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BUILDING INFORMATION MODELING USES FOR DESIGN IN THE ARCHITECTURE, ENGINEERING, AND CONSTRUCTION (AEC) INDUSTRY

A Thesis in

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ABSTRACT

With new technology emerging, facility owners and project participants (designers, contractors, subcontractors and manufacturers) are investigating the most valuable uses for Building Information Modeling (BIM) on their projects. The project team must make decisions on BIM execution at the four different stages of the project: planning, design, construction, and operations. This study, as part of a buildingSMART Alliance project, is focused on the implementation of BIM in the design segment of the AEC industry. The goal is the identification and definition of BIM uses in the design process with the purpose of them being implemented as the basis for a BIM Project Execution Planning procedure.

The research methods employed in this study include a literature review, expert interviews, and qualitative analysis of the data gathered. Interviews with 18 design professionals, engineers, industry experts and BIM champions were conducted, and their perspectives and opinions of using this new technology were collected. Qualitative data was analyzed using a content analysis procedure, and detailed results are presented including a taxonomy for the BIM uses in design, and future research steps.

From the expert interviews, BIM is currently being used for targeted tasks within the design process, but not implemented on projects from initial phases of design through construction to operations. This is due to a lack of planning, infrastructure, tools, and expertise in general, and limited guidelines available for team members involved in the process. The core result of this research is the taxonomy including 15 BIM uses in design with their current frequency of use in four distinctive categories. These categories are: Design Communication, System Analysis, Estimating and Scheduling. The identified BIM uses in design are the basis for preparing a customized project execution plan for BIM.

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“*Your vision will become clear only when you can look into your own heart.*
Who looks outside, dreams; who looks inside, awakes.” Carl Jung

Graduate school was a long, exciting, and unpredictable journey for me. After starting as an architect doing research in digital design and virtual environments, I have become a construction manager and engineer passionate for new technologies and Building Information Modeling. In order to get where I am today, I had to dream! With many goals and achievements left to accomplish, this degree brings me one step closer. I am grateful for the opportunities I have been given and the great people I have met along this journey. They have all helped me realize that I can achieve much more if only I try.

I have a few people to whom I would like to give my heartfelt gratitude. First, I would like to say that I am forever grateful to my family for their unconditional love and understanding, and for believing in me and my dreams every step of the way. I dedicate this thesis to them.

I am very much indebted to my adviser Dr. John Messner, who offered me the incredible opportunity to give my life and career a different path, and at the same time guided, supported, and inspired me to achieve my best. I hope I will develop the outstanding professional and personal qualities he possesses, and in turn, be able to be as good of a mentor to someone else. His wisdom, passion for research, responsibility towards others, and exceptional managerial skills can be only strived for.

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“*The start of something new brings the hope of something great. Anything is possible!*”

Michael S. Pierron

Chapter 1

Introduction to the Research

1.1 Project Execution Planning for Building Information Modeling

Implementation of Building Information Modeling (BIM) on a project level requires comprehensive planning by facility owners and project participants (designers, contractors, subcontractors, and manufacturers) to ensure successful transition from a traditional approach to incorporating this new technology into the project workflow. The current status of BIM in design practice reports a lack of planning in general, and limited guidelines available for team members involved in the process. This typically leads to BIM being used for targeted tasks, but not implemented throughout the lifecycle of a building. This is contrary to how BIM was conceived and it does not allow the new technology to reach its full potential in industry construction projects. A possible solution to the problem would be to provide the early project team with a means for planning successful implementation of BIM throughout the various stages of the project (planning, design, construction, operations). But before creating the BIM Execution Plan, the project team should focus on the desired outcome and determine the appropriate BIM uses on a project in each of these phases. This thesis, as a part of a larger BIM Project Execution Planning research initiative, is focused specifically on planning for the design process.

1.2 Goals and Objectives

The research goal for the BIM Project Execution Planning is to investigate the use of Building Information Modeling in the Architecture, Engineering and Construction (AEC) Industry and develop and disseminate a method to create a BIM Execution Plan in the early stages of a building project.

This thesis focuses specifically on the design stage of BIM Execution Planning. Its primary goal is to *create a taxonomy for BIM uses in design*. This goal is achieved by completing and analyzing expert interviews after performing detailed content analysis of available literature on BIM and its uses. The secondary goal is to *provide a broad overview of BIM implementation in design practice*. The following research objectives were identified:

1. Identify the trends in BIM implementation in design to provide recommendations to owners when procuring BIM design services;
2. Document the most important success and failure factors for BIM implementation in design as perceived by designers;
3. Identify BIM uses in design along with methods and implementation strategies in different project design phases;
4. Organize the identified uses and create a taxonomy for BIM uses in design; and
5. Develop BIM use information sheets in design by listing their goal, objective, description, and benefits (to be used as part of BIM Execution Planning Guide).

1.3 Project Outcomes

The intention is to provide the project team with the information needed to reach decisions in the early project stages about the most suitable strategies for BIM implementation or the best applications of BIM uses in design. This overarching investigation creates the basis for future research project outcomes including the development of a BIM Project Execution Planning Guide with guidelines for BIM implementation and a process mapping procedure intended to direct the team in producing a valuable BIM Execution Plan. This would assure a more customized approach in developing the plan, having in mind different strategies that can be used on a project. This study in particular identifies BIM uses in design and creates a taxonomy for them, along with determining what implementation strategies on the organization and project level should be considered. Also, as an exploratory study, this research discovers the most important topics that need to be investigated further.

1.4 Research Steps

The following research steps were performed to accomplish the objectives of the study:

1. Literature Review: This step clarified the definition of BIM along with identifying various topics on BIM, its current status, challenges and success factors. Review of the available published literature on BIM implementation in design was performed from the industry aspect. Published research that was used were journal papers, BIM guides and various expert articles.
2. Semi-structured Interviews: This step included the identification of BIM methods in design, along with opportunities and challenges. Interview questions were identified after the literature review and several brainstorming sessions with the Computer Integrated Construction (CIC) team members. Questions were modified and pre-tested in two pilot interviews with industry members, and 18 interviews with design professionals, industry experts and BIM champions were collected.

3. Content Analysis: In this step, data collected was analyzed, summarized and the conclusions were drawn. Data analysis was performed using content analysis and mapping to organize the information. Quantifiable data was averaged and organized based upon frequencies.
4. BIM Uses in Design: In this step, the taxonomy was created and BIM uses in design were developed in more detail. The taxonomy of BIM uses in design as a complete interim research product was delivered and will be used as part of how to customize a BIM Project Execution Plan in the design phase.

1.5 Scope Definition

This study is focused on the implementation of BIM in the design phase of the Architecture, Engineering and Construction (AEC) Industry. The research makes a distinction between four phases of a construction project: planning, design, construction and operations. These phases are defined as follows (Sanvido, 1990):

> *"Plan Facility encompasses all the functions required to define the owner's needs and the methods to achieve these. These activities translate the facility idea into a program for design, a project execution plan, and a site for the facility.*
>
> *Design Facility comprises all the functions required to define and communicate the owner's needs to the builder. These activities translate the program and executions plan into bid and construction documents and operations and maintenance documents that allow the facility to meet the owner's needs.*
>
> *Construct Facility includes all functions required to assemble a facility so that it can be operated. These activities translate resources (e.g., materials) in accordance with the design into a completed facility. Typically appropriate facility operations and maintenance documents are generated.*
>
> *Operate Facility comprises all of the activities which are required to operate and maintain a facility for a user. In addition, operating knowledge and information on the performance of the team is generated."*

The chief project participants are: owner, design firm, engineering firms, contractor, subcontractors, fabricators, and facility managers. The AEC industry design and engineering firms at the center of this research design and construct projects throughout the United States, but research participants of this study are mainly from the Mid-Atlantic region and Washington DC area.

1.6 Thesis Outline

The research is presented as follows. This Chapter 1 provides the introduction to the topic, BIM Project Execution Planning, along with the research problem, goals, objectives, and scope definition. Chapter 2 outlines the research procedure and techniques that were used: literature review, expert interviews, content analysis; provides justification for the exploratory research methods used; and also describes the data collection procedure, data analysis and research results. Chapter 3 represents the point of departure and provides the review of existing literature on implementation of BIM. This chapter defines current trends, driving forces, critical factors and different perspectives, and illuminates approaches that design and engineering firms take upon. Chapters 4, 5 and 6 offer the results of the study by providing the summary of the interviews and discussion. All the significant results from the expert interviews are mapped and presented. Chapter 4 focuses on participants’ background information and BIM execution planning. Chapter 5 covers the BIM uses in design, and Chapter 6 delivers the BIM impact analysis. Chapter 7 concludes the study with a summary of results and offers the list of BIM uses in design developed through review of existing literature and expert interviews. Chapter 7 also presents the final conclusions of the study, offers ideas for further research and follow-up studies, and provides a review of the core contribution in the form of a taxonomy for BIM uses in design.

Chapter 2

Research Methods

This chapter describes the research methods used throughout this exploratory study. The methods are further discussed to provide an explanation and justification for their selection. Several different research techniques were used in this study, and the rationale for their use is explained. The techniques, literature review, interviews and content analysis, are briefly described along with the research process performed.

2.1 Research Process

After a focused literature review on various BIM topics, interviews with 18 design professionals, industry experts and BIM champions were conducted; and their perspectives and opinions of using this new technology were analyzed. Important lessons learned, success stories, and recommendations were documented from these interviews. The data received was summarized and conclusions were drawn with the purpose of being incorporated in the design BIM use taxonomy.

The following research steps were performed in this exploratory study:

1. Literature Review
2. Semi-structured Interviews

3. Content Analysis
4. BIM Uses in Design Taxonomy.

2.2 Research Techniques

Since this research is exploratory in nature, social science research techniques have been chosen. These research techniques include literature review, expert interviews and content analysis. The data collected is qualitative in nature with some data collected that can be quantitatively analyzed.

An exploratory research strategy was selected because it is a good approach when (Marshall and Rossman, 1999):

- Investigating little understood phenomena,
- Identifying or discovering important variables, and
- Generating hypotheses for further research.

For an exploratory study, the research strategies used, literature review and interviews, were found to be the most appropriate since the project was operating in discovery, and not verification mode (Guba and Lincoln, 1981). The other viable options were field or case studies (Marshall and Rossman, 1999), which will be done as part of the larger BIM Execution Planning research project but not as part of this study.

An interview is a qualitative method of data collection, where the interviewer asks the questions of interest either in person, over the phone or through some other form of communication. There are several forms of interviews that were considered for this research: structured, semi-structured and open-ended interviews (Yin, 1999).

1. Structured Interviews: This type of interview is close to a questionnaire survey in a sense that all the questions are carefully structured and ordered, and can have a limited number of possible responses choices.
2. Semi-structured Interviews: The interviewer follows a set of questions that need to be answered to collect data for a study. The respondents are free to talk but their discussion is guided and geared towards exploration rather than verification of the facts or hypotheses. The questions need to be carefully worded and delivered in a way to eliminate bias but yield useful insight. This type of interview was selected for the study at hand.
3. Open-ended Interview: The interviewees are asked about the facts, their opinions and suggestions; but are allowed to talk freely about the subject at hand and direct the interview since there are no strict guidelines about the information that needs to be collected.

The last technique used was a content analysis. Content analysis is an accepted technique of systematically analyzing data obtained through qualitative research (Holsti, 1969). As a research method, it was created to investigate and draw inferences from the content of conversation or verbal communication between participants. It can be described as information processing in which content is transformed, through objective and systematic application of categorization rules, into data that can be summarized and compared (Holsti, 1969). Some of the characteristics of content analysis based on Holsti (1969) and Guba and Lincoln (1981) that were used in this study are objectivity, systematic approach and generality.

2.3 Literature Review

This research began with a review of the available references on BIM implementation in practice. The literature review is intended to clarify the definition of Building Information Modeling so its uses can be clearly identified along with identifying various topics on BIM, its current status, challenges and success factors. Review was performed from the industry aspect including impact of BIM on design, issues, benefits, startup costs, cost-benefit ratio, return on investment, legal liabilities, contractual and organizational arrangements, best practices, lessons learned and critical success factors. The published research referenced in the literature review was in the form of journal papers, BIM guides and various expert articles on the topic.

2.4 Semi-structured Interviews

The purpose of conducting interviews was to gain a better understanding of the issues that project teams face during BIM implementation in the design phase of a project. They outlined previous experiences, current best practices, major challenges, lessons learned, and the success factors for implementing BIM. Detailed results from the interviews are presented, along with the initial taxonomy for the BIM uses in the design process, as well as a discussion of the integration with other project stages and future research steps.

A draft list of questions was identified after the review of the available literature and brainstorming sessions with the Computer Integrated Construction (CIC) team members, also members of the BIM Execution Planning research project team. A draft of the interview questions was posted online for feedback and comments from buildingSMART Alliance team members. The outline of the interview questions was also presented at the buildingSMART project meeting. Based on the input from the team members, the interview questions were modified, and then pre-tested in two pilot interviews with industry members with expertise on the subject. The final set of questions was established based on the results from these two interviews and feedback received. A list of questions as well as the mind map version of the questions can be found in Appendices A and B.

In-depth interviews which followed were performed with designers experienced in implementing BIM. The interview technique selected was semi-structured interviews, where the goal was not to get representative or typical responses like in structured interviews, but at the same time the qualitative data collected from the interviews has a certain structure. The interviewees were free to talk about the subject, but the discussion was guided so that the data collected could be analyzed, summarized and then reported. The rationale for selecting the semi-structured form of interview was that the interviewer was interested in pursuing this subject in depth, was dealing with experts who have special knowledge and was operating in discovery, rather than verification mode (Guba and Lincoln, 1981). In this manner, the interviewer's bias is reduced and semi-structured interviews allow the interviewee to lead the conversation and provide their own input on the topic outside of the interview's framework.

2.5 Interviews' Candidates: Selection of Interviewees

Several criteria were used to select the participants for the study. The industry participants were limited to architects or engineers having at least one or more years of experience with implementing BIM, as well as an interest in being part of this study and sharing their experiences. This provided a wide range and a broad perspective of implementation strategies and experiences with BIM. First, a list of possible design offices or companies was developed based on the literature review of the published expert articles and previous BIM experiences with the help and suggestions of the BIM Execution Planning and CIC Research

Group members. Another list was compiled based on the local Washington DC Metro Area BIM users group that meet once a month to exchange experiences and discuss new technology implementation. The last list, retrieved from The Clark Construction Group database, courtesy of their BIM Group and Marketing and Communications Department, was populated with the names of the consultants and business partners knowledgeable and experienced in BIM. A final list was compiled with approximately one hundred names of industry participants. All potential interviewees were contacted via e-mail, with an invitation for participation in the research, which was followed by phone calls within a week after the invitations were sent. This approach yielded many positive responses and resulted in 18 interviews being scheduled and conducted in August and September 2008.

2.6 Interview Process/Procedure

In-depth interviews with designers experienced with BIM implementation were conducted over a period of two months using a semi-structured interview format. The participant's permission to audio record was requested before the start of the interview and an Institutional Review Board (IRB) form, for protecting the rights and welfare of participants, was shared. The participants were briefed about the scope of the research, informed of its larger picture, and ensured about confidentiality of the data collected. The interviews lasted between 45 minutes and one hour. The interview questions were categorized into six sections: Background Information, BIM Execution Planning, BIM Uses in Design, BIM Impact, Case Study, and Concluding Questions.

Background Information focused on the position and responsibilities of the interviewees and their previous experience with BIM implementation. The BIM Execution Plan questions determined if a plan for implementation typically exists, and what were some of the major decisions and process steps. BIM Uses in Design identifies major uses and answers the questions about model detail and content, process, applications, team competencies, legal issues, insurance and contract considerations. BIM Impact collected information on possible metrics and results, along with impact on time, cost, quality, and changes in staff. Major success factors, issues, concerns and risks were also collected. Case Study questions identified potential projects and studies that can be done in the future. Concluding Questions finished the interview with future trends, additional comments and references to other firms or experts. The questions extended beyond the scope of BIM uses for the purpose of achieving the secondary goal of the research which is to provide a broad overview of BIM implementation in design practice.

The interviews were almost all performed in person, with one interview received through e-mail and one conducted over the phone. The written response gave a chance to the interviewee to consider questions longer, but also was under scrutiny of upper management who read and approved the responses. The email response to the questions was one of the shortest set of responses, but included assumed revisions from the management and offered few pieces of information. The interview conducted over the phone, was more to the point, but shorter in length and less revealing than the ones performed in person. This approach is faster at obtaining information, but the interview period was short and impersonal. The face-to-face interviews provide some control over the interview process, but have a higher risk of the interviewer’s bias, more so then interview done in written form or over the phone.

Interviewer’s bias was reduced by asking open-ended questions that do not require an answer within the researcher’s framework, and also navigating the interview, but not offering judgments or leading the answer. Proper measures were taken to avoid bias during the interviews by carefully composing the questions and the delivery. The wording and delivery of the questions was kept as neutral as possible. An additional measure to reduce bias was taken by systematically analyzing the qualitative data using the content analysis procedure, and being objective while analyzing and interpreting the responses given (Simon and Burstein, 1985). The interviews were also audio recorded and transcribed for future reference. Recording the interviews aided accuracy of data collection and interpretation, since all the interviews were transcribed and mind mapped in order to be summarized and used for content analysis on a later note which ensures reliability.

2.7 Content Analysis

The interviews collected were systematically interpreted according to similar classification categories depending on the topic at hand. A content analysis was performed for each of the interviews conducted. With this approach, communication content was transformed by applying categorization rules systematically and objectively into data that can be classified, summarized and compared (Holsti, 1969). All the interviews were transcribed from the audio recordings, and then the most frequent concepts were identified, grouped and organized with establishing possible relationships or connections. A sample interview content analysis can be found in Appendix C. Detailed content analysis can be found in Chapters 4, 5 and 6 with some quantitative data collected and evaluated. A summary of the topics covered and conclusions drawn can be found in Chapter 7. An example of how the data from semi-structured interviews were compiled into categories and then analyzed can be found in Appendix D.

Chapter 3

Literature Review

3.1 BIM in Design

After careful review of the available literature, Building Information Modeling can be seen as a paradigm change in design practice. BIM has a potential to significantly change the Architecture, Engineering and Construction (AEC) Industry. Its strength lies in the possibility to communicate easily and in a more appropriate format the design intent and complex construction information to the project team and participants including the owners, designers, engineers, contractors, fabricators, facility managers and end users. Building virtual models has proven to be a successful technique in the industrial, automobile, aircraft, spacecraft and shipbuilding industry for years (Birx, 2006). The Construction Industry is the only one so far that does not use the full benefits of virtual modeling prior to construction to reduce flaws (Birx, 2006).

The National BIM Standards (NBIMS) offer a definition of BIM:

> *Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder. The BIM is a shared digital representation founded on open standards for interoperability* (NBIMS, 2007).

FMI in collaboration with CMAA’s Emerging Technology committee developed an alternative definition of BIM:

> *Building Information Modeling (BIM) refers to the creation and coordinated use of a collection of digital information about a building project. The information can include cost, schedule, fabrication, maintenance, energy, and 3D models. The information is used for design decision-making, production of high-quality construction documents, predicting performance, cost estimating, and construction planning, and eventually, for managing and operating the facility* (D’Agostino et al., 2007).

Nowadays BIM is being used in “preconstruction, design visualization, constructability reviews, design coordination, planning of trades and systems, 4D construction scheduling and sequencing, 5D quantity survey estimating, prefabrication and modularization, and as-built modeling for facilities operations and maintenance” (Campbell, 2006).

The impact of BIM on design can be mostly detected in the conceptual phase of a project because it supports greater integration and better feedback for early design decisions, followed by the construction level modeling including “detailing, specifications and cost estimation, then the integration of engineering services and supporting new information workflows, and last but not least collaborative design-construction integration” (Eastman et al., 2007). The benefits that come with BIM implementation are consistency across all drawings and reports, automating spatial interference checking, a strong base for interfacing analysis/simulation/cost applications and enhanced visualization. Some of the issues reported are replacing 2D drawings with 3D digital models, managing the level of detail within building models, the development and management of libraries of components and assemblies, and new ways of integrating specifications and cost estimation. On the other hand, practical concerns that design firms are facing when implementing BIM are the selection and evaluation of BIM authoring tools, training, initiating a BIM project, and planning ahead for the new roles and services that are emerging with BIM (Eastman et al., 2007).

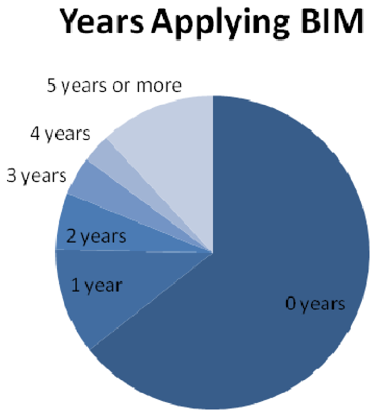
3.2 State of the Industry

FMI/CMAA Eighth Annual Survey of Owners highlights the changes in the construction industry and the impact of BIM. The number of new owners using BIM has risen from 3% in 2003, 4% in 2004, 6% in 2005, and 11% in 2006. The results show the following.

- Close to 35% of the respondents have used BIM for one or more years. But the frequency of BIM compared to total expenditure is much lower and believed to be below 5% by FMI’s opinion, since the owners were not asked this in particular.
- The two greatest obstacles to BIM adoption reported by owners are lack of expertise and lack of industry standards.
- 74% of current BIM users would be likely or very likely to recommend BIM.
- The greatest benefits of BIM that were reported were improved communication and collaboration among project participants. Also other important benefits are: higher quality project execution and decision making, greater assurance of project archival and more comprehensive planning and scheduling (D’Agostino et al., 2007).

Owners that decided to use BIM most often did that after their own investigation (35% of the time), or by recommendation coming from designers and/or construction managers. 74% of BIM users are extremely likely or likely to recommend BIM to others. Only 11% would not recommend it (D’Agostino et al., 2007).

According to the 2006 AIA Firm Survey, 16% of AIA member owned architectural firms have purchased BIM software, and out of this number, 64% are using BIM for billable work. BIM usage was defined by “The Architect’s Handbook of Professional Practice” as “the use of virtual building information models to develop building design solutions, design documentation, and to analyze construction processes.” AIA-owned firms that already implemented BIM reported that this new technology is widely being used for design development (91%), schematic design (86%), and construction documentation (81%) phases (Riskus, 2007).



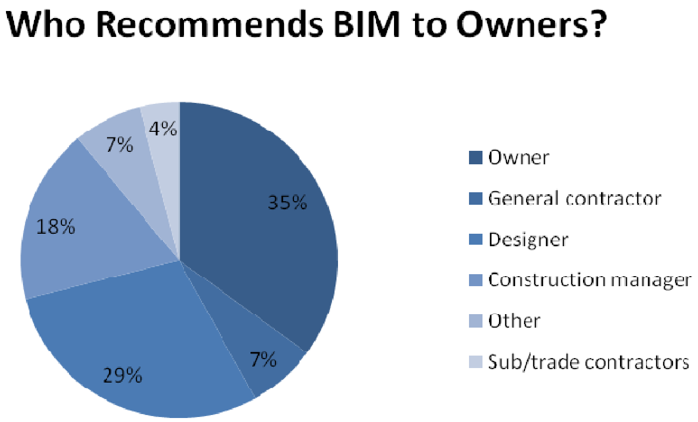


Figure **3-1a**: Years Applying BIM   Figure **3-1b**: Who Recommends BIM to Owners?

Source: FMI/CMAA Eight Annual Survey of Owners: The Perfect Storm – Construction Style.

Large AIA member owned architectural firms with over $5 million in gross billings have implemented BIM at a higher level (46%) as compared to smaller firms with gross billings under $5 million (15%). Smaller firms might be waiting for more industry reports on implementation of BIM before deciding to purchase certain BIM software based on its performance so far. A high percentage of international firms also acquired BIM software (35%), along with 20% of firms with an institutional specialization, 15% of firms with a residential specialization, and 16% of firms with a commercial/industrial focus. This may be due to the General Services Administration (GSA) establishing the National 3D-4D-BIM program in 2003, setting a requirement for firms working on institutional projects to implement BIM and hand over the model for operations and maintenance purposes (Riskus, 2007).

The monthly AIA Work-on-the-Boards survey panel of firm leaders in early 2007 reported the greatest benefits and concerns/risks perceived by the firms. Firms using BIM list enhanced project quality through fewer change orders and more accurate documents as the greatest benefit; and firms not using BIM list enhanced process through sharing digital models for easier collaboration as the greatest benefit. For the greatest concerns/risks, firms that adopted BIM list that a higher percent of project costs are incurred earlier, changing the traditional phase client billing. The ones that are still hesitant with BIM implementation list the lack of client demand as the main reason for not investing yet in BIM, which is not perceived by the BIM experienced firms at all, and can be seen as simple resistance to change (Riskus, 2007).

3.3 Design Services

Traditionally designers have been using plans, elevations and perspectives to represent their design intent. Drawings are still predominantly used in design and engineering, though computers have been adopted in the last fifteen years to support design and drafting mostly in 2D. BIM is making an enormous shift in approach to design since it is replacing 2D drawings with 3D models. Traditional architectural services offered are: feasibility studies, pre-design, schematic design, design development, construction detailing, and construction review. According to the traditional approach and AIA, contract for architectural services comprises of the following distribution of effort or payment schedule: 15% for schematic design, 30% for design development, and 55% for construction documents (AIA 1994). It is widely felt that BIM has an effect on redistribution of the time and effort spent in these different phases by greatly reducing the time spent on the production of construction documents (Eastman et al, 2007).

Standard contracts between owners and designers describe the design phases and the deliverables for each phase. The American Institute of Architects' B141 – 1997 breaks the design into: schematic design, design development, construction documents and bidding. The design starts with the schematic phase in which owner and designers determine the program, schedule and budget of the project. The result of this step is drawings and other documents providing the information about the size and relationship of project components, and the initial selection of building materials and major systems. Based on the schematic design, the designers progress with defining architectural, structural, mechanical and electrical systems and construction materials; and produce a set of drawings documenting form, size and project character. The next phase of the traditional process is the preparation and handover of the construction documents and specifications, addressing building codes and jurisdictional requirements. The standard design contract defines what is to be built but not how it is to be built, which is up to the contractor to resolve. This is one reason for inefficiencies and losses incurred in traditional project delivery. The design phase is followed by the construction phase in which the contractor dominates and takes all the responsibility; while the designers supervise the construction process, administers the contract, and reports to the owner on the progress and quality. The contractor provides at the end of this phase the operations and maintenance information and as-built drawings to the owner. The construction phase is finalized by closeout and commissioning involving the acceptance of the building, handing over the required documentation and processing final payments (NBIMS, 2007).

The traditional fee structure so far has been 15 percent for schematic design, 30 percent for design development, 40 percent for construction documents, and 15 percent for construction administration. This structure would have to change when BIM is used. Since the model needs to be precisely developed in the schematic design phase, more fee might be requested for this stage. Birx (2005) has proposed that this fee structure should have the following new breakdown: 25 percent for SD, 25 percent for DD, 25 percent for CDs, and 25 percent for construction administration. Being the initial creators of the information database, designers might be able to generate more fee for themselves (Birx, 2005).

3.4 Design Coordination Process

Most people feel that the introduction of 2D computer drafting in design firms did not significantly change the way architects practiced, but it simply computerized their practice. 3D computer modeling and BIM on the other hand bring a culture change that infuses all aspects of practice not just the drafting portion. But BIM cannot be equalized with 3D computer modeling, since BIM is predominantly a design tool that has many capabilities of which, one is modeling and producing construction documents. The bottom line, according to Birx (2005) is that architects have more time to spend designing and less time for drafting, and if the 3D model is managed properly, it can be used all the way from design through construction, resulting in construction documents of much better quality. Second, the database lies in the model, which is an advantage because all the information is stored in a central location and the model is a file or a series of files merged together. As a result, any modifications made lead to updating all the other building information. But at the same time, the size of this data can be hard to handle and manage. Still multiple users can work on it at the same time, since BIM software can have a central file system, as long as the users are not modifying the exact same object simultaneously. Third, BIM software creates hundreds of views of the project, and cutting sections or viewing elevations is simplified, and any modifications made are updated in all the sections and views (Birx, 2005).

Going from 2D to 3D is not easy and requires serious preparation and an organized approach. Staub-French and Khanzode (2007) identify the following steps in this process:

1. Identify the Potential Uses of the 3D Models: The way the model would be used decides the level of detail and modeling techniques. 3D models would differ depending if they were used for thermal simulation, cost estimating, fabrication, shop drawings or user group visualization for example.

2. Identify the Modeling Requirements: Establish who would create the 3D model, when the model would be created and how.
    a. Identify the modeling responsibilities for the various scope of work. Establish the responsible party and the transition of the 3D model between parties. For example, a mechanical engineer can model the system to a certain degree in 2D, and then a mechanical subcontractor would detail the scope in 3D. This could be done differently as well.
    b. Establish the scope of the 3D modeling effort and the level of detail to be modeled. Consider how the 3D model would be used, as well as cost-benefit of modeling a scope of work in 3D.
    c. Establish the work breakdown structure. Create a breakdown structure of the project, and determine how the models would be done for each part and integrated and coordinated later.
    d. Create a schedule that identifies key modeling activities. Determine when the models would be created, coordinated, updated and approved for fabrication.
3. Establish the Drawing Protocol: Establish a protocol for drawing conventions so that the 3D models can be easily integrated and coordinated: project reference point (0, 0, 0), file naming convention, version control, layering convention, and color scheme.
4. Establish a Conflict Resolution Process: Set up a process for identifying and resolving conflicts. Identify the specific design review software that would be used, establish the process for sharing drawing files, establish the timing and general meeting process for coordinating the 3D models, and identify a responsible party to facilitate the electronic design coordination process.

5. Develop a Protocol for Addressing Design Questions. Especially if contractors are responsible for developing 3D models, they should be able to contact designers quickly and not to go through the long RFI process.

All design coordination problems can be easily identified by a command in the BIM software. Before even an experienced staff member in charge of coordination would miss numerous conflicts which would lead to “errors and omissions”, requests for change orders, delaying of construction, and payment by the designer for the mistakes. Now with clearly marked in red coordination issues, no conflict can go undetected and unresolved before the construction (Birx, 2005).

3.5 Integrated Delivery: Design-Construction Integration

BIM is proven to enable design-construction integration. Some of the benefits of the designer teaming with the contractor are: early identification of long lead-time items, value engineering as design proceeds with cost estimates and schedules, sharing the model developed by designers with contractors and fabricators, and as a result shortening fabrication and detailing (Eastman et al., 2007).

Construction-level building models are one of the main advantages of BIM. Designers approach the development of models in two ways. The model is expressing in detail the design intent of the architect and the client, and it is up to the contractor to develop a separate construction model for the purpose of coordination and documentation. The other option would be a partially detailed model that can be transferred to the contractor as a starting model, and after being detailed and elaborated, used for construction, coordination and fabrication. The first option has been widely accepted and practiced by designers today to minimize or eliminate liability for arising construction issues (Eastman et al., 2007). The assumption is that the second approach might be better in the future if the potential impediments are resolved. This issue was addressed in the expert interviews for their views on the topic and possible remedies of the situation in the future.

The NIST’s study “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry” (Gallaher et al., 2004) estimated the efficiency losses in the U.S. capital facilities industry to be approximately $15.8 billion per year (based on 2002 data) due to inadequate interoperability. Interoperability was defined in this study as “the ability to manage and communicate electronic product and project data between collaborating firms and within individual companies’ design, construction, maintenance, and business process systems” (NBIMS, 2007).

This brings us to the point that a change in project delivery is necessary. The construction industry goal should be “better, faster, more capable project delivery created by fully integrated, collaborative project teams. Owners must be the ones to drive this change, by leading the creation of collaborative, cross-functional teams comprised of design, construction and facility management professionals” (CURT, 2004). A good way to accomplish this goal is an integrated project delivery approach where construction and operations knowledge and experience is brought early in the design decision making process. The integrated project delivery process was further explained in *Optimizing the Construction Process: An Implementation Strategy* by CURT (2006) and in *The Contractor’s Guide to BIM* (AGC, 2006), and can be seen, compared to the traditional design process, as a preferred design process, showing that if the decisions are made early in the design process, cost of design change can be avoided.

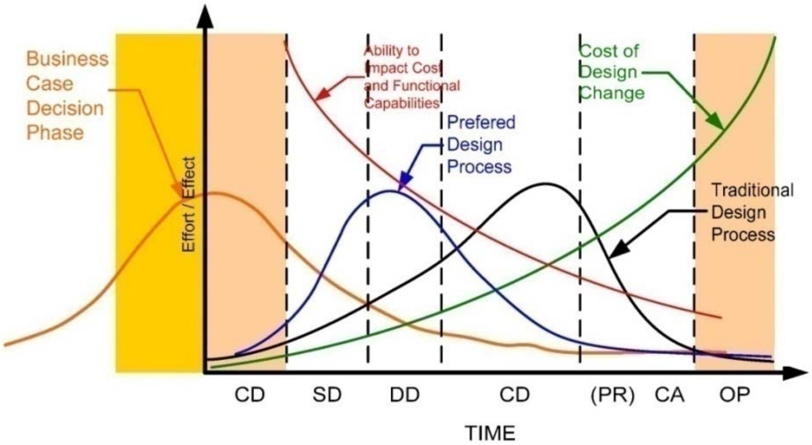


Figure **3-2**: Integrated Project Delivery vs. Traditional Design Process

Source: buildingSMART conference presentation “The Strategic Process Behind BIM Enabled Decision Processes” by David M. Hammond, RLA, APA, Office of Civil Engineering, U.S. Coast Guard

Three new phases emerge in this integrated delivery approach: Design Optimization, Construction Optimization, and Construction Orchestration. Design Optimization involves using advanced analysis software in all areas (structure, energy consumption, lighting, daylighting, air flow (CFD)) to decide what should be built, leading to an intelligent building model and optimized design solution. 3D visualization is one of the most important aspects of the design optimization because it improves communication with all stakeholders and speeds up design decisions. The information transmitted to the contractor can be an intelligent model or a series of discipline specific models. The next phase of Construction Optimization involves contractors, subcontractors and fabricators performing a 3D review process and electronic submittals. The geometry of the discipline specific models is merged and interferences or conflicts are resolved. Schedule added to the 3D model of the facility resolves the construction interferences using 4D techniques, and the construction can begin. The information handed over is a detailed 3D model of the building with the components defined to the level that they can be fabricated from the model. The final phase is Construction Orchestration, involving fabrication of the components in a controlled environment resulting in less waste, less number of hours on the site, less laydown space needed and improved safety overall. The necessary factor for integrated project delivery is technology or Building Information Modeling (NBIMS, 2007). As a conclusion, several authors have strongly supported the need to use integrated delivery method for achieving better results with BIM.

Some guidelines developed by Campbell (2006) and M. A. Mortenson Company to facilitate integrated practice are:

1. *Model, do not draft.* A complete BIM model needs to be developed and coordinated to discover and resolve conflicts early.
2. *Model your own scope of work.* Every designer, engineer, and subcontractor is responsible for modeling his own scope of work in BIM.
3. *Model it at true size.* Everything must be represented at its true size and in the right location. Incorrectly modeled data should not be concealed by disclaimers and dimension overrides.
4. *Be data agnostic.* There are too many file formats and specialized software applications available, therefore standards like IFC, VRML and X3D should be adopted.
5. *Share your information.* Address questions about intellectual property and liability early in the project with adequate legal and contract language.
6. *Manage change.* Develop standards to manage and track design revisions in design and construction.

3.6 BIM Benefits and Challenges

Benefits and challenges perceived are critical for future adoption of BIM, especially from the owners’ point of view. The connection established between benefits and results is crucial for potential new users to decide to implement BIM on their projects. The scorings in the survey of the owners (FMI/CMAA Eight Annual Survey of Owners) were differentiated between non-BIM users and BIM users, but the total score was given as well. Rankings are as expected higher for BIM users since they are certain they are receiving or would receive these benefits. Highest ranked were improved communication and higher quality project execution and decision-making.

Table **3-1**: BIM Benefits and BIM Hurdles

Source: FMI/CMAA Eight Annual Survey of Owners

BIM Benefits			**BIM Hurdles**		
Rate benefits that BIM solutions provide on capital construction projects (Scale: 1=strongly disagree; 5=strongly agree)	All responses		Rate hurdles that slow or prevent adoption of BIM solutions on capital construction projects (Scale: 1=strongly disagree; 5=strongly agree)	All responses	
	Score	Rank		Score	Rank
Improved Communication and Collaboration Among Project Participants	4.22	1	Lack of Expertise	4.09	1
Higher Quality Execution and Decision-Making	4.09	2	Greater System Complexity	3.92	2
Greater Assurance of Project Archival	3.98	3	Lack of Industry Standards	3.92	3
More Comprehensive Planning and Scheduling	3.97	4	Poor Integration with Existing Systems	3.79	4
Higher Quality Construction Results	3.90	5	Different Needs Across Stakeholders	3.72	5
Easier to Achieve Process Standardization	3.89	6	Training Burden	3.66	6
More Reliable Compliance with Regulations	3.73	7	Unclear Business Value and ROI	3.62	7
Greater Productivity from Labor and Assets	3.71	8	Lack of Executive Buy-in	3.57	8
More Consistent Performance Against Budget	3.68	9	Vague Cost Estimates	3.32	9
Significantly Reduced Change Orders/Claims	3.64	10	Legal/Contractual Concerns	3.23	10
Broader Strategic Perspective and Innovation	3.63	11	Security Risks	3.03	11
Decreased Labor Costs	3.52	12			
Measurably Reduced Contingencies	3.49	13			
Improved Safety Performance	3.44	14			
Competitive Advantage in Recruiting and Staffing	3.39	15			

The scoring of all hurdles or challenges is much lower by BIM users since they are more confident they can or would be overcome. Non-users rank a lack of executive buy-in as more significant, while BIM users rank higher the challenges that arise from different needs across different stakeholders. Not expected, security risks and legal/contractual concerns were ranked low (D’Agostino et al., 2007).

Based on the experience of the design and engineering firms who already adopted BIM, the following benefits were recognized (Staub-French and Khanzode, 2007):

1. Most design conflicts are identified prior to construction,
2. Productivity is significantly improved,

3. Less rework,
4. Increased opportunity for pre-fabrication,
5. Fewer Requests for Information (RFIs),
6. Fewer Change Orders,
7. Design errors can be identified prior to construction,
8. Ability to build the system with a less skilled labor force,
9. Improved safety performance,
10. Better cost control.

To realize these benefits some compromises had to be made. Productivity was improved, but design time increased. Rework was avoided, but design coordination time increased. The project team made more informal decisions, but the time it took to design, plan and estimate the project increased. The efficiency of the installation process increased, but the design cost and time increased as well (Staub-French and Khanzode, 2007).

To take advantage of these benefits, owners need to bring a project team together early in the project, designers need to work more on the overall design and its coordination and less on detailed design; contractors need to be skillful at manipulating and managing the 3D model, work closely with designers, and provide their input early in the design; and subcontractors need to be able to do more detailed design, work closely with the designers and engineers, and help coordinate designs early in the process (Staub-French and Khanzode, 2007).

Benefits of implementing BIM are evident, but they have to be justified considering additional costs involved, training staff and introducing new procedures. Fee for design services is either calculated as a percentage of construction cost or an hourly rate. For designers to offset their costs, a solution would be to start offering new services that can be added to their fee. Some of the possible services can include: performance-based design using analysis applications and simulations, integrating design with construction leading to faster construction, facilitating offsite fabrication of assemblies, and reducing field work (Eastman et al., 2007).

3.7 BIM Design Productivity Benefits

To justify the additional cost involved with implementing BIM, the production benefits need to be assessed. One way is to track the reduction of errors by the lowered number of Requests for Information (RFIs) and Change Orders (COs) on a project. Another way would be to assess the increase in labor productivity, measured as the total cost of labor hours and salaries, to realize a certain task. The return on the investment can be determined by comparing the investment in BIM required with the reduction in labor costs. Few firms keep track of the unit costs based on floor area or facade area during design phases, like design development and construction documents, but these metrics can be very valuable in performing cost-benefit analysis of BIM implementation (Thomas et al., 1999). Little research data has been published on productivity gains and this can be one of the greatest challenges for the design firms to track their costs and time and money savings (Sacks and Barak, 2006). The annual return on investment and the time needed to regain the cost can be determined by dividing the total annual benefit by the total cost including labor training cost, learning curve cost and hardware and software costs (Eastman et al., 2007).

Though the key application of BIM is currently in the design and construction field, there are other creative applications that can lead to production benefits (Birx, 2006):

1. Visualization. Model renderings are done as package services and add to the design fees.
2. Fabrication and shop drawings. The BIM model if properly set up from the beginning can be fully used for fabrication and construction purposes.

3. Code reviews. Code officials find BIM models as a great tool for the project code reviews.
4. Forensic analysis. BIM model can be used in multiple ways to analyze the building, its evacuation plans and potential failures and leaks.
5. Facilities management. BIM model can be also used for further renovations, space planning and maintenance of the building.
6. Construction information database. Single source of information is aiding everyone involved with the process of constructing a building.
7. Cost estimating. Material quantities are easily extracted from the BIM model and can be automatically adjusted with changes made in the model.
8. Construction sequencing. Ordering, fabrication and delivery schedules for building materials and systems are easily created from the BIM model.

At present time, most design firms and construction companies are not keeping track of the cost involved with BIM implementation, and the cost gains due to improved productivity and technology. These metrics need to start being collected in order to quantify precisely the cost-benefit ratio of BIM. Also an understanding must be reached of what information precisely is crucial for each business activity in construction (NBIMS, 2007).

Key success factors were also identified:

1. Strong leadership by the client or executive leadership within the company,
2. The team buy-in and BIM skilled personnel in the team,
3. Transparency and accessibility of electronic information,
4. Ability to use the information across the design/construction team,
5. Appropriate quality assurance methods and procedures,
6. Collaboration that includes the trades,

7. Recognition of new project roles, i.e. information manager,
8. Mutual trust.

3.8 New and Changed Staffing within Design Firms

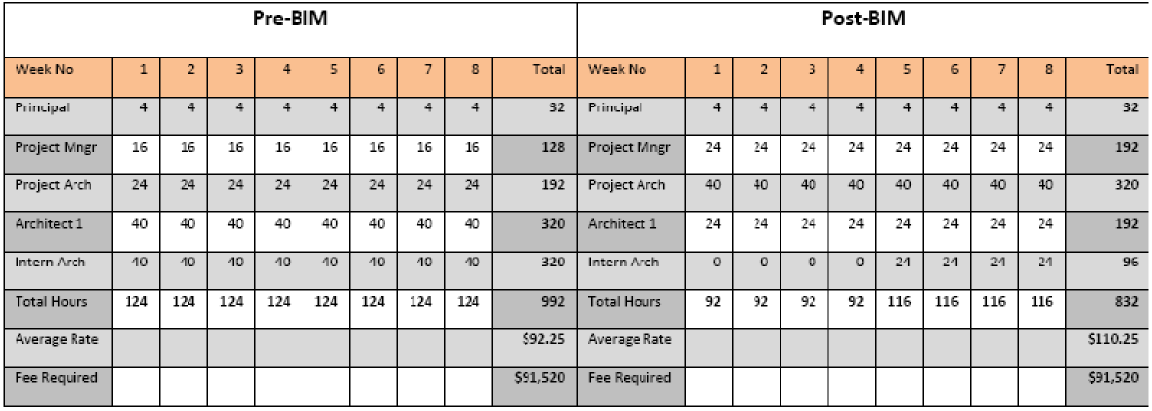
One of the main challenges in implementing BIM is the transition that needs to be made in adopting new practices, methods of working, and documenting work. Another challenge that firms face when it comes to staff and training are new roles that arise with the new technology: Model Manager maintaining model's data integrity and Systems Integrator setting up exchange methods for BIM data with consultants (Eastman et al., 2007).

BIM is changing the way the project needs to be staffed. In a traditional approach the project staff would include a principal, a part-time project manager, a project architect, a full time architect 1 and full time intern. With BIM, more senior staff needs to be involved early in the project, the average hourly rate has increased, and less man-hours are needed to finish the project. Working in BIM requires more experience, which would mean that the principal is involved the same as before, the project manager and architect need to put in more hours, while the architect 1 and intern would work less hours due to the process automatization. This also means that young architects starting their career would spend less time learning drafting and more time designing (Birx, 2005). This analysis is represented in Table 3-2, but can be considered an educated guess on how the new hours would look like in the changed scenario with BIM.

New technology requires team members in charge of managing the model, training the staff and providing IT support. Staff needs to be aware of the purpose and use of the information involved, life cycle aspect of information, quality assurance issues, how to create and use the information, and security issues such as confidentiality, virus checking and backup (NBIMS, 2007).

Table **3-2**: Pre-BIM and Post-BIM Man-hours Needed to Finish the Project

Source: Birx, G. W. (2005). BIM Evokes Revolutionary Changes to Architecture Practice at Ayers/Saint/Gross.



Pre-BIM										Post-BIM									
Week No	1	2	3	4	5	6	7	8	Total	Week No	1	2	3	4	5	6	7	8	Total
Principal	4	4	4	4	4	4	4	4	32	Principal	4	4	4	4	4	4	4	4	32
Project Mngr	16	16	16	16	16	16	16	16	128	Project Mngr	24	24	24	24	24	24	24	24	192
Project Arch	24	24	24	24	24	24	24	24	192	Project Arch	40	40	40	40	40	40	40	40	320
Architect 1	40	40	40	40	40	40	40	40	320	Architect 1	24	24	24	24	24	24	24	24	192
Intern Arch	40	40	40	40	40	40	40	40	320	Intern Arch	0	0	0	0	24	24	24	24	96
Total Hours	124	124	124	124	124	124	124	124	992	Total Hours	92	92	92	92	116	116	116	116	832
Average Rate									$92.25	Average Rate									$110.25
Fee Required									$91,520	Fee Required									$91,520

3.9 BIM Contractual Terms

Since the 2D information on paper is replaced by 3D intelligent models, questions of contracts, liability, risk management and insurability need to be addressed. The general consensus is that the model needs to be accurate at all times to be used as intended. Due to the transitional period, most contracts still include the need for paper copies of all the construction documents. Standard contract language in case of sole usage of BIM model needs to be changed or special contract clauses should be added to assure adequate allocation of responsibility in creating, maintaining and handing over the model (NBIMS, 2007).

Recently new documents have been released on how to change contractual terms if using BIM or sharing the model in a traditional, design build or integrated project delivery. More information can be found in the following published documents: the AIA E202 document, the AGC Consensus Docs BIM Addendum and the AIA IPD Documents.

3.10 Conclusion

While there are various reports and papers on Building Information Modeling in design and construction, there are few sources that provide specific data on implementation of BIM in practice. Furthermore, currently there are no guidelines to lead the project team members in how to develop an execution plan for BIM in design and construction. This research is being done with the intention to provide a taxonomy of BIM uses in design and informed guidelines for the early project participants that would assist in preparing a customized project execution plan for BIM. New contract language on BIM implementation identifies the need for a BIM execution plan, but no detailed method for developing this plan is yet available.

Chapter 4

BIM Execution Planning

The expert interviews performed during the data collection process are analyzed and discussed in Chapters 4, 5 and 6 in the categories they were collected: Background Information, BIM Execution Planning, BIM Uses in Design, BIM Impact Analysis, and Concluding Questions. The information obtained from the interviewees is reported and indicated with the designation of "[I-#]" to indicate the number of the interviewee that made the statement. Before each summary and analysis, the question posed to the participants is further explained if needed. A brief discussion follows each data analysis result. Chapter 7 concludes with global findings and propositions for further investigation.

4.1 Background Information

4.1.1 Participants

The interview began with industry experts stating their name and the name of the company for record, and sharing their title or position in the design firm or company along with briefly explaining their responsibilities. Table 4-1 gives a concise overview of the titles or positions of the interviewees. They all belong to one of the three distinctive groups: Executives, Designers or BIM Support.

Table **4-1**: Titles or Positions of the Interviewed Industry Experts

1.	Virtual Design and Construction Eng	**10.**	Project Designer in Base Building Arch
2.	Manager for Design Services	**11.**	Principal and Structural Engineer
3.	Principal and Senior Analyst	**12.**	Director of Design
4.	Senior Applications Manager	**13.**	Architect and Business Owner
5.	Principal Architect	**14.**	Managing Principal
6.	Arch Intern/Digital Design Coordinator	**15.**	Applications Administrator
7.	Senior VP, Associate Managing Principal	**16.**	Director of Research and Development
8.	Senior Associate and Architect	**17.**	Project Manager/BIM Committee Co-Chair
9.	Principal and Project Manager	**18.**	Principal and Technical Director

4.1.2 Design Firm/Company

Most of the interviewees decided to not share their design firm or company yearly revenue due to confidential pretext; this question was later dropped from the list. The number of employees for each company was identified, and Figure 4-1 shows the breakdown in the following categories:

- Small size design firm/company 1-30 employees: 22%;
- Medium size design firm/company 31-150 employees: 28%;
- Large size design office/company 150+ employees: 50%.

Many of the interviewees come from large design firms, but there is an equal representation of the small and medium size firms in the sample.

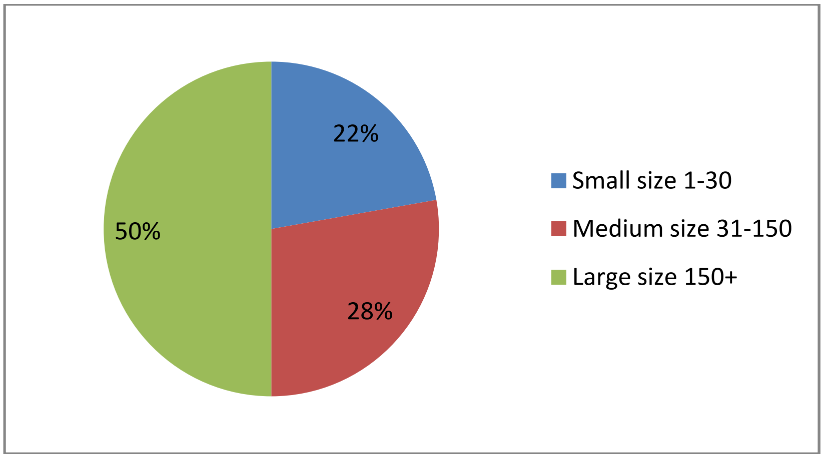


Figure **4-1**: Number of Employees in the Interviewees' Design Firms or Companies

4.1.3 Previous BIM Experience

All the interviewees confirmed that they had previous experience with BIM and implemented it in their day-to-day practice; therefore the interview could continue, otherwise it would be interrupted at this point as the participants would not be considered experienced in this area.

The years of experience of the interview respondents were sorted in the subsequent groups (see Figure 4-2):

- Beginner level (less than 1 year of experience): 28%;
- Intermediate level (1 to 5 years of experience): 33%;
- Advanced level (more than 5 years of experience): 39%.

Although the levels of experience are equally represented, the majority of the interviewees have substantial knowledge and understanding of BIM, since they have been using some form of Building Information Modeling for more than one year.

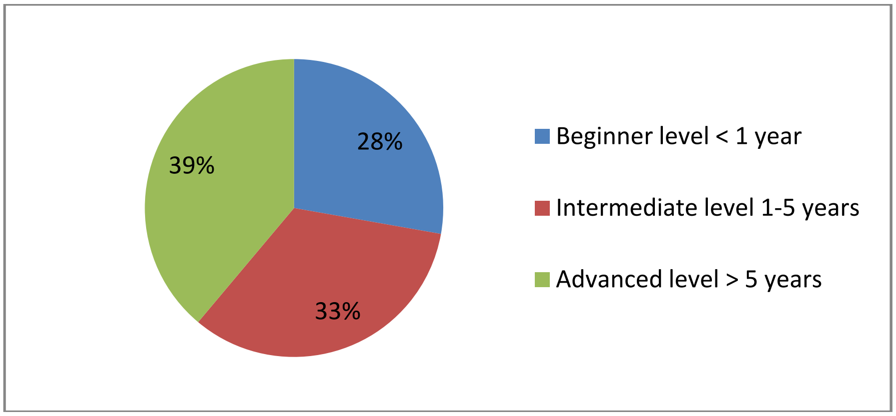


Figure **4-2**: Interviewees' Years of Experience with BIM

The years of experience of the design firm/company with BIM were reported as the following (see Figure 4-3):

- Beginner level (less than 1 year of experience): 11%;
- Intermediate level (1 to 5 years of experience): 50%;
- Advanced level (more than 5 years of experience): 39%.

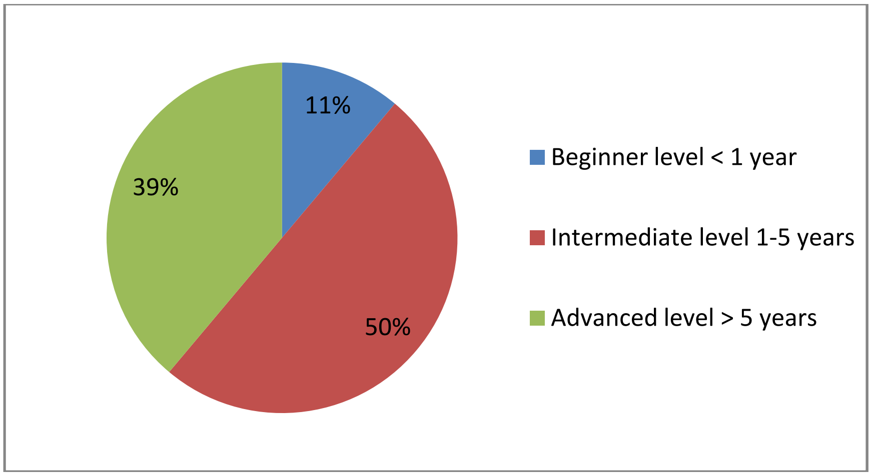


Figure **4-3**: Design Firm/Company's Years of Experience with BIM

As opposed to the personal experience of the interview respondents, they report a higher level of knowledge of BIM for the design firm/company on the intermediate level (between 1 and

5 years). This could be due to the higher hierarchical position of some of the respondents who may not be as personally involved with the implementation of BIM, or the marketing efforts of the design firms/companies to advertise BIM as part of their services and expertise.

4.2 BIM Execution Planning

The interviewed participants were asked about their experience with BIM Execution Planning. Most of the respondents said they do not have a document for BIM Execution Planning. In the case that they did have written guidelines, they were in a bulleted outline form with brief instructions usually explaining the process implemented, level of detail or BIM model granularity, but contained no practice or procedures manual. Most of the respondents gave the interviewer an overview of the participants involved and the process that was used to develop the plan, the majority saying that it was a valuable activity. Also a large number either did not have the plan at hand or would rather not share the details considering that it might offer them considerable competitive advantage in the future. The respondents’ answers will be summarized, reviewed and conclusions drawn in Chapter 7.

In conclusion, one third of the respondents did not have a specific plan, the rest had some form of an informal plan, and only one design office had an extensive implementation plan. This shows the need for the existence and establishment of standards and guidelines in this changing area of the construction industry. The following are summarized responses on this topic.

Interviewee No.1 [I-1] confirmed the company has a basic plan in a form of a bulleted outline, but no practice or procedures manual yet. They also confirmed that a common set of standards and guidelines would be very useful in construction industry at this point of BIM implementation. The second interviewee [I-2] negated the existence of such plan at the time of the interview.

The third respondent [I-3], though not having one specific plan in the company, worked as a consultant on other firms' strategic implementation of BIM and shared what are the most important factors to be considered.

Participants: Senior firm leaders need to articulate and support the vision, and have someone with authority, like a BIM champion or team captain, to drive the process. This is crucial, since employees might be very talented and knowledgeable, but not allowed to make any changes without senior buy-in.

Decisions: The absolute first decision must be to commit! BIM is not about implementing new technology or software, but about transforming the construction industry, and openness to considering other ways of doing business is very important. BIM should be a tool to achieve this transformation, not in any case the end result or a goal. The interviewee also stressed significance of early involvement of the constructor in the decision making process, as well as collocation of the design and construction team. There is nothing about current practice that prevents either the early involvement of the project team or the collocation.

Process: Design firm or company needs to take a close look at its core competencies and market needs, leverage them and broaden their market appeal. If the design firm aligns technology with its business goals and core competencies, it can be very successful regardless of the specialty. The change of mindset is also essential: from cost-based to value-based business propositions. The practice of selling time rather than value needs to be changed. The design team must concentrate on how to produce higher value for the same price. If more efficient and productive, designers will be more profitable in the end since they would be able to do more work of higher value for less effort.

Interviewee No.5 [I-5] personally started the BIM Execution Plan and got it approved by senior management, however it took a year and a half between accepting the plan and beginning the first project.

Decisions: A focus group was formed with champions of each design division and they learned BIM software together. Since then, more than 50% are using it on everyday tasks. They have also managed to convince project managers and principals, by using the numbers from the pilot project, to buy more BIM software licenses and hardware. A plan was developed on how to train the company, with the ambitious goal of 100% BIM in a year and a half.

Process: A fast tracked pilot project was executed and the solution was delivered to the satisfied client in half the time and half the staff compared to the traditional approach.

Interviewee No.6 [I-6] negated the existence of an implementation plan, but the design office was working at the time on setting up a plan with their software vendor on how to start a project in BIM (set up files and templates, troubleshoot, check progress, train staff and address properly the learning curve).

Decisions: Record everything and learn from your experience (how to execute projects in BIM, set the training ground, develop BIM standards, create new positions, and produce a step by step manual for BIM).

Company No.7 [I-7] had a management team and key technical staff (CAD managers and BIM gurus) working on the BIM Execution Plan.

Decisions: Work in multiple platforms was mandatory, and the project team had to agree on software and version (Bentley Microstation, AutoCAD, Autodesk ADT and Autodesk Revit), and granularity (level of detail) of the model since it impacts the size and the complexity of the model.

Process: Trial and error, since no wide available BIM standards exist yet. Develop model definition, its setup, granularity and format, and determine BIM expectations. BIM needs to be defined since everyone has different and usually wrong perception and vision of BIM (intelligent objects, photorealistic rendering, model fly-through, etc).

Interviewee No.8 [I-8] offered this view of the BIM Execution Planning in his company:

Participants: Project architect and manager have developed an informal BIM Execution Plan, but the design office is in the process of doing a more formal holistic plan (Business Application Strategic Plan) and a technical plan for individual projects.

Decisions: Execution of the model (one or multiple, model setup, model uses, provided to the client or used internally), size of the project team, etc.

Process: Initially a software representative was hired as a consultant to assist in software implementation, but later a 3rd party consultant (large expert BIM firm) was engaged to help strategize, assist in the development of the models, and do more than just global implementation and standardization plan. The third step was to outsource modeling of the building components, and the team was allowed to spend more time focusing on the design information.

The design office No.9 [I-9] had a BIM coordinator working with a Model Master on the structure of the composite BIM model. Initial aspirations were humble: just to get a good set of coordinated drawings. However, the question was how to use BIM to their advantage.

Process: Process diagram was issued to the whole team. The agreement was achieved to post the latest model on the FTP site every Friday. On Monday morning, a new model would be downloaded and the highlighted changes would be reviewed. The BIM Execution Plan was planned to be developed after consulting with the software representative and getting his input.

Interviewee No.10 [I-10] stressed that buy-in is critical to get BIM moving forward and it must begin at the top (management, partners and principals on board first, then directors and project managers).

Decisions: The challenge is to understand the firm and its needs. Phase 1 of BIM implementation needs to bring up the level of understanding throughout the firm (start with pilot projects, BIM savvy people build synergy, set up standards and templates). Phase 2 entitles marketing and presenting BIM outside of the office to spread the message in working and coordinating with consultants. Phase 3 offers new capabilities (prefabrication, advanced energy modeling, new workflows, and different alliances) which would lead to more efficient and better design of buildings.

Design office No.11 [I-11] does not have a BIM Execution Plan, and the interviewee believes such plan is not needed until they make the step to full BIM. For the conflict resolution model, only major building items are needed and level of detail is of less importance.

<u>Participants</u>: A principal, designer or project manager and lead CAD person are expected to be involved in negotiations.

<u>Decisions</u>: Division of work, performance specification items, level of detail, model access, legal issues, etc.

Interviewee No.12 [I-12] also negates the existence of a BIM Execution Plan.

<u>Decisions</u>: A cohesive understanding and acceptance of BIM is vital. Everybody has to be adaptive and come together as a team on this process change.

Design office No.13 [I-13] also does not have a specific BIM Execution Plan.

Company No.14 [I-14] has a BIM Execution Plan, but more in a form of notes and outlines and not formalized. The new technology is just being implemented and each project has different requirements, or projects are international and production takes place oversees with partners in the local markets. Since these projects progress up to design development phase, BIM requirements are more limited on these projects. A comprehensive plan for BIM does not exist, but a separate plan is developed for each project.

<u>Participants</u>: The corporate BIM manager leads the company in implementing the technology, as well as several leadership positions in each office. However, extensive training is done across the board. A BIM Execution Plan is created by collaborative effort of the corporate BIM manager and all leaders in the office.

Interviewee No.15 [I-15] talks about the plan which was not yet formalized:

Participants: Each project team has its own BIM coordinator who is in charge of how the model is built and takes care of the standards that need to be followed. The team starts with a simpler project. The BIM coordinator meets with Applications Manager to decide how the team is going to work and details of the basic setup for a project (one or more files, worksets, etc).

Decisions: Standards are key and templates with basic essentials are used that have generic families and the schedules set up accordingly. It is up to users to import new content, which is better than to give them all the possible model contents at once.

Company No.16 [I-16] has a very elaborate BIM Execution Plan:

Participants: A corporate BIM manager and BIM implementation group drive the process. Also, all practice groups' representatives give their input and help define goals, since BIM has serious ramifications on legal, financial, sustainability issues, etc. The process needs to be practice driven and not driven by technology. Most importantly senior level buy-in needs to be in place (understand changes, benefits and risks, and make corporate wide goal of implementing BIM to establish industry leadership).

Decisions: A goal set to fully implement BIM in three years.

Process: BIM has the ability to change the way of practicing, partnering and delivering projects. The process started with strategic BIM plan and Innovation Technology Group experimenting and doing pilot projects, when the leadership decided to take the whole company in this direction. The BIM Execution Plan cannot be shared since it represents competitive advantage for the company, but the overview is the following:

Level 1: Design, documentation and visualization are much more streamlined by using BIM technology. BIM makes the design process more intelligent and coordinated, decisions effective and waste eliminated. Level 2: More tight integration exists between disciplines and understanding of spatial issues or conflicts is better. BIM is used to expand on analytical applications (targeting performance, environment, cost, etc) that were separate discreet processes before, and now offer a much more streamlined practice using the same model. Level 3: Integrated Project Delivery (IPD) is enabled by using the model and data in design and extending them to construction manager for cost, constructability analysis and logistical planning, and down to subcontractors for automatized fabrication.

The company is currently at Level 2 and exploring Level 3, but most of the AEC industry is at Level 1 since potential for BIM during the whole lifecycle of a building can be a bit overwhelming. The first round of projects showed that the company is much more profitable and producing better work while still absorbing the learning curve.

Interviewee No.17 [I-17] shared that the company has decided a BIM Execution Plan is not required at this early stage in development, but possibly when the AEC industry moves past the basics of BIM and starts utilizing it 100%.

Participants: Members of the design team (architect, structural engineer, MEP engineers) as well as the owner need to be involved in creation of a BIM Execution Plan.

Design office No.18 [I-18] has an implementation plan but is unable to share it since it is a competitive issue.

Participants: Board of Directors, the Executive Committee and all the respective offices were involved in creation of the implementation plan.

Decisions: Very aggressive plan was implemented during the past 2-3 years. Managing director of the region set the goals, decided on the software and started pilot projects in BIM.

Chapter 5

BIM Uses in Design

This chapter discusses various items associated with BIM uses in design. It starts with the identification of BIM uses that were developed from this research. Then it covers the topics of model content and level of detail, modeling process and software applications, team competencies, and legal, insurance and contractual considerations. The BIM uses are outlined along with interview comments regarding the uses. The information obtained from the interviewees is reported and indicated with the designation of "[I-#]" to indicate the number of the interviewee that made the statement. Not all statements have been validated through research so the reader should only evaluate these statements as one opinion from an experienced person.

5.1 BIM Uses in Design

A taxonomy of BIM uses was created based on the literature review and the results from the expert interviews, and it identifies approximately 15 BIM uses in design. After the taxonomy was produced, each BIM use was investigated in more detail for the BIM Execution Planning Guide. Appendix F offers an example of one BIM use in design, offering more industry member insight merged with information published on the specific BIM use in the literature. An overview of the frequency of these BIM uses derived from the data collected and expert interviews can be reviewed in Appendix E. The BIM uses are further presented in this section and some general comments from the interviews are summarized. For a more detailed investigation of these BIM uses, please refer to the BIM Execution Planning Guide.

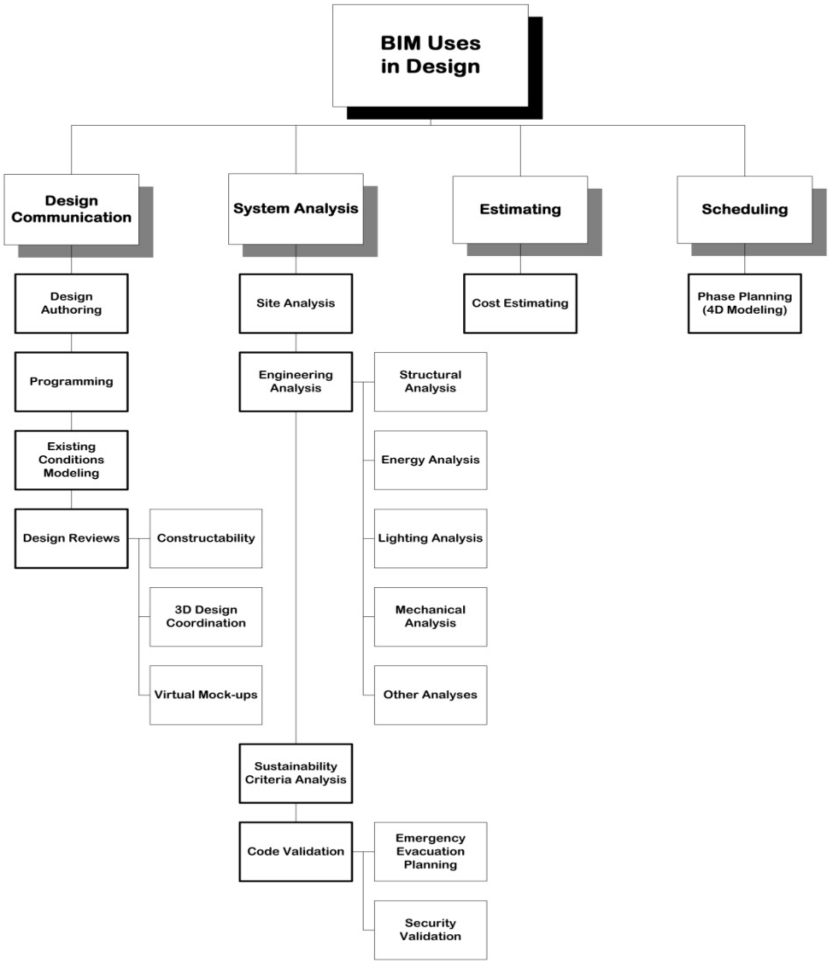


Figure **5-1**: BIM Uses in Design Taxonomy Guide

5.1.1 Design Authoring

Design Authoring is defined as a basic BIM use in which 3D software is used to create and develop a BIM model based on criteria that is important to the translation of the building's design (CIC, 2009). There are two types of applications at the core of a BIM-based design process (Tardif, 2008):

- Design Authoring tools and
- Audit and Analysis tools.

Authoring tools create models while audit and analysis tools analyze or add to the richness of information in a model. Design authoring tools are a first step towards BIM and the key is connecting 3D model with powerful database of properties, quantities, means and methods, costs and schedules (Tardif, 2008). Once created, a BIM model greatly enables communication of design intent to the client, consultants and other stakeholders. Most of audit and analysis tools, on the other hand, can be used for Design Review and Engineering Analysis BIM uses.

5.1.2 Programming

Programming is defined as a process in which a spatial program is utilized to efficiently and accurately assess design performance in regard to spatial requirements (CIC, 2009). It can also be defined as design discovery and definition [I-5]. Eleven design offices explained how they use BIM for programming purposes (61%). It is considered to be a very important part of architectural practice, since a design program is necessary and very valuable to develop while making critical decisions in this phase.

Programming brings most value to the project when needs and options are discussed with the client and the best approach is analyzed. Clients would rather not compensate designers for this service, but this mindset needs to be changed. Most benefits can already be reaped from BIM, since preliminary model is started at this point and it becomes schematic design, design development and finally construction documents. There is a lot of preliminary information and visual data offered to the client and all stakeholders at this point early in design development.

A good number of design firms still do programming in the traditional way with hand sketching, graphic blocks and elements, or using Sketchup for initial ideas, but this approach has no continuum with a BIM authoring tool [I-7]. Some of the available applications aid with blocking and stacking of programming relationships (OPS and Trelligence). During programming a lot of design analyses are done, and hundreds of schemes and different possibilities are generated. Then they are filtered out based on appropriateness, context, and performance, and presented to the client. The project team, by doing these initial design analyses, can be confident that the design is progressing in the right direction. Clients are usually impressed by the use of BIM in even the earliest phases of design [I-9].

BIM programming tools can present a tremendous labor saving device in ruling out bad design ideas early on. Presenting programming options and design visualization often help clients obtain funding for their projects and communicate their vision to the stakeholders [I-12]. Animated renditions and massing representations at the early stage of the project are always included in the proposal phase [I-14]. A few design offices have their own “home grown” programming tools and databases. These tools analyze space requirements and are automating the programming process based on little input, like number of employees, and build a program based on rules of thumb. OPS is one of the widely available BIM programming tools that is web based. It takes programming data, does number crunching, and produces utilization of spaces, special arrangements, as well as blocking and stacking of spaces. The software can then export the created information into the desired file format and to BIM authoring tool for further analysis and improvement [I-16].

5.1.3 Existing Conditions Modeling

Existing Conditions Modeling is defined as a process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility (CIC, 2009). One good example for this BIM use would be historic preservation of theatres which include complex interior spaces and many details. It is very expensive, labor intensive and time consuming to document existing conditions manually. 3D laser scanning, though pricey, is still far less expensive than sending design staff to remote job sites to document and manually enter data into CAD. Measuring existing conditions has little value for these specialized firms, so the business decision is to outsource existing condition modeling with 3D laser scanning and devote designers' time to high value adding tasks. Profit increases since no low-value work is done; cost decreases but not as much as time which leads to delivering projects months earlier [I-3].

5.1.4 Design Reviews

Design Reviews are a group of BIM uses. Design Review is defined as a process in which design is reviewed for constructability, coordination of systems and visualization of spaces and building details (CIC, 2009). They were covered in three categories: Constructability, 3D Design Coordination and Virtual Mockups. Majority of interviewed design offices use BIM for constructability and 3D design coordination purposes. A significant percentage mentioned they had used some form of virtual mockups for the clients, either for specific spaces or the building details. Value engineering in the traditional approach happens when the design is complete, while 80% of the cost of the building is determined in the first 20% of the design stage. The ability to affect cost is very limited to the last 20% of design; however value engineering is much more effective in the BIM environment. Design reviews early in design lead to fewer questions and less miscommunication between the design team members [I-17].

5.1.4.1 Constructability

Constructability is defined as a review of the building model along with plans and specification to determine constructability of the project and coordinate with other project participants (CIC, 2009). As part of design reviews, constructability is one of the most frequent BIM uses implemented by all the interviewed participants, since it is much easier to communicate construction details in 3D [I-5]. The contractor reviews the model and drawings in a back and forth process, trying to understand the design and distinguish different aspects and problems. The project team also runs clash detection and evaluates the design. In this process, a number of compromises need to be made to be able to hand off drawings fully coordinated [I-7]. This is one of the biggest benefits of BIM: eliminating tedious manual design review in exchange for more precise, fast, and visual review of building constructability.

5.1.4.2 3D Coordination

3D coordination is defined as a process in which 3D software is used to model the detailed designed building components, followed by automated identification of spatial conflicts between components through a collision detection algorithm. The conflicts can then be resolved by relocating building components (CIC, 2009). 3D coordination is currently used frequently, as well as constructability review done in collaboration with the contractor. In this case, it is up to the designer and consultants to resolve coordination issues on the design level. Software is also readily available to ease this 3D coordination effort like Autodesk Revit, Navisworks, Bentley

Navigator, and Solibri Model Checker. Some comments from interviews included that BIM increases communicability with structural engineers and other consultants when used for coordination purposes. Instead of communicating every other day or weekly, some designers talk to consultants twice a day, since every design change has a lot of consequences in the model and usually needs to be discussed immediately [I-4]. The BIM model has a strong potential to illuminate a lot of errors that would occur in 2D drafting solely, and helps designers to stay on top of everything given that they are instantly notified of any changes. 3D coordination is easily the biggest bonus of BIM, with so many demands in place to coordinate different trades [I-6]. This primary use of BIM for error checking and conflict avoidance and resolution leads to developing better and more coordinated documents, fewer change orders, and better designed buildings overall [I-7].

5.1.4.3 Virtual Mock-up

A Virtual Mock-up is defined as a review of the building model used to showcase the design to the stakeholders and evaluate meeting the program and set criteria (CIC, 2009). It is mostly done either in complicated projects for construction details like wall sections or ceilings, or for certain chosen spaces in the project that would benefit greatly from building the virtual mock-up. Examples for those chosen spaces can be courtrooms, operating rooms, patient rooms, auditoriums, concert halls, or any space that would benefit from review and testing by its future end users and clients making the investment. Other software, not necessarily BIM, can be also used for visualization like Autodesk Impression, 3D Studio Max and Sketchup. However, visualization is not the ultimate goal since it is as well part of the architectural design [I-4]. Mock-ups can be also done of a whole campus, a few buildings, or typical spaces to communicate to the client what the next project could be [I-6].

Most important, mockups are usually done in healthcare facilities to test operating rooms, patient rooms and nurses' stations and ensure all equipment, medical gas delivery, and utilities can properly reach and take care of patients. Digital simulations are usually very valuable to check that relationships are proper and to get the approval from the end users: doctors and nurses. For example, the sightlines are crucial in visualizing the patients from the nursing stations. User group meetings occur early in schematic design phase to discuss sightlines and position of medical equipment in interactive work sessions with architects, engineers and medical equipment manufacturers [I-9].

Engineers can also benefit from virtual mock-ups if this technique is used to mock-up some unusual geometry and analyze how building components fit together in space [I-11]. Marketing aspect for clients is also important especially in high end projects where taking a virtual walking tour of building with various interior schemes can yield better sales in the end for the investor [I-16]. At the same time, it is good to keep in mind that full size mockups cannot sometimes be simulated realistically on computer, and the software and hardware might need to advance for virtual mockups to be a full success [I-15].

5.1.5 Site Analysis

Site Analysis is defined as a process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project. The site data collected is used to first select the site, and then position the building based on engineering criteria (CIC, 2009). Only five design offices mentioned potential usage of BIM for the purpose of site analysis (27%), and a large number of interviewees were not even sure exactly how to use BIM for this type of analysis. However, they perceive tremendous potential in doing calculations, orientation studies, topography, modeling existent and future underground utilities, etc.

Sometimes site analysis is more part of environmental or civil engineering and not performed by architectural designers but outsourced to consultants [I-10]. Available software that can take part in site analysis is: Google Earth Pro, Geographic Information System (GIS) [I-12], Ecotech, Sketchup, Geopack Bentley, and Autodesk Civil 3D [I-18].

5.1.6 Engineering Analyses

Engineering Analysis is defined as a process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications. Development of this information is the base for what is passed on to the owner and/or operator for use in the building's systems (CIC, 2009).

BIM model as a virtual representation of a facility with its digital database enables various engineering analyses. These analyses and performance simulations can significantly improve the design of the facility and the energy consumption during its lifecycle in the future. Audit and analysis tools (Tardif, 2008) play a key role in analyzing building information models or adding to the richness of information in a model. Applications typically focus on one analysis area such as structural analysis, energy modeling or mechanical analysis.

5.1.6.1 Structural Analysis

Structural Analysis is defined as a process to develop analytical structural representation of a building model, document the information needed for the third party analysis application and integrate it with the structural design model (CIC, 2009). This BIM use, as part of various engineering analyses, was mentioned mostly by AE firms or specialized structural engineering firms. Usually, this service is outsourced from architects to consultants. Currently structural analysis cannot be done directly in the BIM authoring software, but by using some of the external applications or a 3rd party software since there is no direct way to do analysis and make changes in the authoring software [I-15].

There are several software applications that support BIM for structural analysis: ETABS/SAP, RAM Structural System/RAM Advanse, RISA, STAAD, ROBOT, etc (Khemlani, 2007). With BIM, the analytical and the building models are created simultaneously, thereby improving workflow and reducing the chances of error. Without BIM, individual models must be produced to initiate each type of structural analysis. A common complaint of structural firms is that their highly educated staff spends too much time transcribing information from one software package to another, configuring various analytical models for input into different analysis software applications, and then manually coordinating the analysis and design results with documentation (Autodesk, 2008). Integration of structural analysis with BIM can drastically improve documentation of design information and facilitate the collaboration between the architects and the structural engineers.

5.1.6.2 Energy Analysis

Energy Analysis is defined as a process to predict energy loads and usage in a building and to provide multiple alternatives and strategies for better energy performance (CIC, 2009). This type of analysis was done even before BIM emerged in the AEC industry, but usually too late in the design process to incorporate the results of the analysis for life cycle cost evaluations and value engineering. There is an abundance of energy modeling and analysis software. An extensive list of available applications can be found online in the Building Energy Software Tools Directory (see References). The software most frequently mentioned and used by the interviewees was: Ecotech, IES, and Green Building Studio. These tools try out different design scenarios and examine the energy model change [I-7] while decisions about shape, orientation and fenestration pattern are made to fine tune the design. Ideally, the energy modeling tools should be in hands of designer, since often decisions are made quickly in design before energy analysis results can be even brought on board [I-16]. Climate Control software is another application offering basic energy modeling information for site conditions with option to download all wind, rain and sun information for the site. Adding those tools to the BIM model, as the design progresses, aids tremendously site analysis and sustainability efforts [I-18].

5.1.6.3 Lighting Analysis

Lighting Analysis is defined as a process in which various lighting scenarios are explored to determine efficient use of daylight and reduce lighting energy use for the optimal building performance (CIC, 2009). This analysis is considered to be part of engineering analysis and can be also part of sustainability evaluation: however it was not further elaborated on by the interviewees or part of their expertise. Some BIM tools for lighting analysis are still very rudimentary, but when they become more integrated in one database, more rich capabilities will be extracted out of them [I-7]. This sort of analysis in done independently by lighting designers and consultants, but can be also part of sustainability criteria analysis in order to achieve the Leadership in Energy and Environmental Design (LEED) Green Building Rating System^{TM} points.

5.1.6.4 Mechanical Analysis

Mechanical Analysis is defined as a process in which various scenarios are explored to determine efficient use of mechanical systems (Heating, Ventilating, and Air-Conditioning –

HVAC) for the optimal building performance (CIC, 2009). This analysis is not fully developed since mechanical BIM tools are lagging behind the architectural and structural ones. Most consultants choose not to use these tools yet, though they might be experimenting with them. Some interviewees felt that existing mechanical BIM software is not set up yet to work with large projects and it will take 3-5 years for a more integrated design solution to emerge and to build confidence in this software to be used on more complex projects [I-7].

5.1.6.5 Other Engineering Analyses

Many engineering analyses which can be performed might have not been mentioned in the expert interviews, since they were rarely done, still not well developed, unknown to the interviewees or maybe just done by their consultants depending on the project requirements (i.e., acoustical analysis, etc). For these analyses, a category “Others” is added to the taxonomy of BIM uses in design. Please refer to Figure 7-2 or Appendix E for more details. Some of the possible other analyses that can be done which have been referenced in literature include:

- Earthquake Analysis,
- Fire Protection Analysis,
- Acoustical Analysis,
- Forensic Building Analysis,
- Moisture Intrusion Analysis,
- Microbial Investigations, and
- Infrared Analysis.

5.1.7 Sustainability Criteria Analysis

Sustainability Criteria Analysis is defined as a process in which all sustainable aspects and features of a building are tracked in order to obtain the desired sustainable certification by condensing various criteria analyses into a single database (CIC, 2009). This analysis is done by almost all interviewed design offices and it is part of their everyday practice, but most are doing the evaluation the traditional way and have no full BIM capabilities yet in this area [I-4]. Energy and lighting analyses are mostly used to complement sustainability evaluation and secure the Leadership in Energy and Environmental Design (LEED) points [I-7]. Though sustainability and energy modeling start to be core beliefs of the interviewed companies, with all projects turning green or having a sustainable component to them, software is still disconnected from the rating system and reporting points. One interviewee stated that no sustainability evaluation can be done in one model nor can all the points be recorded from one model. Some of the obvious obstacles are how to do innovation points or thermal comfort points when survey results are needed for these [I-8]. Autodesk is currently working with the U.S. Green Building Council (USGBC) on unique software to track all the sustainability points [I-10].

Another interviewee stated that since the technology does not have the capability to do the environmental analysis for the sustainability efforts, design offices combine available software capabilities with spreadsheets to keep track of the achieved points. For example, a tracking sheet in Autodesk Revit can be used for certain points while Ecotech is utilized to confirm rules of thumb, building orientation, do comparative cost studies, thermal analysis, etc [I-15]. Also, an external database can be used from which designers can pull pertinent information about systems and products into the BIM model. Instead of building the information into the content, designers can outsource the sustainable evaluation to an external database for analysis [I-16]. This type of evaluation usually requires an internally developed score card; time dedicated to research and deciding with the clients what level of sustainability is desired; design elements that can be achieved; and how sustainability affects the program set from the beginning of the design process [I-18].

5.1.8 Code Validation

Code Validation is defined as a process to check the building design for compliance with project specific codes by using the 3D BIM model (CIC, 2009). This analysis was identified as another important BIM use from the literature, but the majority of the interviewees responded that they are still manually checking codes. Several design offices are trying to move forward in this direction (16% of interviewed firms), but the software is not readily available or trusted for this purpose yet. Solibri Model Checker is software that can be used for checking the project design for code compliance as well as checking General Services Administration (GSA), National Standard and military requirements (calculate egress, circulation paths, etc). The International Code Council (ICC) project Smart Codes can also perform code checking and validation [I-3]. Site and code restrictions should be investigated first and then generate design solutions, but it is important to note that codes are very open to local interpretation [I-5].

Code checking for structural design can be done only in design analysis software such as RAM for steel and ADAPT for concrete, and then the design can be imported back into the BIM authoring tool [I-11]. Egress paths, fire rated walls, ADA requirements, turning radiuses can all be checked or highlighted as they relate to the local codes and help designers to facilitate data evaluation [I-14]. But code officials have not yet been able to use electronic data for code review, though this might be possible in the near future [I-18].

Two more BIM uses were identified from the literature under Code Validation, though not being as frequent or utilized by the interviewees: Emergency Evacuation Planning and

Security Validation. These two BIM uses are not further elaborated, but their definitions are as follows. Emergency Evacuation Planning is defined as a process to plan an emergency evacuation strategy using 3D BIM model navigation and simulation, and have it evaluated, improved and communicated to the client, end users or interested parties (CIC, 2009). Security Validation is defined as a process to analyze building security by using 3D BIM model navigation and simulation and provide better understanding of the security system vulnerabilities (CIC, 2009).

5.1.9 Cost Estimating

Cost Estimating is defined as a process in which a BIM model can offer a reasonably accurate quantity take-off and cost estimate early in the design process and provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns (CIC, 2009). It is one of the unusual BIM uses in the design phase, since it is traditionally done by the contractor or a hired cost estimator, but it is very useful at this stage of the process. A significant number of the interviewees responded that they might be able to provide quantity take-offs from the BIM model and possibly even cost estimating, however they have not been asked to provide those services yet. At this time, it is difficult to suggest new services, since clients are not willing to pay more and the construction market is down [I-4].

One of the questions to be addressed is who is responsible for the data in the model used for quantity take-offs and if contractors would accept the responsibility, since designers provided the information and the BIM model [I-5]. The contractor would still need to do detailed costing, but some tasks which overlap with budgeting and scheduling between design and construction might exist [I-7]. The early cost estimating by designers can be used to back check certain suspicious aspects and offer early estimates of costly items, intended for value engineering efforts. BIM models need to be very accurate to do take-offs, and mutual agreement between designer, consultants and contractor has to be achieved on which building components can be modeled or drafted in more informal fashion. If the BIM model is not intended to be handed off to the contractor, it may not be acceptable later to be used as an estimating, fabricating and contracting tool. This leads to a cultural shift in how we approach the model in terms of the level of seriousness, because contractors have expectations that need to be better understood in order for the model to be shared. At the same time, the legal structure needs to catch up so handoffs can be more smooth in the future. Also, one interviewee felt that the issue of added value of the correctly built model needs to be addressed as added service and fee for the designer, if the model is being built from the beginning for the purpose of being used in construction and operations [I-9].

When estimates are performed faster and earlier in design, the clients can make easier decisions in which direction to go since they are more aware of the ramifications of chosen materials [I-10]. Half of the battle is to get accurate material quantities, which the BIM model can provide. This leads to a better understanding of construction cost during preliminary stages of design [I-11]. Even basic comparative studies can be very useful, like comparing metal panel vs. glass vs. brick.

One of the available software applications, US Cost Success Estimator, establishes the link between the BIM model and the RS Means database. Anytime a change is made and exported to the ODBC database, the calculations can be quickly run again and give the designer a fairly accurate estimate of the cost fluctuations [I-15]. Another approach would be to extract the information from the BIM model and connect it to cost estimating sources externally, and not bring cost data to the model.

Cost estimating gives designers more power and control over value engineering exercises. The estimator usually has no association with visual ramifications of the decisions and focuses on cost of materials only. Designers understand the problem visually and spatially, and can make decisions about cost more effectively, understanding the impact on the environment [I-16].

5.1.10 Phase Planning (4D Modeling)

Phase Planning (4D Modeling) is defined as a process in which a 4D model (3D model with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit or addition, or to show the construction sequence and space requirements on a building site (CIC, 2009). This is the last BIM use identified in the design phase. 4D modeling is usually associated with adding time or schedule to the BIM model and used for construction and trade coordination purposes on the job site. Phase planning can be used to understand better phases of a project and their demarcation when moving people from one to another building in case of renovations [I-7]. Projects can be phased as well by cost loaded schedule, by construction, by occupancy, etc. If a project is fast tracked, then adequate management is needed for architectural scheduling and phasing in case the phasing affects what the space will be at any given time (occupied but needs to be phased in, swing space to move people around, etc) [I-8].

4D modeling can also help the client in interviewing the construction managers on how the project will be phased [I-9]. Phase planning can be done for space utilization when the model is phased to illustrate graphically people moving through the space due to renovations or tenant fit-out [I-12]. This can also be part of the service market for architects, though sequencing is traditionally done by the contractor. Understanding durations of tenant fit-out activities and having additional information can lead to more intelligent decisions in the end [I-10].

Considering space utilization and planning, building managers are always trying to understand the spaces in the building better and how they are being used, but tools at their disposal are typically completely separate from the design information and never up to date and accurate. If space utilization information is part of the BIM model, it can be used for complete analysis of building spaces and the design documentation would continuously be updated. On the other hand, if information can be pulled into external database, then it can be used in the operations or facilities management and portfolio management system [I-16].

5.2 Model Content and Level of Detail

Model content and level of detail are very important questions to address when building a model, since BIM software applications have the ability to embody a tremendous amount of detail. All the information usually never gets added due to this process being very time consuming, laborious, and typically not the responsibility of the designer [I-3]. That is the main reason why owners and designers are struggling on how to define the best level of detail and extensive but limited list of model contents.

One of the next steps in the BIM revolution would be manufacturers providing designers with their product data, moving BIM to a new level. Currently model content carries geometry and some limited information, but few elements have finishes, pricing, specifications, etc. A few manufacturers offered libraries of their products with all selections, but now they are hesitant to share this information due to liability for misrepresentation and outdated pricing. This is one of the biggest roadblocks to implementing product selection in Building Information Modeling [I-5].

Best practices need to be established for using BIM in design offices. Currently, the size of the model can easily become an issue due to the amount of information that can be embedded. To resolve this, components are sometimes simplified, grouped and even drafted with 2D lines and planes. Standards need to be created so that a model component can be detailed for rendering purposes at one instance, but not copied in that complex form thousands of times throughout the project decreasing model manageability [I-6].

One of the design offices suggests the approach of model granularity, which is decided per project by a design team in collaboration with all project participants considering future information needs. Model contents depend on the contract and if the client has a level of detail or granularity requirements. If a greater level of model granularity is agreed upon, more work and coordination efforts are needed. For example, guidelines for modeling the building elements suggested by one design firm: mechanical ducts 10” or more, electrical conduits 2.5” or more, slab penetrations over 6x6”, etc. They made these suggestions since small pipe is rarely a conflict or reason for change order, but ductwork conflicting with the beam is frequently a problem. The contractor would be able to decide on the best place for pipe less than 2” that is economical and works well, or route it differently based on cost. BIM modeling guidelines can be even more rigorous with modeling pipes less than 2”, but it all depends on the contract and agreement with the contractor and owner on the best value approach [I-7].

Another option would be to outsource the creation of the library and model components, and instead of spending internal human resources, spend financial resources [I-8]. The winning combination of the model components and level of detail still needs to be developed. For an example, if a healthcare facility model is loaded with medical equipment components, the BIM model gets very cumbersome. It is important to be mindful of how the model is built, so that a minimal amount of remedial work needs to be done when it is handed off to the contractor, owner or facility manager [I-9]. Another thing to keep in sight is the Construction Operations Building Information Exchange (COBIE) standard and how to enter the data as it is created during design construction, and commissioning, and collect it later on from the model for facility management.

Setting BIM standards is an ongoing and very important endeavor. As owners get more sophisticated and project requirements increase, the future might bring even more detailed BIM models than today. Since the ultimate goal would be to have one model started by a designer and shared along the way, the model needs to be setup properly from the beginning and be more robust if serving more groups (architects, consultants, contractor, subcontractors, fabricators, manufacturers, facilities managers, etc). Currently designers and contractors rarely share the model or have handoffs. Therefore, designers may take shortcuts while modeling because of time constraints and less requirements in place [I-10]. For example, structural BIM model contents would depend on the objective. If a model is used for conflict avoidance, only major structural members defining the geometry of the structure would be included. No mesh or rebar in the concrete would be modeled in this case, since it does not affect the geometry. If the model is developed for construction purposes, then it may have every piece of rebar and all these elements need to be smart and carry properties or information. The model in this case would be much more complex, and the level of detail and the file size would increase dramatically. But these more comprehensive BIM models are currently hard to find. It is in the owner's best interest, however, to invest in this new BIM technology. If a very precise model is provided, everyone would have the same information, and the bids on the bid day would be much tighter [I-11].

The BIM applications are setup in a way that more information is required than the client actually needs or the designer is eager to share. The decision of when to stop modeling has to be seriously considered to avoid more exploration and technical development, getting lost in details, and doing more work than is required for a successful project. This is one of the initial struggles of designers when a project is started in BIM [I-14]. One of the design offices interviewed supports a common sense approach and has a rule of thumb about what to model and what to draft instead. They previously aimed to model everything, but the BIM model got too complicated, slowed down and had performance issues. If the manufacturer's components are used, caution should be taken since the abundance of information provided and very precise modeling can slow down the model and decrease its manageability [I-15].

Another approach would be to have a central library built with generic content, not manufacturer specific. Each project would track more specific information at a project level and not a master central library level. A special group can be formed to create content only based on the staff feedback and project needs. An interesting solution has been developed by McGraw Hill and launched in May 2008: Architect's Design Studio tool (www.architectsdesignstudio.com). This BIM application contains external manufacturers' database with product information, not a library of objects. The BIM model is queried, exported to Architect's Design Studio online, and all the building components are organized in a search for a good product match. At this instance, a designer can explore all manufacturers who can provide that product as part of the database, including the cost data. When the products are chosen, their attributes and information can be easily taken back to the model (depending on the application). This seems to be a very good solution to model content when you start generic, explore, make decisions, and add information back to the model to continue with design development [I-16].

5.3 Modeling Process and Software Applications

The process used to create a model was described briefly by each interviewee. Software applications were also mentioned and commented on, however, an extensive list of currently available BIM software can be found online under specific vendor names.

Design office No.1 [I-1] decided to cross train its staff on both major BIM platforms now available (Bentley and Autodesk), which gives them more leverage between these two software providers. The staff can move laterally between the two and play out the strengths and weaknesses of both. So far this design office has been sharing the model in a design-build project delivery, though the model is strictly marked for informational use only. BIM model uses, type and quantity of information included, are tracked when it goes into construction [I-1]. In order to share models, a unified approach is recommended due to interoperability issues [I-2].

Some of the most frequent software applications used are: Triforma, Microstation (Bentley), AutoCAD, Architectural Desktop (ADT), Autodesk Building Systems (ABS), Revit, Navisworks (Autodesk), Archicad (Graphisoft), Gehry Technologies Digital Projects, Integrated Environmenttal Solution (IES), Ecotech, Green Building Studio, etc [I-7 and 8]. A good portion of design offices have built templates from which they start their projects in a form of customizing a standard BIM file with certain wall types and materials uploaded, and have the other ones erased [I-12]. Design offices make a distinction between full BIM (social BIM) implementation when the model is shared with the contractor, and BIM light (lonely BIM) when the model is used just for conflict resolution. The contractor in this case never sees this model or benefits from it, but possibly is constructing his own model for coordinating the trades [I-11]. The AEC industry is slowly moving towards a social BIM concept in which models are shared and handed off from designers and consultants, to contractors and facility managers at the end covering the whole lifecycle of the building.

5.4 Team Competencies

Various team competencies were listed as important by the interviewees. Their answers were summarized and conclusions are offered in Chapter 7. Solid BIM training is considered to be one of the crucial competencies to be successful in BIM implementation. Senior designers have the design and construction knowledge, but might not know the software, while the young staff is comfortable using the software, but seriously lacks the building experience. Synergy of the team in this time of change is very important [I-7]. No designer can operate by himself since teamwork is essential and everyone becomes connected with the rest of the team [I-6]. People need to be brought together and start team building from day one, since decisions made would impact everyone down the line, internally and externally [I-10].

Company management needs to understand BIM on both a corporate and strategic level. Project management and senior staff need to make a cultural shift from drafting to modeling. More collaboration, verbal and digital communication, is happening in the same database at the same time, so there is a necessity for everyone to be a team player [I-8]. Database management is offering a different approach to design. The project is structured using worksets, and a designer is having other coworkers locked out of his workset when modifying the project database [I-9].

Team composition also changes, given that a smaller number of more experienced people is more effective on a BIM project. A number of interviewees agreed that more senior staff is needed up front to get the model setup, get going in the right direction, and make serious decisions early on in the schematic stage of design. Staffing level, then again, is more of a horizontal line, there is no more adding staff later on since the staffing is much more uniform [I-11].

Some of the listed skills are: problem solving, positive attitude, flexibility, collaboration, communication, coordination, and knowledge of design disciplines and design tools [I-12]. Everyone needs to be trained in BIM software, have a consistent understanding of the technology and apply it in equal fashion throughout the team [I-14]. Agreement on how much to model and how much to draft along with model setup, and a concept of work sharing are crucial after proper training. Every change made can and will affect the entire team, which raises the question about liability [I-15].

BIM gives the opportunity to better manage the project team and a better way to mentor, since senior staff is spending more time with junior staff as the model is progressing [I-16]. Due to the change in practice, it is imperative for senior people to lead the building technology effort. In order to build a model, construction knowledge is a must, and nothing can be hidden in the model like in 2D drawings. Building the model virtually is like building the project and the knowledge of building technology is required. Most design offices stressed the importance of a senior designer sitting with junior staff, and while they are running the model, the senior person's input moves modeling faster, making quick decisions about products, coordination and model contents. To achieve a smooth transition from college to the working environment, it is up to higher education institutions to teach young designers building technology and not just design [I-18].

5.5 Legal, Insurance and Contractual Considerations

Legal, insurance and contractual considerations were identified by the interviewees as one of the most important issues to address with the implementation of new technology. Many design offices are adding some BIM contract language to limit their liability, to start by using the BIM model for information only. In that case, after the model is handed off, if anyone is making changes or modifying the design somehow, the design office is not responsible for those changes [I-1].

One interviewee stated that sharing drawings in the form of AutoCAD files (DWGs) usually went along with a disclaimer, electronic paralegal agreement, or the drawings were delivered in read only (DWF) format where the original can be altered, but the file cannot be saved. BIM needs to have a similar approach with a disclaimer on how to share the model. However, many clients are not requiring BIM models yet, and so there is no urgency to deliver and protect the model. However, if everyone is sharing the benefits, everyone needs to share the risk together [I-4]. Responsibility has to be allocated when models, information, and data are shared. Until this is resolved, BIM model will not be shared with the contractor, facility manager or owner unless the barriers are removed. Nowadays, owners mostly are still not using the data provided in the model, and since software and file formats become out of date fast, migration policies for data received need to be in place to handle this transition [I-5].

The American Institute of Architects (AIA) offers a contract for sharing the electronic model, but there are no precedents available yet. BIM contract language started to appear, but most of it is untested so far. The legal system has not fully reacted yet, given that case law drives contracts and someone has to be on trial first for contracts to fully develop [I-7].

Contractual relationships are needed for teaming and collaboration. If the contractual relationship exists with the owner only, then not everyone is on the same team at the end of the day. Handing the model over is still considered high risk, because responsibility for the data is not defined yet, which is against open standards, collaboration and communication. A better environment is created in design-build relationship, when the designer and contractor are working together before construction documents are complete. Owners, who have a long term investment in lifecycle maintenance of the building, create requirements knowing that BIM has to be incorporated in contractual relationship [I-8].

One interviewee stated that the AIA has an ongoing effort to utilize integrated project delivery (IPD) and share the profit pool as a way of the future. Using BIM is another vehicle to make this change in project delivery happen. In this case, everyone is on the same team and usual frictions between project participants are not that evident. IPD offers a different legal structure from anything before, in a form of true partnership, and traditional fighting is eliminated or reduced. Early interaction with the contractor, his engagement and intervention are very beneficial. If the designer and contractor work together on constructability and market forces, designing a project that the owner cannot afford can be avoided. The BIM model started by the designer is usually not used for fabrication purposes, since a different level of effort would be needed and more serious approach to building the model. Many of the interviewed designers voiced that if the model is handed off and the owner is getting the benefits of the early intelligence, design offices would like to expect nominal additional fee for the model creation as compensation [I-9].

One interviewee [I-10] stated that there is no case work to show that BIM projects are more or less risky, therefore the insurance rates are not impacted. BIM is actually seen as being less risky down the line, because the conflicts that tend to lead to claims are avoided, and possibly the rates would be reduced for everyone. Though there are no insurance impediments, the questions about model ownership, control, responsibility and defining risk have to be addressed sooner or later [I-11].

Electronic information in a model is authored, signed and sealed, and if changes are made, there are records of them. Designers are still obliged to provide 2D drawings as contractual documents, but for them to be replaced by the model, it is very important for different platforms to be completely compatible, work in any format and export generic BIM that can be imported or exported to any other BIM software [I-12]. Industry Foundation Classes (IFC) might be the answer to bridge this gap, though as the basic bare bones model; it is the lowest common denominator between various BIM software applications [I-15]. New contracts will need to be drafted that are specifically incorporating BIM technologies and the limitations the client would have to adhere to if receiving the model instead of set of construction documents [I-14].

BIM implemented in design offices can lead to less risk since drawings are tighter and analyzed better. However, when the model is being shared, there are a number of unknowns and no strong separation between design and construction. Contractual language should help develop partnerships between design and construction team, and long term business relationships should be built with contractors that have the same mindset and attitude towards new technology implementation [I-15].

To conclude, the general consensus was that traditional processes carry more risk than the added risk of information sharing in BIM. Contractors and owners are starting to realize the value of the BIM model and how it can help them in their everyday practice (reduce the time needed for estimating, help with tight schedule, etc). While the BIM model is strictly used to create a set of

2D construction documents, no special legal or insurance considerations are needed to cover the use of the model except perhaps a supplemental agreement [I-16]. When the model is used to its full capacity, legal and insurance considerations should be changed [I-17].

Chapter 6

BIM Impact Analysis

This chapter contains the results of the 18 interviews related to the impact of BIM in the design process. The chapter is organized by topic area based on the questions asked to the participants of the interviews. It is important to note that the information provided is based on interview responses and has not been validated through detailed research on each item.

6.1 BIM Impact Analysis

Most of the interviewees stated that their design offices did not perform an official or extensive analysis of the impact of BIM on their projects. Some of the responses received are shared in the following paragraphs.

Design office No.1 [I-1], after finishing three projects using BIM for design coordination, so far has no RFIs related to conflicts or document quality, but only on site existing conditions and clarification of specifications. However, just because the model was handed off as collision free, the contractor does not necessarily have to build it that way. When this design office started with BIM implementation, the productivity dropped 35%, but after 4-5 months (and not the anticipated 6 months), it was back at the same level of productivity as before, and the second project with the same design team noted an increase in productivity. This design office decided not to charge more for using BIM. It had to shift internal funding around and take less fee to cover the inefficiencies, but in the end, it did break even and exceed projections. So far no losses are reported in year 2007 for the projects done in BIM.

Another design office had only anecdotal data to report with 80% decrease in clashes, savings in cost for rework, time savings and getting RFIs answered in two weeks. There was also reduced productivity for a period of time due to training [I-2].

Interviewee No.6 [I-6] reported that their design office is keeping track of everything and would eventually do a back analysis. They have been working on only one large BIM project for over a year, and it is hard to compare this project to any other due to its size, and much easier to compare projects of the same or smaller size [I-6]. Design office No.7 [I-7], on the other hand, can compare two projects similar in size, type, scope and schedule. Both projects are healthcare facilities, and one is designed in BIM and the other one conventionally. Comparison between these two shows that more time was spent in schematic design in BIM approach, and the other one spent more resources in construction documents phase. However, at the end, both projects made a profit, though having equally experienced teams who produced differently, but the difference in outcomes was not noticeable. BIM project team expected to pay a penalty for the learning curve, this being their first project in BIM, but they learned quickly, and this was avoided [I-7].

Design office No.8 [I-8] has performed a BIM impact analysis on small projects from 2000 to 2004 and while some projects were successful, some failed on several levels. Hours to complete the project were used as a metric on these projects. Virtual Design and Construction (VDC) initiative was started on the corporate level to sell the business model to the clients and show the advantages of BIM [I-8]. Designer No.9 [I-9] also confirmed that most data is anecdotal. Conflicts are resolved ahead of time, before ordering and fabrication, which tends to reduce the friction between parties involved and the rate of RFIs is much lower.

Data from the design office [I-12], tracking staffing on their projects, show an increase of 250% in staff later in the design phase on five different projects having the traditional approach. Conversely, BIM projects have more expenditure (cost, time and energy) in the beginning phases, but it decreases as design progresses, and new staff is never added to the job. The design team has to work consistently together, know the job inside and out, and have ownership of it. Staff added later on has no investment in the job, they do not know it well and it is not very efficient, so the quality of work goes down rapidly [I-12].

To conclude, most design offices have no BIM metrics yet. They are just assuming the impact of BIM based on project data and tracking hours [I-15]. Comprehensive study or detailed analysis is rarely done, but projects' performances are tracked for possible future investigation. Very few projects have not been profitable, and most are as profitable as before if not more [I-16 and I-17]. BIM metrics can also be tracked on the implementation side by monitoring the number of people using BIM, number of hours spent designing in BIM, percentage of projects done in BIM, etc [I-18]. When formal metrics are established, it will be easier to measure and compare the quality of BIM implementation within a design office on a corporate and project level.

6.2 Impact on Cost, Time and Quality

The questions on BIM impact were asked separately for cost, time, overall project delivery time and quality. Some of the initial benefits mentioned were: increased efficiency, more time for added services, better quality, completeness of drawings, and extending BIM to operations.

6.2.1 Cost

For BIM to be successful, it has to be made cost effective into the future. Though the cost will be changing with time and circumstances, costs associated with BIM as mentioned by interviewees follows. Construction and change order costs are going down due to the conflicts detected and resolved [I-2]. Initial cost of hardware, new software, training of staff and keeping them up to date is very important to consider and increasing [I-2]. Conversely, unit cost of professional design services is decreasing, but return on investment (ROI) is considered to be high since 50% less staff is required on a project. Staff spends less time to finish a design, achieves better accuracy, and delivers projects on time or ahead of time with less RFIs [I-3 and I-4]. Architectural practice in general is speeding up; projects are fast tracked, and designs can be changed quickly with reduced manpower [I-6].

Large projects in BIM require strong strategic and team management with a high level of collaboration. More resources are needed to create the database and manage cooperation between team members; therefore it is hard to calculate benefits of timing, cost, etc. However, even on large projects, a dramatic increase in efficiency and decrease in costing and errors and omissions (E&O) is noted [I-8].

Better coordinated construction documents lead to bids for different trades to be under budget and not so many requests for information (RFIs) are issued during the bidding process. Smaller teams are formed for BIM projects, but individuals as part of the team are pricier. Conversely, the schematic design phase becomes more expensive due to the added burden of modeling more information and training the staff. As a result, it has been suggested that the design fees have to be restructured to affect the reality of building the model. Design contracts need to be revised to truthfully reflect the level of effort of building a model, possibly split the design fee in the following way: 25% schematic, 25% design development, 25% construction documents and 25% construction administration. The owners should not object to this change, since they are benefiting the most by receiving better information earlier in the process and having a chance to intercept cost issues before construction [I-9].

Cost of design in BIM decreases for the owner by having to address reduced issues in the field. Nevertheless, cost increases for the designer by having to model the project and include more information than in traditional drawings. In the end, if the project costs less and is delivered faster, additional value is provided and the designer should be compensated. The amount of this potential additional fee is still significantly less than the value the owner is obtaining from the BIM model [I-11].

Cost is always increased in the beginning of the design process due to the information needed and making decisions. The clients will often change their mind, and the more they do that through construction documents, the more costly it is. If design is better communicated in the beginning and informed decisions are made with increased confidence, the cost of using BIM decreases [I-12].

On the other hand, some design offices find that BIM either does not affect cost at the time since the clients are charged more and the fees are adjusted because of the construction market [I-13] or BIM as start up technology has to cost more and take longer since their staff has to be retrained and make changes [I-14]. Another design office assesses that cost and time spent stay the same in traditional vs. BIM approach. Hardly any project is brought under budget which is just the nature of design and not necessarily the learning curve, and value engineering will always be present [I-15].

It would be valuable to do performance analysis on every project. Though significant costs are incurred due to hardware, software and training, at the same time, there is no question that the design office is more productive and effective as a result [I-16]. Any change brought to practice requires learning costs associated with it [I-17]. Losing some productivity time and fee to make the implementation happen is a reality. It is crucial to make sure that the project team has an execution plan in place or significant time can be lost if the model has to be rebuilt [I-18].

6.2.2 Time

After implementing BIM, one of interviewed design offices found that at a traditional 35% completion, they were at 50% developed design and that their schedule was reduced. As a result, decisions have to be made earlier by clients or tenants which is harder to do [I-1]. The amount of time for completing tasks is decreasing [I-3], especially in the construction documents phase [I-9], leading to the overall design schedule being shortened. The design team can also be more proactive and share more information with clients and consultants in the early stages of design [I-4].

In general, time is positively affected from the construction schedule point of view, but design can take longer or shorter depending on people's expectations of BIM and modeling [I-5]. The enormous advantage is that clients cannot read or understand 2D drawings well, but presented with a 3D model, they tend to change their mind less at later stages when changes are very costly [I-12].

Conversely, some interviewees disagree that time is saved because every project is unique and different [I-18]. Additional time and money has to be spent on gearing up the design office or company to execute BIM, while time savings can be more prevalent in the construction administration phase. A benefit is that more time is spent exploring design and investing in quality design, and less time is wasted updating changes through the set of disconnected drawings [I-16 and I-17].

Project delivery time is marked by a reduction in overall delivery time, using time in the beginning to eliminate conflicts [I-1, 2, 3], and the ability to completely build design decisions into the model [I-5].

6.2.3 Quality

The quality of projects generally increases with BIM implementation and this is supported by most interviewees. Quality control and assurance of models can be done internally or by an independent review team, and this is part of a model manager's responsibilities to make sure fully coordinated drawings are submitted [I-1].

For having good quality BIM model for operations and maintenance purposes, an as-built is needed for every building component over 2" in size. According to one interviewee, having a building model for operations can drive the cost of design and construction though the quality of project delivery would be obviously better. A balance between cost and time spent is critical for achieving quality [I-2].

Another interviewee agreed that quality improved since BIM software does the coordination for the design team, conflicts are caught immediately, and as a result there are less RFIs [I-6]. Though the quality of drawings increased due to better coordination, there is still a lot to prove to clients about the quality of construction documents and models [I-9]. Increased quality of BIM models will lead to owners using models for facilities management and operations purposes, and eventually requiring and driving the implementation themselves while reaping the benefits [I-10].

To conclude, if BIM is fully implemented, quality of design would prevent many time and cost delay issues [I-11]. Last minute adding of staff, which is not fully invested and committed to the project, would be avoided as well [I-12]. Only one respondent disagreed that the quality increases significantly, since the overall project delivery quality is still lacking [I-17]. Another confirmed that only the quality is improved with BIM realistically, not cost or time. When design offices absorb BIM completely, project quality will decidedly improve within years' time. Projects will cost less money, be done faster, while keeping the constant level of quality [I-14].

6.3 Design Staff Composition

One third of the interview respondents said that the composition of design staff did not change. The rest explained in more detail how the staff changed over time with the introduction of new technology. With moving to BIM, technologically advanced staff is more in demand, and advantageous is to have a more technological and less academic background. Changing practice and technology present mostly a challenge to motivate and lead individuals through the process. Crucial elements are leadership, management, mentoring and incentives to be successful in accepting the change [I-2].

The individual creating the model has to have a high level of knowledge of architecture and building systems. No longer can entry level staff be given drafting tasks that were far below their knowledge and skill level anyway and did not enhance their professional development [I-3].

Composition of design staff in office No.4 [I-4] did not change much since everyone on the team had to be educated in BIM. They started with two champions on the team being training in the basics of BIM. A special in-house tutorial was set up for different project types in the length of 16-24 hours. The tutorial was intended to be absorbed completely after being covered for three times in a period of a few months. When a new project begins, one champion with 1-3 novices works closely with an Applications Manager on adopting new software and workflow [I-4].

During the transition to BIM, one small design office cut the number of their staff by 70%. The remaining designers had to be more experienced since designing in BIM represent more of a decisions process and not a drawing process [I-5]. Large design offices may completely restructure the design staff by having BIM leaders, BIM coordinators, Model managers, and BIM users [I-6]. Other design offices kept the same roles of coordinators, technicians and designers, but predict in the near future a total collapse of the hierarchy when BIM tools become more intelligent and automated. Organizations may become much flatter and not have the same hierarchy as before [I-7].

A company can also decide to outsource the modeling or creating the model components. In that case, the approach on a global strategic level changes, but the design staff composition may stay the same [I-8]. Or lead CAD individuals become a Model Master having the similar function of keeping the files and model in order. These personnel have to be meticulous, disciplined, technologically savvy and ever forward [I-9].

Interviewee No.10 predicted the change would happen in time with having no drafters just designers, and also having specialty occupations (energy modeler, prefabrication person, etc) [I-10]. Until BIM is fully implemented and not just used for conflict avoidance, another engineering design office does not plan on changing the composition of its design staff. When this happens, a BIM Model Manager position would emerge for each job and personnel will be in charge of keeping the model up to date and correct at all times [I-11]. Two other design offices also did not change staff composition due to BIM, but either have fewer people working on a project, or personnel changed due to economy or limited computer knowledge [I-12, 13].

Another large design office has corporate and local BIM managers who are compensated for their leadership role and technical proficiency in this particular area. Their scope of work is one of project architects with some project manager capabilities, essentially utilizing the technology and overseeing the BIM projects in the office [I-14].

Design office No.16 has a lead modeler on every project that coordinates the disciplines and is responsible for maintaining and auditing the model. A project architect before, this individual is knowledgeable about BIM, how it changes the process, and is looking for opportunities to extend the information outside of the project team and mentor the junior staff working on designing tasks now vs. rudimentary drawing tasks before [I-16].

The last two design offices interviewed shared that BIM did not affect their staff composition, but traditional design phasing would change as a direct result of BIM. Designers have to allow models to be more accurate and develop it in such a way to lead the decision-making process [I-17, 18]. To conclude, while some design offices completely restructured their staff, others did not have major changes so far, but predict and expect them in the future as BIM implementation advances.

6.4 Critical Success Factors

Critical success factors are listed as discussed by the interviewees. A summary is also provided in Chapter 7. Factors perceived as important in BIM implementation are both on the company and project level and listed in no particular order.

An organizational change management and motivational challenge for staff is crucial in changing practice and implementing new technology [I-2]. Upper management must strongly support the BIM implementation. Staff has to be open minded, and willing to research and learn new technology. Previous experience in CAD drafting is not necessary, and actually proved to be detrimental to accepting BIM [I-4]. It is good to keep in mind that the BIM model has to be set up early with the model contents defined and all disciplines involved in the process. Limited application of BIM leads to only limited reward, and full benefit is gained only out of doing full BIM [I-1].

Some of the critical success factors are collaboration, communication, data collection and analysis instead of drafting, best practices setup, training of staff, raising the understanding of BIM, and resolving how to operate in this global change [I-5, 6]. Timing of training shortly before the project starts along with setting up all the standards is important. Capability and flexibility of the team, quality of their knowledge and how well they communicate with each other are deciding factors of success [I-7]. For BIM to be accepted and embraced by clients, the design office must meet their expectations in a reduction in claims and achieving better building designs with sustainability, life safety, security, aesthetics, high performance, and preservation [I-8].

Senior buy-in, consensus building in organization on implementing BIM and owner requirements are driving BIM, and also experienced people early on the project, who understand the business and can control and use the software [I-9, 10]. An understanding of software limitations and investment of senior people upfront to make sure the model is a good working model from day one are recommended [I-11]. Designers and architectural interns have to know building technology, construction details and be able to think three-dimensionally. Some might be better at design, and some in technical aspects of drawing, but modeling is merging the two [I-13].

BIM software is very different from Computer Aided Design and Drafting (CADD) and the users should not try to make it work similar to CADD. The learning curve is unavoidable, and though more time has to be invested upfront, that effort is rewarded later on when working on construction documents. Proper training of staff is critical to success. The training has to be incremental, high quality, project focused and with continuous commitment. It is not beneficial to do the training all at once, but divide it by a week or two. Three months are needed to get comfortable with BIM software and another three months to get confident [I-15].

A practice driven approach, flexibility and adopting changes are very important since BIM is not just a technology [I-16, 17]. It is commendable that the process is pre-planned possibly with a BIM Execution Plan. For BIM modeling to be successful, team members must meet, strategize, think out the process and delivery, and then execute it. Rather than BIM software forcing designers to change the process, the software should be modified to recognize the process and make it work [I-18].

To conclude, the key to success is in a strategic approach to implementation on both a company and project level best accompanied with a BIM Execution Plan.

6.5 Issues and Concerns

The issues and concerns raised by the interviewees are included in this section. Some of them can be addressed now and some might be resolved in the future.

Software applications are an issue since they are not 100% interoperable or usable, critical model size is limited, and there are limits to the number of model files and people working on the model [I-1].

Another matter the owners are struggling with is if the benefit of BIM is worth the cost for new construction. The owners want to ensure that they are receiving the benefits if paying for the cost of BIM [I-2].

Since junior staff cannot receive just drafting tasks anymore due to the nature of BIM software applications, their lack of experience in making decisions, and limited construction technology knowledge is increasing the liability [I-5]. Also experienced but poorly trained people can make errors that can compound themselves if not addressed quickly, since all components are linked and dependent on one another [I-6].

Losing control of information is one of the major fears of designers since the one who has the information has the power. Ideally designers would like to run the BIM process because they are giving away the information, and construction managers would rather have the control over BIM, but ultimately the owner gets the information. While building the model, design decisions have to be made faster, but getting the information from the client can considerably slow down the process. All technical issues must be addressed on time like interoperability of software, size of the model, along with legal aspects like changing the contract model sharing language [I-7].

Business implementation models for BIM from planning to operations do not exist yet. This business model would be able to ease the transition of handing down the information without concern regarding giving away the data [I-8]. For designers and contractors to be able to collaborate and work on the same model, it was suggested for designers to be compensated if the model is built in a manner to be used for construction and operations purposes in the future [I-12]. Libraries and components are still missing to modify and use in the model but hopefully will be more developed shortly [I-13].

Theoretically only good things will come out of BIM technology. The fact that the building is virtually built and modeled in 3D cuts down on the number of RFIs, mistakes in construction, and a lot of waste and issues that were not dealt with before [I-14]. On the other hand, BIM authoring tools make it easy to do a bad building or design, and switching to BIM is mainly an educational issue and alleviating the resistance to change [I-15]. Other mentioned issues were: sharing the information outside of construction documents, deciding who has control of certain model elements and who takes ownership of the model at the end. Model accuracy is really important since information cannot be hidden or dimensions forced like it was possible in CAD drawings [I-16, 17, 18].

To conclude, many different issues and concerns are attached to BIM implementation, but with time and experience many of them can be resolved or properly addressed.

6.6 Risks

A list of risks for BIM implementation can be divided in two groups: duty risks and unknown risks. Duty risks are the ones that designers knowingly assume based on signed contracts and professional licensure. These risks are frequently mistaken for unknown risks without distinguishing them. Duty risks cannot be changed after executing a contract, but unknown risks can be adjusted by increasing knowledge and carefully executing BIM [I-3].

One risk is to choose the wrong type of project when starting BIM execution and changing the practice to BIM [I-4]. The level of BIM understanding throughout the team has to be the same, as well as expectations set by clients and subcontractors. Considering modeling and model components, manufacturer’s product data supplied as objects can potentially be incorrect and represent liability. If these products are not modeled according to the company’s standards, the company or design office needs to create its own objects and input their information to have model integrity, avoid corrupted drawings and incorrect data [I-7].

One of the most important risks to consider is legal protection not being set in place yet when sharing the model which was mentioned by several design offices [I-9, 10, 11]. Solutions to this could include a single purpose entity approach with an agreement not to sue each other, as well as incentives like bonuses and rewards. If successful with BIM implementation and with legal protection in place, the project team will be further driving the use of this new technology [I-10].

Legal issues and liability have to be defined correctly and explained clearly to each of the individual parties [I-11]. Sharing electronic drawings that look right but are not and access to these drawings is still considered a high risk [I-13]. Project managers not accepting the technology yet also represent a risk since they can cancel BIM quickly if they have a bad experience [I-15].

Although advocated as the most appropriate project delivery for BIM, integrated project delivery (IPD) carries a lot of unknown risks. Technology to support this type of delivery system is still immature, interoperability between BIM tools is yet to be developed, and sharing information between distributed teams is still a problem [I-16].

To conclude, companies and design offices are still trying to determine what the real risks are and how to implement the model across stakeholders. Rarely the model is shared and if shared it is usually with a data waiver or exclusion that the model is for reference only [I-18]. All these unknown and known risks will have to be addressed in the near future for BIM to be widely accepted and successfully change the AEC industry.

6.7 Future Industry Trends

Future industry trends predicted by the interviewees were very diverse. These are some of the most frequent responses received.

A consistent trend across the industry is owners making the transition to BIM and raising their requirements for model deliverables in requests for proposal (RFPs). As a result of this trend, designers and contractors are pushed with new technology to deliver better projects, faster and less expensive [I-2]. The European model of architectural and AE firms merging together is possible in the United States, though there are some strong economic factors that may prevent this from happening. Many firms might merge into design build type firms, big conglomerates or join forces into developers [I-7]. The organizational structure of companies and design offices might change at some point due to BIM. Even if the corporate structure does not change significantly, more often there would be teams working frequently together and having mutual trust in IPD. An increase in specialization will also be in order, since people will become highly skilled in certain areas [I-3].

On the fabrication side, manufacturers will provide more and more data about their products and components online, which can be easily dropped into the model, manipulated, providing specifications, cost and comparative cost to enable tighter bids. Software as a result will also need to become more interoperable and compatible [I-5]. Another technology trend is the IFC (Industry Foundation Classes) format that is becoming more robust and a universal format for BIM. Many agencies are working on creating a standard for BIM implementation, in order to have convergence on database standards [I-8].

Greater integration with the owners using the model in their facilities management (FM) software and closer working relationship between designers and contractors are in the future. Many visions are attainable when modeling becomes ubiquitous and all the information is in the BIM model [I-9]. In time, more and more information will be added to the model. As a result, 2D drawings may not disappear, but they might become second to the model and used as contract documents. In the future, much more fabrication is expected from digital models where the building components are built off site, laser cut and assembled in controlled environment, then brought to site [I-15]. BIM will be tied more with operations, facilities management, and into fabrication and the supply chain which might affect the type of architecture due to a lot more prefabrication involved. In this way, the design delivery process will be streamlined especially in an integrated project delivery (IPD) scenario [I-16].

Lifecycle asset management is the next step being considered. Software applications get outdated each year, and archiving is very limited due to constant changes. Vendors have to take some responsibility since the value is in data not software. If software applications get upgraded, the data should be able to migrate as well. As-built files must be kept current and reliable so they are still valuable for operations and maintenance (O&M) in the future [I-5].

BIM is supporting better collaboration with clients, improving communication between different disciplines, and moving forward buildings' designed and construction [I-6]. More virtual communication and collaboration with people around the globe might be happening very soon experiencing virtually and visually building together [I-8]. BIM momentum is building and years from now the AEC industry will change tremendously with prototyping, eliminating shop drawings, and trusting the BIM model. The work force in the future is expected to be versed in many different BIM software applications and switch easily between them [I-10]. BIM will become more prevalent and more of a norm then exception in a few years time, similar to green technologies. Delivering projects in BIM and construction documents replaced by the model are the next big step in BIM development and acceptance [I-11]. BIM used to be a differentiator for some companies and design offices, but in a short time it will become the way everyone does business, especially on the government projects. Design-build (DB) and integrated project delivery (IPD) are emerging as clients' methods of delivery preference [I-12].

Academia is also affected by the necessity to create new curriculum for BIM by having different programs or tracks focusing on virtual design and construction (VDC). VDC offers a more holistic approach and it might replace the term BIM. Academia has an important role to invest time and resources in developing this aspect of the profession and educate young people to use new technology. Leadership programs should be introduced so that students understand not only different technologies being applied, but also how to integrate them and be decisive and effective in promoting the use of BIM [I-14].

Architects have to resume the role of leader of the building process, rather than relinquishing authority and liability by turning their responsibility to contractors. This would involve higher risk but the reward would be greater, since with BIM transparency, designers are able to identify and resolve problems with much greater accuracy which decreases the risks and claims for everyone in the long run. It is up to designers to be more in leadership positions and integrate the information using technology. Information is very powerful and designers can have more control if they decide to reclaim that power [I-14]. Architects were once master builders who knew how to deal with politics, local environment, design and building process. This position was lost a long time ago and there is a potential to regain it with BIM [I-14].

Chapter 7

Conclusions

This chapter provides a summary of the research results followed by core contributions of the study, some limitations that are inherent to the research methods used, and a brief discussion of future research possibilities. The conclusions were made based on content analysis using categorization and frequency of responses given on certain subjects. If the topic was mentioned and talked about by the interviewees more than two times, it was included in the research results and summary. If a topic was mentioned just once, it was not included or it became a part of another topic, if similar, by explaining it better.

Based on 18 interviews with industry members completed and analyzed, and detailed content analysis of available literature on BIM, a taxonomy for BIM uses in design was created and is presented in Figure 7-2 and section 7.2. The taxonomy along with frequencies of use can be found in Appendix E. A broad overview of BIM implementation in design practice was also achieved on the following topics: BIM Execution Planning, BIM Impact Analysis and BIM Future Trends.

7.1 BIM Execution Planning Conclusions

One third of the interview respondents did not have a specific BIM Execution Plan, while others had an informal plan, and only one design office had an extensive implementation plan. This shows an area for potential future development and the establishment of standards and guidelines.

Participants involved in the creation of the BIM Execution Plan are:

- **Senior firm leaders** (partners, principals, board of directors): articulate and support the vision, ensure senior buy-in and create holistic and strategic plan.
- **Steering/Executive committee or Implementation group:**
  a. Corporate BIM manager: leads the company in implementing the technology;
  b. BIM champion/Team captain: drives the process with authority.
- **Management team and key technical staff** (former CAD managers, now BIM leaders):
  a. BIM coordinator/Model master: in charge of the composite BIM model;
  b. Project manager/Project architect: prepares technical plan for the project;
  c. Design team members (designer and consultants): all need to be involved in the creation of the BIM Execution Plan.

Buy-in is characterized as a critical ingredient to get BIM moving forward, but the decision needs to come from the top. Senior buy-in, understanding changes, benefits and risks, and making corporate-wide goal of implementing BIM to establish industry leadership are all necessary and key to success. Broad training in BIM has to take place throughout implementing organizations. Visionary and comprehensive BIM plans are ideally separate for each project and put together by collaborative effort of the corporate BIM manager and others leaders in the office. The corporate BIM manager with an implementation group or steering/executive committee drives the process. The implementation has to be practice driven and not just considered a new technology to employ. Ideally, representatives from all practice groups give their input and help define the goals. When the decision is made to implement BIM, the best strategy would be to start with creating the BIM Execution Plan and procuring pilot projects.

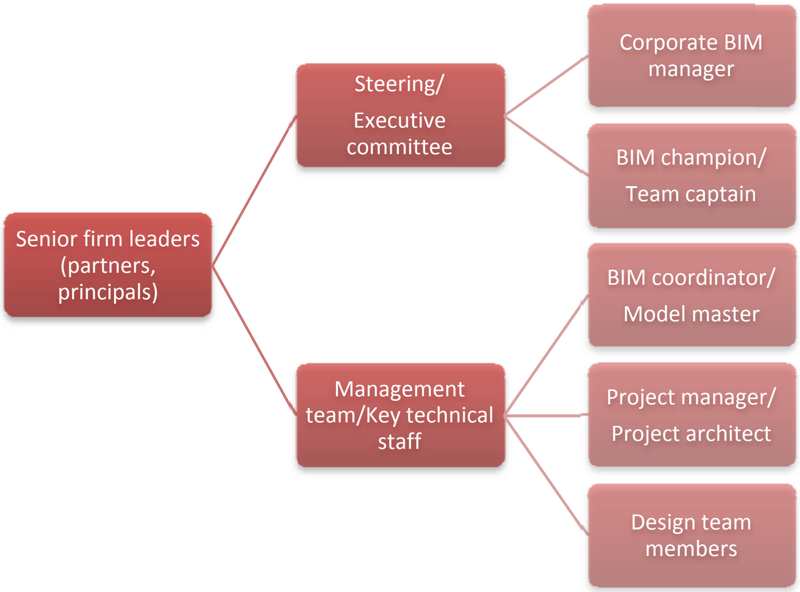


Figure **7-1**: Potential Participants in the Creation of BIM Execution Plans

Decisions to be made in the creation of the BIM Execution Plan include the following:

- The first decision is to gain senior level commitment. Everyone has to be adaptive and come together as a team on this process change.
- The team must also decide that it is acceptable to do business differently. BIM is a tool not the end result or the goal.
- The team must decide to appropriately train the team to achieve a level of understanding of BIM throughout the firm. Start with pilot projects and BIM savvy people to build synergy. A cohesive understanding and acceptance of BIM are essential.

- Create new positions or job descriptions as appropriate to explore new options and move forward with BIM technology.
- Advocate early involvement of the contractor in the decision making process. Collocation of the design and construction team can be very beneficial.
- Develop BIM standards and create a step by step manual on how to execute BIM.
- Decide how to setup the model, how to manage multiple files, share the model with stakeholders and how to select BIM uses.
- Decide on the division of work, worksets, access to the model, legal issues, level of detail, and performance specification items.
- Record appropriate knowledge and learn from previous experiences how to do work in the future, how to train staff, how much detail is necessary, etc.
- Learn to work in multiple platforms, if possible, and agree on software applications, version, and typical granularity or level of detail of the model.
- Start with humble initial aspirations, i.e., a good set of coordinated drawings. Choose a simpler project; decide on the basic setup; and plan how the design team is going to work.
- Market and present BIM outside of the design office, and spread the message to owners, consultants and contractors.
- Explore new capabilities (i.e., prefabrication, advanced energy modeling, etc), new workflows, and different alliances leading to better and more efficient design.
- Set goals on levels of BIM implementation and the number of years to accomplish these goals.

The possible process steps that can be used to develop the BIM Execution Plan are:

- Leverage core competencies and broaden market appeal of the company or design office.

- Align technology with business goals and core competencies to be successful regardless of the specialty.
- Change the mindset from cost based to value based business propositions and aim to produce higher value for the same price.
- Develop a plan on how to train the company or design office and set goal of using BIM on all projects.
- Execute a few pilot projects in BIM and compare them with the traditionally delivered projects.
- Prepare for trial and error in the beginning, since no BIM standards exist thus far. Define BIM and expectations for BIM; develop definition of the model, its granularity and format.
- Hire software representative or 3rd party consultants to assist in BIM implementation. This person should help strategize, assist in developing the models, and do global implementation and standardization plan.
- Setup a plan with software vendors on how to start a project in BIM. Decide how to setup files, templates, troubleshoot, check progress, train staff and address the learning curve.
- Achieve agreement that on certain day or hour the latest model has to be posted on the model sharing (FTP) site.
- Consider outsourcing the modeling if appropriate and allow the design team to spend more time focusing on the information that goes into these models.
- Consider expanding design services with analytical applications (performance, environment, cost, etc.) by using the same data from the models to perform analyses.
- Enable design-build or integrated project delivery by extending the use of data from design models to contractors for cost, constructability and logistical planning, and to manufacturers for fabrication.

7.2 Taxonomy of BIM Uses in Design

BIM uses in design have been classified into 4 categories based on the review of the published literature, and results from the expert interviews. These categories are:

- Design Communication;
- System Analysis;
- Estimating; and
- Scheduling.

The following BIM uses were identified under these four categories:

- **Design Authoring** is defined as a basic BIM use in which 3D software is used to create and develop a BIM model based on criteria that is important to the translation of the building’s design (CIC, 2009).
- **Programming** is defined as a process in which a spatial program is utilized to efficiently and accurately assess design performance in regard to spatial requirements (CIC, 2009).
- **Existing Conditions Modeling** is defined as a process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility (CIC, 2009).
- **Design Reviews** are a group of BIM uses. Design Review is defined as a process in which design is reviewed for constructability, coordination of systems and visualization of spaces and building details (CIC, 2009).
    a. **Constructability** is defined as a review of the building model along with plans and specification to determine constructability of the project and coordinate with other project participants (CIC, 2009).
    b. **3D Coordination** is defined as a process in which 3D software is used to model the detailed designed building components, followed by automated identification of

spatial conflicts between components through a collision detection algorithm. The conflicts can then be resolved by relocating building components (CIC, 2009).

   c. **Virtual Mock-up** is defined as a review of the building model used to showcase the design to the stakeholders and evaluate meeting the program and set criteria (CIC, 2009).

- **Site Analysis** is defined as a process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project. The site data collected is used to first select the site, and then position the building based on engineering criteria (CIC, 2009).
- **Engineering Analyses** are a group of BIM uses. Engineering Analysis is defined as a process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications. Development of this information is the base for what is passed on to the owner and/or operator for use in the building's systems (CIC, 2009).
    a. **Structural Analysis** is defined as a process to develop analytical structural representation of a building model, document the information needed for the third party analysis application and integrate it with the structural design model (CIC, 2009).
    b. **Energy Analysis** is defined as a process to predict energy loads and usage in a building and to provide multiple alternatives and strategies for better energy performance (CIC, 2009).
    c. **Lighting Analysis** is defined as a process in which various lighting scenarios are explored to determine efficient use of daylight and reduce lighting energy use for the optimal building performance (CIC, 2009).

   d. **Mechanical Analysis** is defined as a process in which various scenarios are explored to determine efficient use of mechanical systems (Heating, Ventilating, and Air-Conditioning – HVAC) for the optimal building performance (CIC, 2009).

- **Other Engineering Analyses**: earthquake, fire protection, acoustical, forensic, moisture intrusion, microbial investigations, and infrared analysis.
- **Sustainability Criteria Analysis** is defined as a process in which all sustainable aspects and features of a building are tracked in order to obtain the desired sustainable certification by condensing various criteria analyses into a single database (CIC, 2009).
- **Code Validation** is defined as a process to check the building design for compliance with project specific codes by using the 3D BIM model (CIC, 2009). Emergency Evacuation Planning and Security Validation can be considered as additional BIM uses under Code Validation or separately from it.
   a. **Emergency Evacuation Planning** is defined as a process to plan an emergency evacuation strategy using 3D BIM model navigation and simulation, and have it evaluated, improved and communicated to the client, end users or interested parties (CIC, 2009).
   b. **Security Validation** is defined as a process to analyze building security by using 3D BIM model navigation and simulation and provide better understanding of the security system vulnerabilities (CIC, 2009).
- **Cost Estimating** is defined as a process in which a BIM model can offer a reasonably accurate quantity take-off and cost estimate early in the design process and provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns (CIC, 2009).
- **Phase Planning (4D Modeling)** is defined as a process in which a 4D model (3D model with the added dimension of time) is utilized to effectively plan the phased occupancy in

a renovation, retrofit or addition, or to show the construction sequence and space requirements on a building site (CIC, 2009).

The taxonomy of BIM uses in design developed in this research can be found in Figure 7-2, and the BIM uses frequencies based on expert interviews can be found in Appendix E.

Model contents and level of detail conclusions and lessons learned are as follows:

- Define the best level of detail and extensive but limited list of model contents. BIM software applications have the ability to embody tremendous amounts of detail that may not add value.
- Develop BIM standards and best practices for model manageability. Setup the model properly to be shared and to serve more groups, and ensure successful handoffs. Components should be modeled simpler to reduce the model size and detailed only for rendering purposes at one instance. Model contents depend on the clients' and contract requirements.
- Divide up worksets properly and model precisely. If everyone has the same information, the bids are much more accurate.
- Decide when to stop with modeling to avoid getting lost in detail and doing more work than required. Use common sense and rules of thumb regarding what to model and what to draft instead. Full BIM models are thus far rare to find; for example mesh and rebar in concrete increases complexity, level of detail, and file size of the model.
- Establish model granularity or level of detail per project by design team. The higher the level of detail, the more work and coordination efforts is needed.

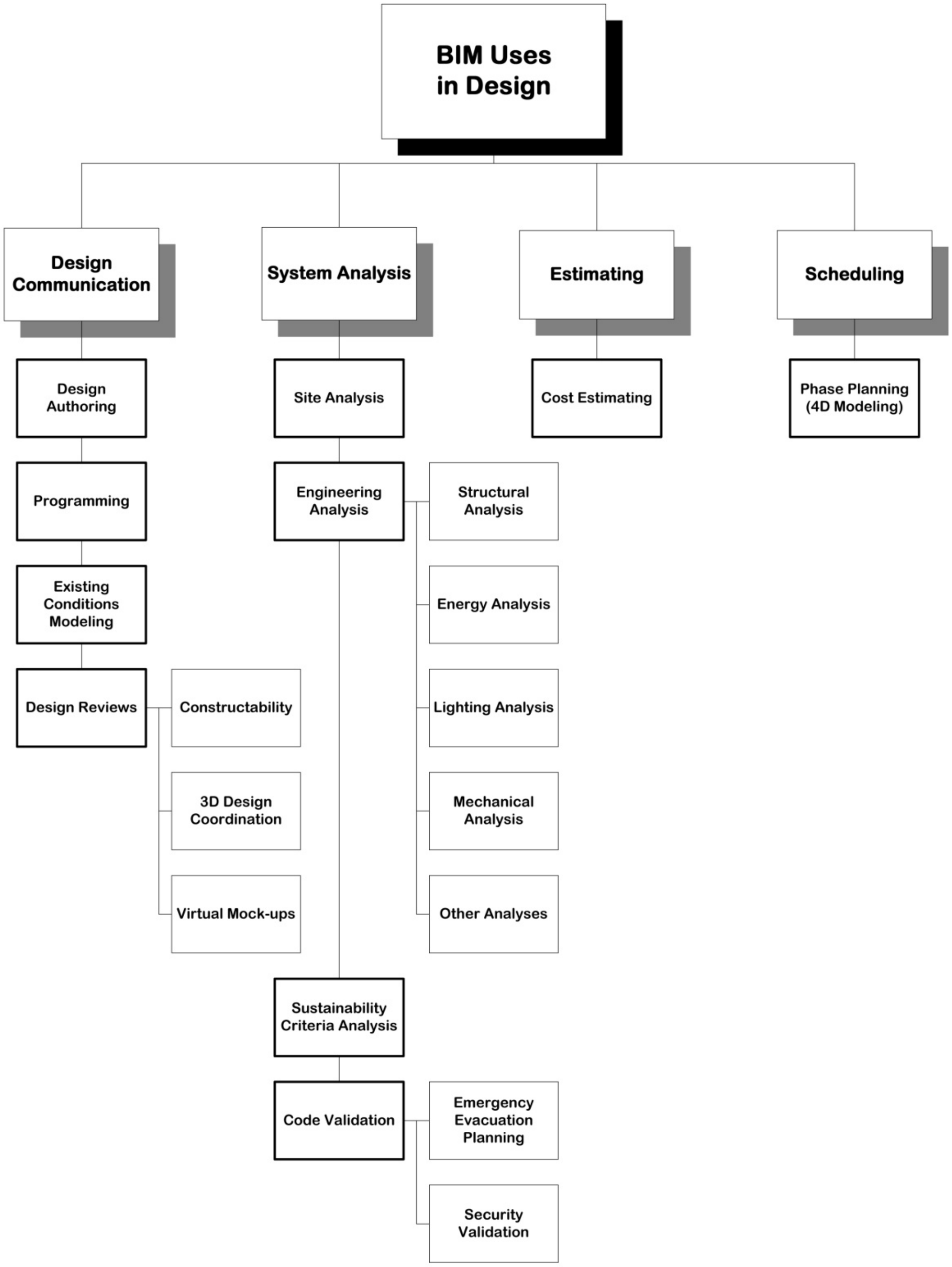


Figure **7-2**: The BIM Uses in Design Taxonomy

- Build a central library with generic content not manufacturer specific. Track more specific information at the project level and form a special group to create content based on arose needs and staff feedback.

Some of the steps in the process used for BIM implementation are:

- Build templates to start projects with customizing a standard BIM file. Upload certain wall types and materials and have others deleted.
- Track model uses, type and quantity of information included for winning combination when the model goes into construction.
- Start with light BIM and progress to full BIM (lonely vs. social BIM concept). Use a model for coordination and conflict resolution with consultants to start, but progress to sharing the model with the contractor, subcontractors, manufacturers and fabricators.
- Share the model in design-build or integrated project delivery. This unified approach is recommended to resolve interoperability and legal issues.

Team competencies required in the process of BIM implementation are as follows.

- Management has to embrace BIM on corporate and strategic level, understand the idea behind BIM and distinguish the functional uses of BIM software applications.
- Imperative for senior staff is to lead the building technology effort. Building knowledge is core competency and not the actual idea of BIM. It is up to the higher education institutions to teach building technology and not just design.
- Good solid BIM training is considered to be one of the crucial competencies to be successful in BIM implementation.
- Cultural shift of modeling instead of drafting is mainly affecting project management and senior level staff.

- Team size decreases while level of experience increases. Smaller number of more experienced people is more effective on a BIM job. More senior staff is required upfront to get the model setup and make serious decisions early on. Staffing level is more horizontal and there are no more adding of staff as the project progresses.
- Team building is recommended from day one. Decisions made will impact everyone down the line internally and externally.
- Teamwork and synergy of the team are very important since everyone is connected. Things change globally in BIM and no one can operate by oneself. Senior designers contribute to the team with their building knowledge while junior designers offer their software knowledge.

The top listed skills for BIM implementation can be reviewed in Figure 7-3.

Figure **7-3**: Top Skills for BIM Implementation

Legal, insurance and contractual considerations identified by the interviewees and literature include:

- Many offices are adding BIM contract language to limit their liability or sharing the model under premise for information only. No precedents exist thus far for sharing the model, and since case law drives contracts, most BIM contract language remains untested.
- Full implementation of BIM would lead to revised legal and insurance considerations. The traditional process carries more risk, but there are currently limits in trusting the model. Models tend to be shared with disclaimers, electronic paralegal agreements or delivered in read-only format.
- If everyone is sharing the benefits, everyone should share the risk. Turning the model over to the client is still considered a high risk. A contractual relationship is needed for teaming and collaboration. A good environment is offered in design-build or integrated project delivery (IPD) contractual relationship. IPD has a different legal structure in the form of a true partnership, and traditional fighting should be reduced. AIA has an ongoing effort to develop IPD agreement structures.
- Insurance addresses BIM in a very neutral way. There is no case law to show BIM projects are more or less risky, so it does not tend to impact insurance rates at this time.

7.3 Limitations of the Research

The research is intended to provide the taxonomy of BIM uses in design for the BIM Execution Planning Guide by drawing on published articles, papers, guides, and experiences and best practices from the AEC industry. Although the findings of this study are believed to cover broad strategies, experiences, and implementation techniques; it is important to remember that the interviewed participants represent a sample of design offices and companies experimenting and implementing BIM in the Mid-Atlantic region of U.S.

This research presents the results from the 18 interviews conducted in a period of August-September 2008. The responses received cannot be regarded as comprehensive of all BIM uses and implementation in design. Therefore, the conclusions cannot be considered to provide an comprehensive list, but more to be a common denominator for the responses received from the expert interviews.

Though it can be considered that the current status of BIM implementation, challenges, issues, risks and concerns were captured, some of the findings cannot be generalized. A large number of the designers and engineers interviewed have more advanced practices of BIM, while several of them have limited experience in BIM implementation. Regarding the BIM uses identified, though a very complete list was presented, there is still the possibility of adding other uses that were not recognized by interviewed industry participants or not yet developed at the time. The sample size of interviewees is representative, but by no means statistically significant to draw general conclusions for the whole population.

Another limitation that was noted is the non-existence of hard data to support BIM impact analysis. Measurements are rarely done, metrics are not established and only anecdotal data is presented. This form of study would greatly benefit from some quantitative data collected, analyzed and presented to support the statements and findings of the study.

7.4 Future Research

This thesis has identified an extensive list of BIM uses in design. The results of the study show the taxonomy of potential BIM uses, and provide valuable insight into the strategic implementation topics that have been addressed by design offices and companies on a corporate and project level. Various BIM impacts were identified in the study, but a detailed analysis of each of the factors or uses was not performed. The results and conclusions of this study are exploratory and are intended to be used to build upon, or as a starting point for further research in this area.

The future research should validate the taxonomy of BIM uses in design and further develop them. Also a follow up with industry participants in the form of a survey (web-based, by phone, or e-mail) would be very beneficial to verify the top listed responses and provide basic ratings or additional feedback.

This study was primarily done with participants in the greater Washington D.C. metro area. Further research or comparison can be done in other areas of the United States to verify design BIM uses nationally. Also, the results of the national study could be used in comparison with BIM advances in Europe, Asia or Australia.

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Appendix A

Interview Questions

Interview Questions

1. Background Information

- State your name and the name of the company.
    - What is your title/position and what are your responsibilities in the company?
    - What is your company yearly revenue? How many employees do you have?
- Have you already implemented BIM? Y/N
    - How many years of experience do you (personally) have with BIM?
    - How many years of experience does your company have with BIM?

2. BIM Execution Planning

- Have you or your company ever been involved in the development of a BIM Execution Plan on a project? Y/N
    - Yes – Who was involved? What decisions were made? What process did you use to develop the plan? Did you feel this was a valuable activity? Why, or why not? Can we get a copy?
    - No – Are you planning to? Who should be involved; make decisions?

3. Uses of BIM

- Please list functional uses for BIM that are either being implemented, or are uses that you would like to implement in the future. Describe how and why are using BIM for each (Functional Use; Description; Goal/Objective).
- After obtaining a list of uses and their description, then investigate the following for different uses:
  - How do you decide what to include in the model and at what level of detail for achieving the objective (Contents; Level of Detail)?
  - How do you create the model? What process, applications and data exchange/file formats (Modeling Process; Applications; Data Exchange/File Formats)?
  - What team competencies are needed (Team Competencies)?
  - What legal, insurance or contractual items do you consider (Legal/Insurance/Contractual Considerations)?
  - Do you reference additional resources or are you aware of good sources of information related to this use of BIM (Additional BIM Use Resources: Description, Studies, Examples, Software Applications, 3rd Party Vendors)?

4. Organizational Level

- Have you performed an analysis of the impact that BIM has on achieving the tasks that you perform in a project? Y/N
  - What is the impact of BIM on design/engineering (cost, time, overall project delivery time, quality)?

- Has the composition of your design staff changed? Y/N
  - What are new roles that arose with this technology?

- What are critical factors in successful implementation of BIM?
- What issues and concerns are you encountering on projects that incorporate BIM in design? What do you think are the risks emerging with BIM implementation?

5. Project Level: Case Study

- Do you have particular projects that you can identify that have gained significant value through the use of BIM? Y/N
  - If so, what tasks were performed in BIM?
  - Why do you feel there was significant value gained?
  - Would you be willing to share additional information with us regarding the case study, or is the case study documented so that we can review additional details?

6. Concluding Questions

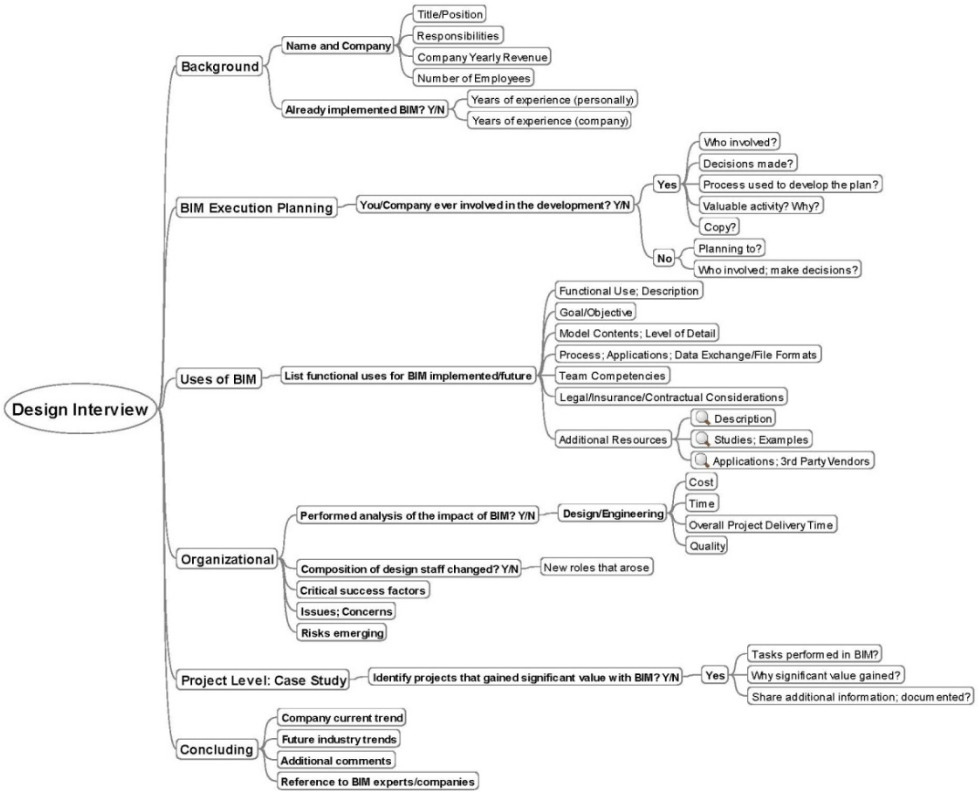
- What is the current trend within your company toward performing more projects with BIM?
- What do you feel are the high value future industry trends in BIM?
- Do you have any additional comments or items that you feel are important to consider?
- Can you refer us to other BIM experts or companies we can interview?

Thank you for your time!

Appendix B

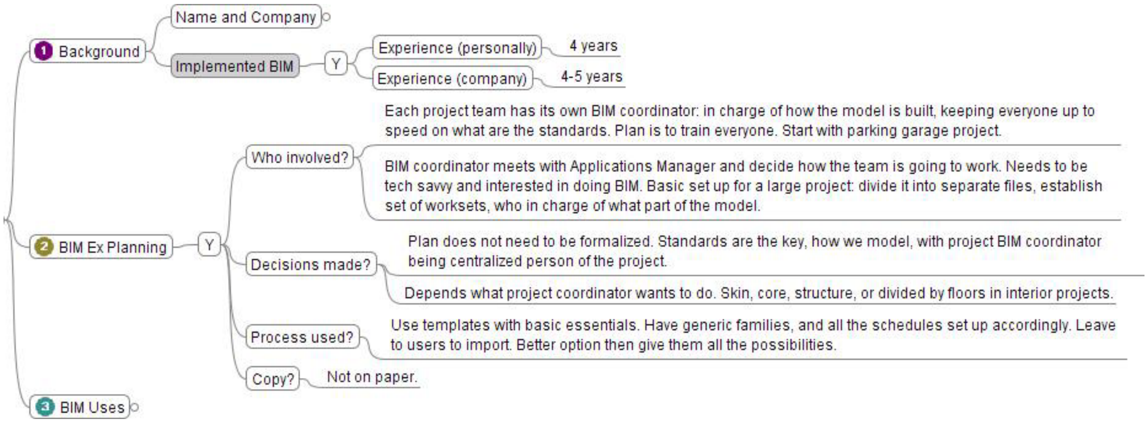
Interview Questions Mind Map

Interview Questions Mind Map



Appendix C

Content Analysis Mind Map Example

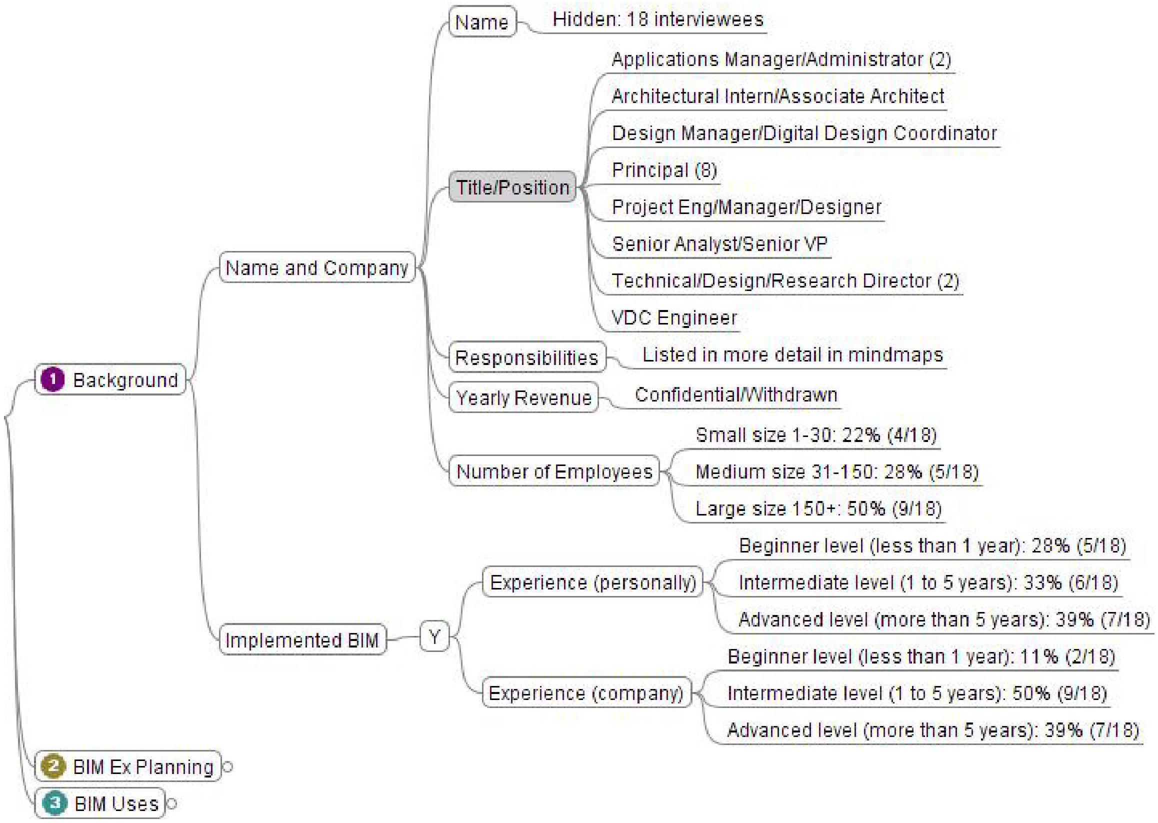


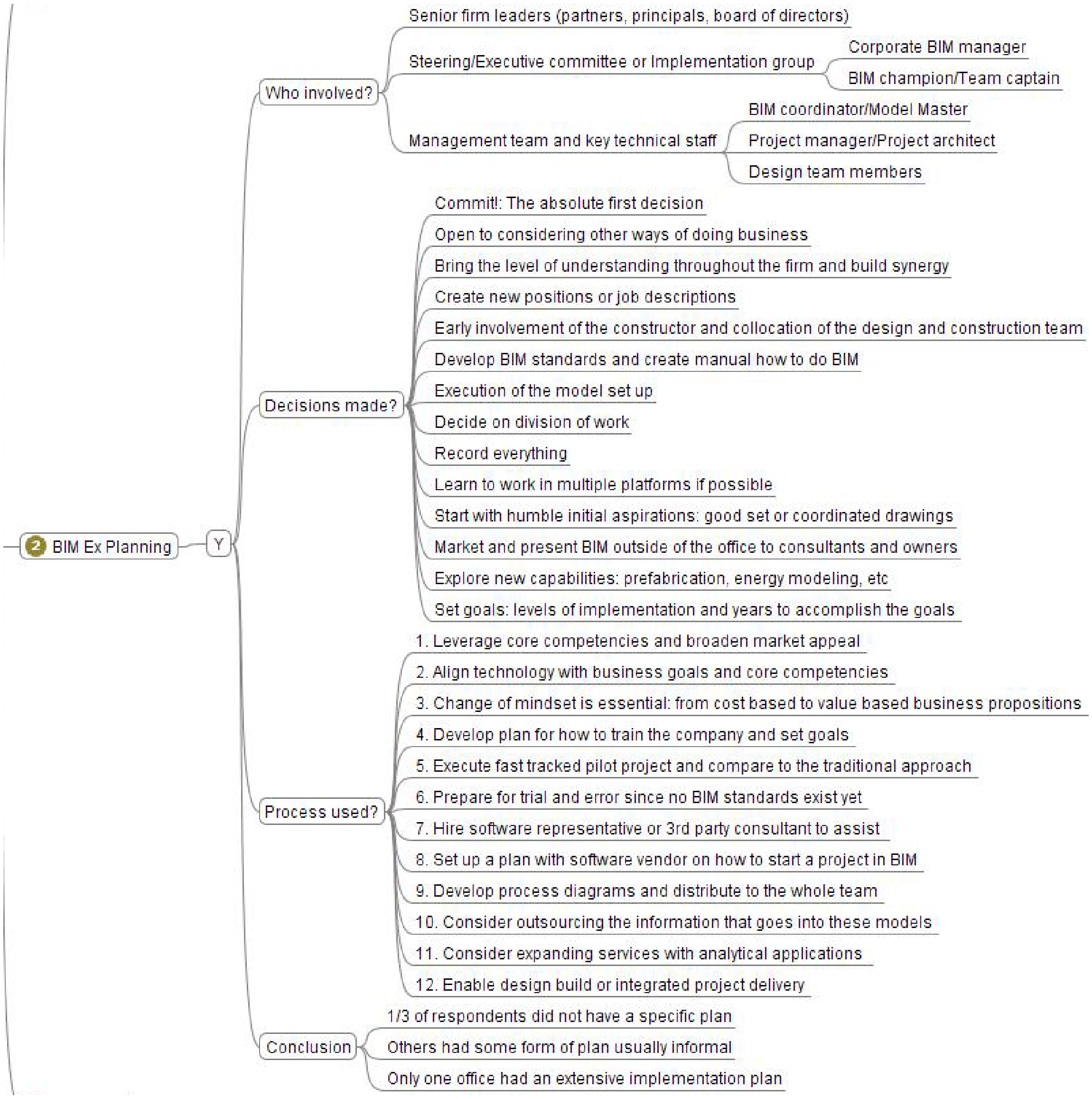
- ① Background
  - Name and Company
  - Implemented BIM
    - Y
      - Experience (personally)
        - 4 years
      - Experience (company)
        - 4-5 years
- ② BIM Ex Planning
  - Y
    - Who involved?
      - Each project team has its own BIM coordinator: in charge of how the model is built, keeping everyone up to speed on what are the standards. Plan is to train everyone. Start with parking garage project.
      - BIM coordinator meets with Applications Manager and decide how the team is going to work. Needs to be tech savvy and interested in doing BIM. Basic set up for a large project: divide it into separate files, establish set of worksets, who in charge of what part of the model.
    - Decisions made?
      - Plan does not need to be formalized. Standards are the key, how we model, with project BIM coordinator being centralized person of the project.
      - Depends what project coordinator wants to do. Skin, core, structure, or divided by floors in interior projects.
    - Process used?
      - Use templates with basic essentials. Have generic families, and all the schedules set up accordingly. Leave to users to import. Better option then give them all the possibilities.
    - Copy?
      - Not on paper.
- ③ BIM Uses

- ③ BIM Uses
  - Functional Use/Description
    - Programming
      - For massing studies, for proposals and winning the project, cool graphics, visualization, etc. Architects start with Sketchup and continue with Revit. Interiors still work in Autocad.
    - Site Analysis
      - Laying out the context and check certain views, very simple studies, like sun studies, etc. Like to use Ecotech and get more info out of it.
    - Design Reviews
      - Constructibility
        - Yes.
      - 3D Coordination
        - Structural engineers working in Revit, and MEP joined as well. Use Revit mainly for clash detection. Not NW.
      - Virtual Mock-ups
        - Model as a virtual mockup. Look into that in the future, as the software gets better.
        - Full size mockups cannot sometimes be simulated realistically on computer.
    - Code Checking
      - Egress paths, fire rated walls, ADA, turning radiuses ingrained in family templates.
    - Engineering Analysis
      - Structural Analysis
        - Structural engineers link their model to ours, and if they make changes, we see it immediately. Export to RAM, Etabs, but have to use 3rd party software to make it work. Not direct way to make changes.
      - Energy/Lighting
        - Ecotech.
      - HVAC Analysis
        - Still in 2D Autocad.
    - Sustainability (LEED) Evaluation
      - Sheet in Revit where you can keep track of certain points, but complicated.
      - Sustainable design with Ecotech to confirm rules of thumb, orient the building differently, comparative studies for cost, thermal analysis, very detailed, etc. IES: web based.
    - Cost Estimating
      - Very basic comparative studies: area of metal panel vs. area of glass vs. area of brick. US cost: establish the link between the model and their Success Estimator software linked to RS means database.
      - Anytime we made a change and exported it out to ODBC database, run their calcs fast again and give us a fairly accurate estimate.
    - Phase Planning (4D Modeling)
      - Great for existing vs. new construction, not as intuitive, but for existing projects it works very well. Tenant fitout: fast projects.
  - Model Contents/Level of Detail
    - Common sense. Rule of thumb: what we model and what we draft. Not model window sill with all the flashing inside of it, just model the overall shape, and go into the detail view. BIM model might get too complicated, slows down and has performance issues. We used to model nut and bolt.
    - Many manufacturers providing family information and modeling too much and precise, then when you bring it in your model, it slows everything down. Start off with worksets: divide up worksets the most logical way, up to the project BIM coordinator, and turn off the worksets you are not working on.
  - Team Competencies
    - Every change you make can and will affect all on the team. The concept behind work sharing. How much to model and how much to draft. Model set up and training also crutial.
  - Legal/Insurance/Contractual
    - Share 3D dwf. Cannot protect the model and make it read only. Click on the wall and find all info about the object but cannot change it. How much model vs. how much draft?
    - Not yet change the contracts. More and mode being asked to share the model, but have not yet.
      IFC can bridge the gap, though the basic bare bones model, it is the lowest common denominator between these two softwares.

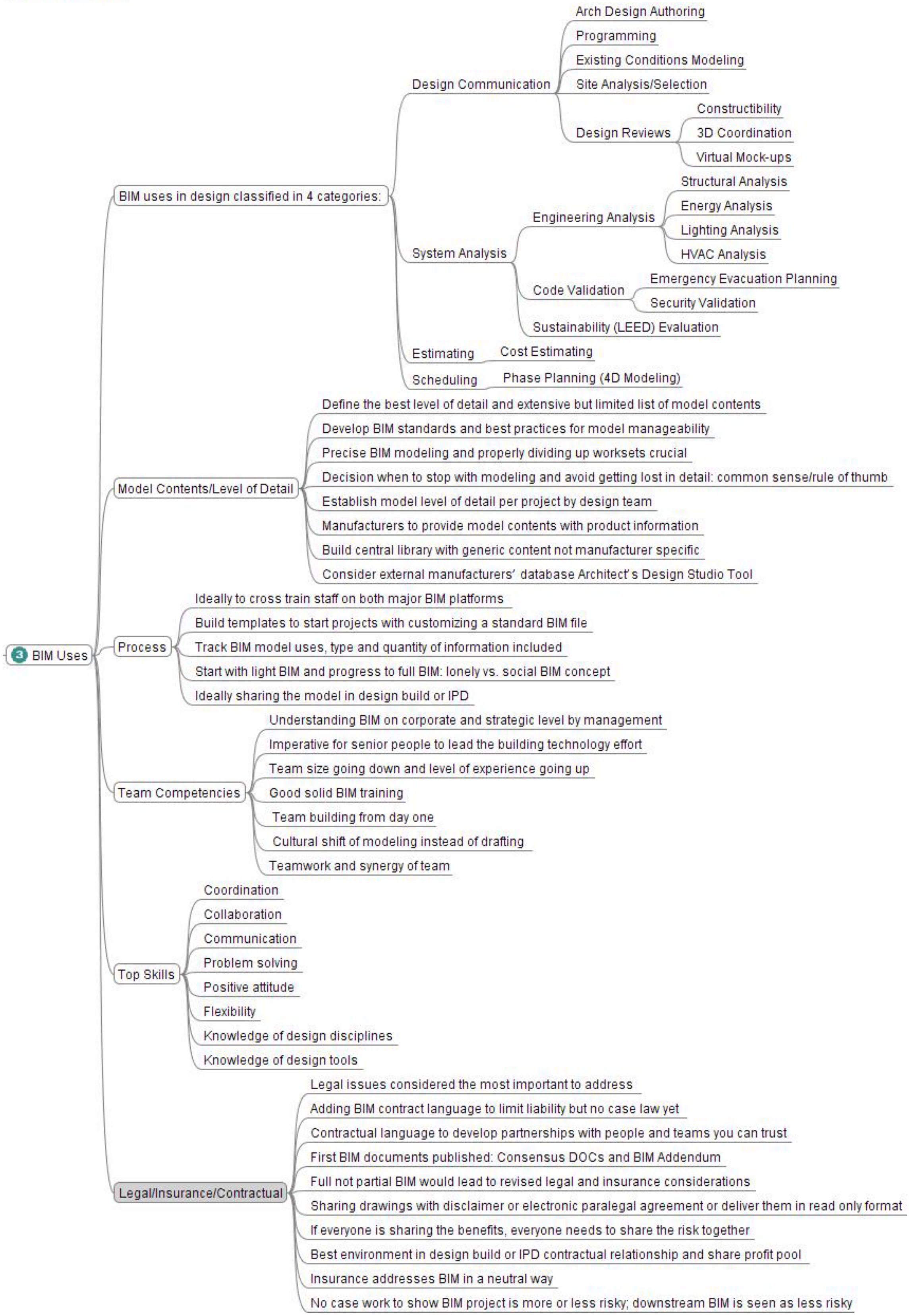
Appendix D

Final Master Mind Map


1 Background
Name and Company
Name
Hidden: 18 interviewees
Title/Position
Applications Manager/Administrator (2)
Architectural Intern/Associate Architect
Design Manager/Digital Design Coordinator
Principal (8)
Project Eng/Manager/Designer
Senior Analyst/Senior VP
Technical/Design/Research Director (2)
VDC Engineer
Responsibilities
Listed in more detail in mindmaps
Yearly Revenue
Confidential/Withdrawn
Number of Employees
Small size 1-30: 22% (4/18)
Medium size 31-150: 28% (5/18)
Large size 150+: 50% (9/18)
Implemented BIM
Y
Experience (personally)
Beginner level (less than 1 year): 28% (5/18)
Intermediate level (1 to 5 years): 33% (6/18)
Advanced level (more than 5 years): 39% (7/18)
Experience (company)
Beginner level (less than 1 year): 11% (2/18)
Intermediate level (1 to 5 years): 50% (9/18)
Advanced level (more than 5 years): 39% (7/18)
2 BIM Ex Planning
3 BIM Uses

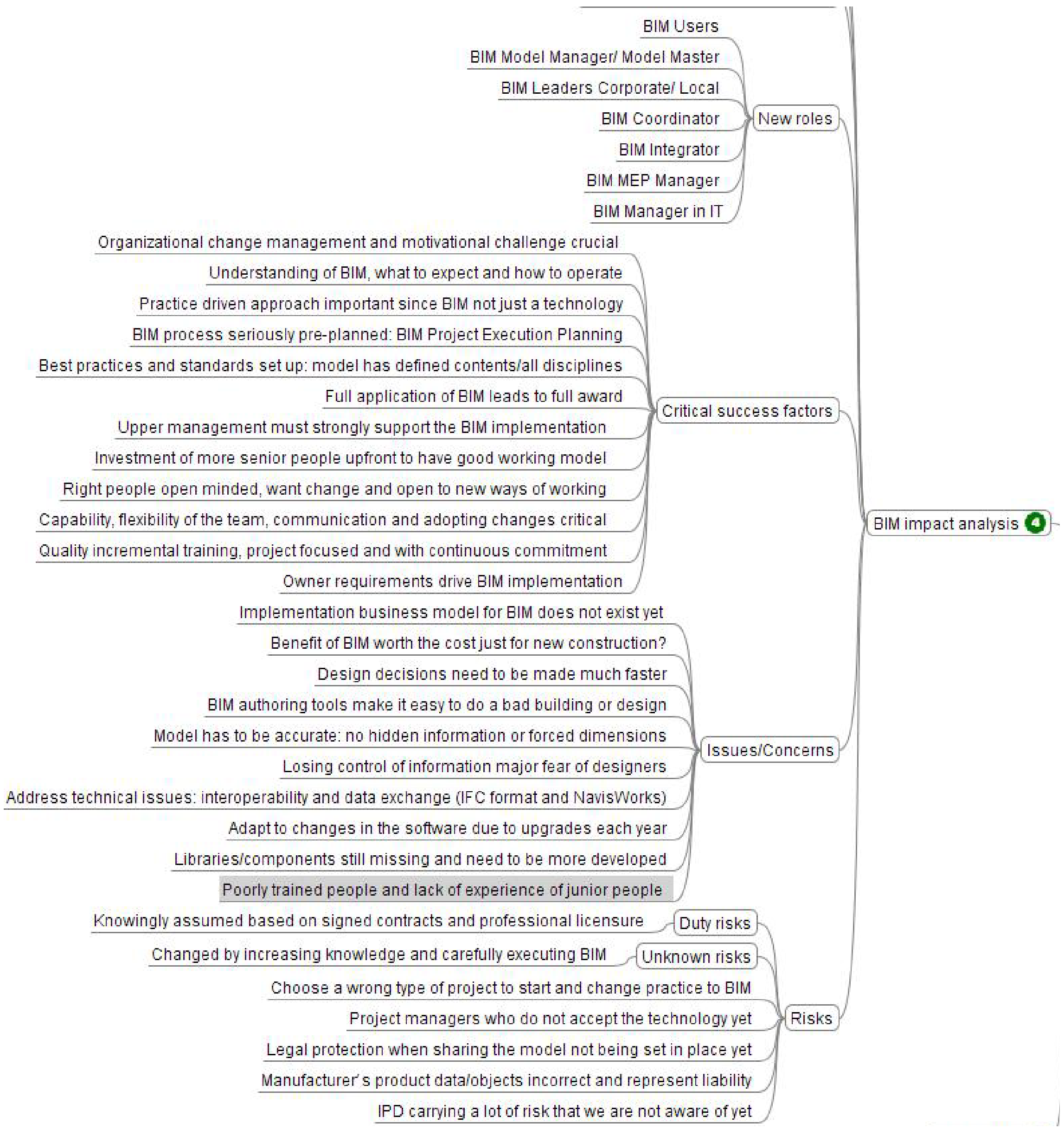


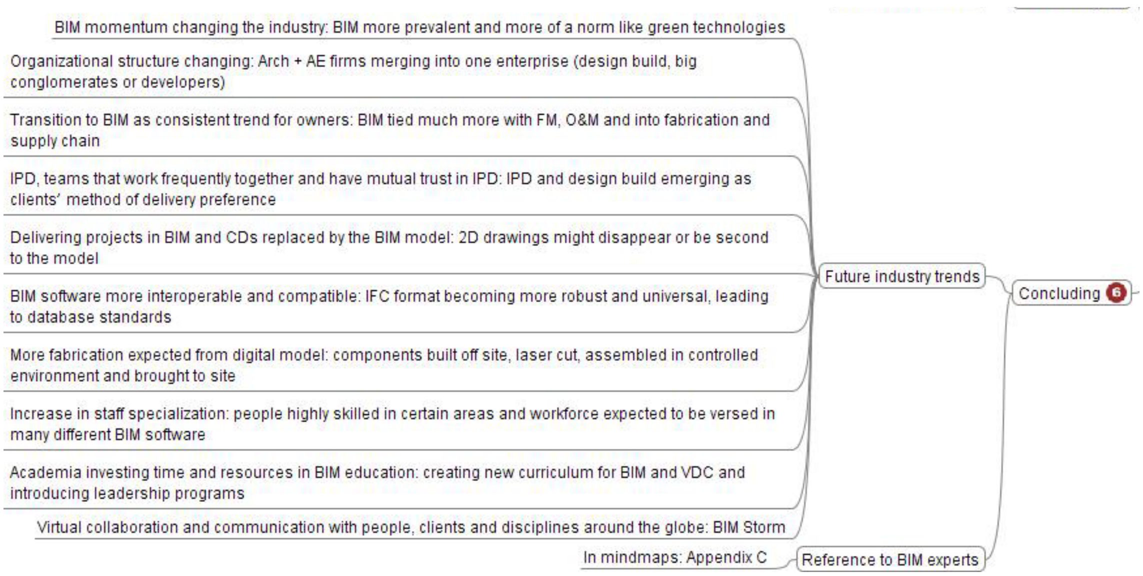
- 2 BIM Ex Planning
  - Y
    - Who involved?
      - Senior firm leaders (partners, principals, board of directors)
      - Steering/Executive committee or Implementation group
        - Corporate BIM manager
        - BIM champion/Team captain
      - Management team and key technical staff
        - BIM coordinator/Model Master
        - Project manager/Project architect
        - Design team members
    - Decisions made?
      - Commit!: The absolute first decision
      - Open to considering other ways of doing business
      - Bring the level of understanding throughout the firm and build synergy
      - Create new positions or job descriptions
      - Early involvement of the constructor and collocation of the design and construction team
      - Develop BIM standards and create manual how to do BIM
      - Execution of the model set up
      - Decide on division of work
      - Record everything
      - Learn to work in multiple platforms if possible
      - Start with humble initial aspirations: good set or coordinated drawings
      - Market and present BIM outside of the office to consultants and owners
      - Explore new capabilities: prefabrication, energy modeling, etc
      - Set goals: levels of implementation and years to accomplish the goals
    - Process used?
      - 1. Leverage core competencies and broaden market appeal
      - 2. Align technology with business goals and core competencies
      - 3. Change of mindset is essential: from cost based to value based business propositions
      - 4. Develop plan for how to train the company and set goals
      - 5. Execute fast tracked pilot project and compare to the traditional approach
      - 6. Prepare for trial and error since no BIM standards exist yet
      - 7. Hire software representative or 3rd party consultant to assist
      - 8. Set up a plan with software vendor on how to start a project in BIM
      - 9. Develop process diagrams and distribute to the whole team
      - 10. Consider outsourcing the information that goes into these models
      - 11. Consider expanding services with analytical applications
      - 12. Enable design build or integrated project delivery
    - Conclusion
      - 1/3 of respondents did not have a specific plan
      - Others had some form of plan usually informal
      - Only one office had an extensive implementation plan



- BIM Uses
  - BIM uses in design classified in 4 categories:
    - Design Communication
      - Arch Design Authoring
      - Programming
      - Existing Conditions Modeling
      - Site Analysis/Selection
      - Design Reviews
        - Constructibility
        - 3D Coordination
        - Virtual Mock-ups
    - System Analysis
      - Engineering Analysis
        - Structural Analysis
        - Energy Analysis
        - Lighting Analysis
        - HVAC Analysis
      - Code Validation
        - Emergency Evacuation Planning
        - Security Validation
      - Sustainability (LEED) Evaluation
    - Estimating
      - Cost Estimating
    - Scheduling
      - Phase Planning (4D Modeling)
  - Model Contents/Level of Detail
    - Define the best level of detail and extensive but limited list of model contents
    - Develop BIM standards and best practices for model manageability
    - Precise BIM modeling and properly dividing up worksets crucial
    - Decision when to stop with modeling and avoid getting lost in detail: common sense/rule of thumb
    - Establish model level of detail per project by design team
    - Manufacturers to provide model contents with product information
    - Build central library with generic content not manufacturer specific
    - Consider external manufacturers' database Architect's Design Studio Tool
  - Process
    - Ideally to cross train staff on both major BIM platforms
    - Build templates to start projects with customizing a standard BIM file
    - Track BIM model uses, type and quantity of information included
    - Start with light BIM and progress to full BIM: lonely vs. social BIM concept
    - Ideally sharing the model in design build or IPD
  - Team Competencies
    - Understanding BIM on corporate and strategic level by management
    - Imperative for senior people to lead the building technology effort
    - Team size going down and level of experience going up
    - Good solid BIM training
    - Team building from day one
    - Cultural shift of modeling instead of drafting
    - Teamwork and synergy of team
  - Top Skills
    - Coordination
    - Collaboration
    - Communication
    - Problem solving
    - Positive attitude
    - Flexibility
    - Knowledge of design disciplines
    - Knowledge of design tools
  - Legal/Insurance/Contractual
    - Legal issues considered the most important to address
    - Adding BIM contract language to limit liability but no case law yet
    - Contractual language to develop partnerships with people and teams you can trust
    - First BIM documents published: Consensus DOCs and BIM Addendum
    - Full not partial BIM would lead to revised legal and insurance considerations
    - Sharing drawings with disclaimer or electronic paralegal agreement or deliver them in read only format
    - If everyone is sharing the benefits, everyone needs to share the risk together
    - Best environment in design build or IPD contractual relationship and share profit pool
    - Insurance addresses BIM in a neutral way
    - No case work to show BIM project is more or less risky; downstream BIM is seen as less risky


BIM impact analysis
Y/N
Detailed analysis rarely done and no metrics yet
Project data and performances tracked: mostly profitable as before if not more
No RFIs on conflicts or document quality
Metrics: no measurable data available yet
Hours to complete the project
RFI tracking system
Conflicts resolved
# of people using BIM
% of projects done in BIM
Productivity
Starts with 35% less productivity but after 4-5 months back to the same level
Following projects having increase
Anecdotal data
80% decrease in clashes
Savings in cost for rework
Time savings
RFIs answered in two weeks
Design/Engineering
Cost
Cost Up
Hardware/software
Training staff
Schematic design phase
More information included
Cost Down
Unit cost of professional services
Decrease in errors and omissions
Better CDs → Bids under budget
Construction and change order cost
Design better communicated
Time
Time negatively affected
Gearing up the company to execute BIM
Time positively affected
Architectural practice and design in general fast tracked
Reduction in overall delivery time by eliminating conflicts
Overall design schedule: time savings in CD and CA phase
Project Delivery Time
Reduction in overall delivery time by eliminating conflicts in the beginning
Quality
Quality negatively affected
Overall project delivery quality still lacking
Only quality improved not time or cost
Quality positively affected
Project quality in general goes up
Better coordination: issues caught immediately
Much less RFIs initiated
No last minute adding of the staff
Design staff composition changed
Y
Large design offices completely restructured its staff: BIM users, BIM leaders, BIM coordinators, etc
Small design offices cut the number of their staff: remaining staff more experienced
Others still have same roles, but might have total collapse of the hierarchy with BIM
Challenge to motivate individuals and lead them through the process:
Leadership+Management+Mentoring+Incentives
N
1/3 of respondents said the design staff composition did not change


BIM Users
BIM Model Manager/ Model Master
BIM Leaders Corporate/ Local
BIM Coordinator
New roles
BIM Integrator
BIM MEP Manager
BIM Manager in IT
Organizational change management and motivational challenge crucial
Understanding of BIM, what to expect and how to operate
Practice driven approach important since BIM not just a technology
BIM process seriously pre-planned: BIM Project Execution Planning
Best practices and standards set up: model has defined contents/all disciplines
Full application of BIM leads to full award
Critical success factors
Upper management must strongly support the BIM implementation
Investment of more senior people upfront to have good working model
Right people open minded, want change and open to new ways of working
Capability, flexibility of the team, communication and adopting changes critical
BIM impact analysis
4
Quality incremental training, project focused and with continuous commitment
Owner requirements drive BIM implementation
Implementation business model for BIM does not exist yet
Benefit of BIM worth the cost just for new construction?
Design decisions need to be made much faster
BIM authoring tools make it easy to do a bad building or design
Model has to be accurate: no hidden information or forced dimensions
Issues/Concerns
Losing control of information major fear of designers
Address technical issues: interoperability and data exchange (IFC format and NavisWorks)
Adapt to changes in the software due to upgrades each year
Libraries/components still missing and need to be more developed
Poorly trained people and lack of experience of junior people
Knowingly assumed based on signed contracts and professional licensure
Duty risks
Changed by increasing knowledge and carefully executing BIM
Unknown risks
Choose a wrong type of project to start and change practice to BIM
Project managers who do not accept the technology yet
Risks
Legal protection when sharing the model not being set in place yet
Manufacturer's product data/objects incorrect and represent liability
IPD carrying a lot of risk that we are not aware of yet


BIM momentum changing the industry: BIM more prevalent and more of a norm like green technologies
Organizational structure changing: Arch + AE firms merging into one enterprise (design build, big conglomerates or developers)
Transition to BIM as consistent trend for owners: BIM tied much more with FM, O&M and into fabrication and supply chain
IPD, teams that work frequently together and have mutual trust in IPD: IPD and design build emerging as clients' method of delivery preference
Delivering projects in BIM and CDs replaced by the BIM model: 2D drawings might disappear or be second to the model
BIM software more interoperable and compatible: IFC format becoming more robust and universal, leading to database standards
More fabrication expected from digital model: components built off site, laser cut, assembled in controlled environment and brought to site
Increase in staff specialization: people highly skilled in certain areas and workforce expected to be versed in many different BIM software
Academia investing time and resources in BIM education: creating new curriculum for BIM and VDC and introducing leadership programs
Virtual collaboration and communication with people, clients and disciplines around the globe: BIM Storm
Future industry trends
Concluding
6
In mindmaps: Appendix C
Reference to BIM experts

Appendix E

BIM Uses in Design Taxonomy with Frequencies

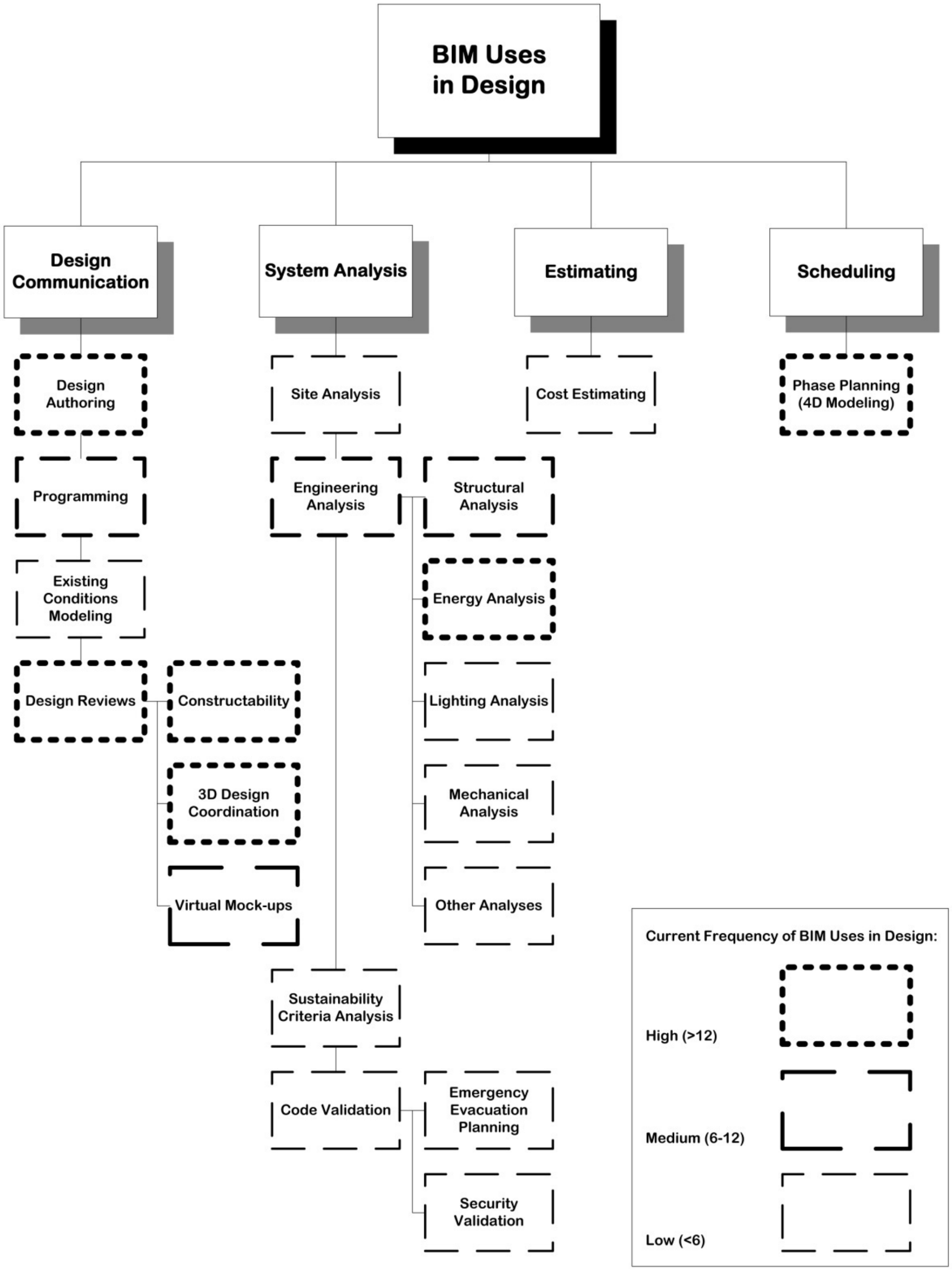


Figure **E-1**: BIM Uses in Design Taxonomy with Frequencies

Appendix F

BIM Use in Design Example

Cost Estimating

Objective(s):

- ✓ Rough order of magnitude estimates for planning, schematic and design development stages
- ✓ Feedback on the construction cost change as the design progresses and changes
- ✓ Accessible and documented building cost information along with the proposed budget
- ✓ Preliminary quantities and cost estimates of building materials, elements and system components

Description:

A process in which a BIM model can offer a reasonable accurate quantity take-off and cost estimate early in the design process and provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns. This process also allow designers to see the cost effects of their changes in a timely manner which can help curb excessive budget overruns due to project modifications. If the BIM model is shared with contractor, time for detail estimate can decrease dramatically and precision can go up.

Potential Benefits:

- Precisely estimate material quantities and generate quick revisions if needed (BIM and Cost Estimating, 2007)
- Stay within budget constraints with frequent preliminary cost estimates while the design progresses
- Better visual representation of project and construction elements that need to be estimated: taken off and priced (Khemlani, 2006)
- Provide cost information to the owner during the early decision making phase of design (Lee et al., 2008)
- Focus on more value adding activities in estimating like identifying construction assemblies, generating pricing and factoring risks then quantity take-off, which are essential for high quality estimates (BIM and Cost Estimating, 2007)
- Exploring different design options and concepts within the owner's budget
- Saving estimator's time and allowing to focus on more important issues in an estimate since take-offs can be automatically provided
- Quickly be able to determine costs of specific objects (Khemlani, 2006)

Levels of Detail Considerations:

- Type of estimate: rough order of magnitude, assembly, etc decides required level of detail in the model. It depends on the desired outcome: if only quantities are wanted, not much detail is needed, but if you want a very detailed estimate, a more detailed model would be required.

Team Competencies Required:

- Knowledge of estimating in general and BIM authoring and estimating software.
- General construction knowledge of how buildings come together.

Potential Modeling Methods:

- Very dependent on the software used to do the estimate:
- Quantities can be extracted and sent to the contractor or cost estimator (BIM and Cost Estimating, 2007),
- BIM modeling application can read cost data from an object library based on assemblies (Lee et al., 2008 and Khemlani, 2006), or
- BIM model can be opened within costing software which will match cost with construction elements (BIM and Cost Estimating, 2007).

Potential Outputs:

- Rough order of magnitude estimates, material quantity take-offs, cost estimates of various assemblies done for comparison and possible value engineering in a fraction of time needed for traditional estimate.

Legal/Commitment Considerations:

- It will be difficult to eliminate detailed cost estimates prepared by contractors for proposals and bids. Additionally, contractors will still need to create a schedule of values for payment which may be able to be based off a spreadsheet output from a BIM model. Preliminary cost estimates can be used to form the budgets and for early decision making and value engineering. (Dean and McClendon, 2007)
- Designers must be very cautious when entering any type of cost information into a BIM model. If a contractor uses the designer's cost information to create a bid and some of the information is incorrect, the designer could be held legally responsible. It is important for the designer to consider this both during BIM model creation as well as during the creation of the contract.
- A quantity take-off could be inaccurate due to how the BIM was created. For example, if a thickened slab around a column is modeled as the slab plus another concrete element instead of only one element (as it would be built), a quantity take-off of the concrete surface finishing area would be incorrect because it would double count the surface of the slab that was thickened. For this reason, it is important for a designer to be careful while creating a BIM model. It is also critical that the designer states the extent of the BIM's accuracy and for what purposes the BIM model may be used.

Additional Resources

Case Study Examples:

- Medical Research Lab and Expeditionary Hospital Facility (Manning and Messner, 2008)
- Various Case Studies (Buckley, 2008)

Software Applications:

- DProfiler
- Innovaya
- Sage Timberline Office Estimating
- Autodesk Revit
- Digital Project
- U.S. Cost Success Design Exchange (Success Estimator)

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