Mass., Industrial Management Review Association at the Alfred P. Sloan School of Management, Massachusetts Institute of Technology.

Smith, D. K. and M. Tardif (2009). Building information modeling : a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. Hoboken, N.J., Wiley.

Smith, H. and P. Fingar (2003). Business process management : the third wave. Tampa, Fla., Meghan-Kiffer Press.

Sowell, K. (2009). Creating and Presenting Activity Models. L. P.K. Sowell and Custom Enterprise Solutions.

Stefan Boeykens, H. N. (2008). "“Improving Design Workflow in Architectural Design Applications”." International Journal Of Architectural Computing **4**(4): 5.

Stewart, D. W. and P. N. Shamdasani (1990). Focus groups : theory and practice. Newbury Park, Calif., Sage Publications.

Strauss, A. L. and J. M. Corbin (1998). Basics of qualitative research : techniques and procedures for developing grounded theory. Thousand Oaks, Sage Publications.

Tech, G. (2011). "BIM Courses of Georgia Tech ". from http://bim.arch.gatech.edu/app/bimtools/tools_list.asp.

The State of Wisconsin, D. o. A. D. o. S. F. D. (June 17 , 2009). Report on the current state of BIM technologies and recommendations for implementation.

Thomas Ng, S., Chen, S.E., McGeorge, D., Lam, K., Evans, S. (2001). "Current state of IT usage by Australian subcontractors." **1**.

Underwood, J. and U. Isikdag (2010). Handbook of research on building information modeling and construction informatics : concepts and technologies. Hershey, PA, Information Science Reference.

Ward, M. A. (2009). " ‘Building Structural Frame: Steelwork" ". from http://www.leeds.ac.uk/civil/research/cae/step/ap230/ap_revw/rd_modls.htm.

White, S. A. (2006). Process Modeling Notations and Workflow Patterns. United States, IBM Corp.

White, S. A. (2008). Process Modeling Notations and Workflow Patterns, IBM Corp., United States.

Williams, A. (2004). “Building model benefits: design team tests Autodesk Revit on large projects” CADalyst.

Yin, R. K. (1984). Case study research : design and methods. Beverly Hills, Calif., Sage Publications.

Yin, R. K. (1989). Case study research : design and methods. Newbury Park, Calif., Sage Publications.

Yin, R. K. (1993). Applications of case study research. Newbury Park, Calif., SAGE Publications.

Yin, R. K. (1994). Case study research : design and methods. Thousand Oaks, Sage Publications.

Yin, R. K. (2003). Applications of case study research. Thousand Oaks, Sage Publications.

Yin, R. K. (2003). Case study research : design and methods. Thousand Oaks, Calif., Sage Publications.

Yin, R. K. (2009). Case study research : design and methods. Los Angeles, Calif., Sage Publications.

Yin, R. K. (2012). Applications of case study research. Thousand Oaks, SAGE.

Yoders, J. (August 13, 2009). " First Wisconsin, now Texas mandates BIM for state projects." from http://www.bdcnetwork.com/blog/1340000734/post/1350047735.html and http://www.allbusiness.com/environment-natural-resources/land-use-development/12960009-1.html