BUILDING INFORMATION MODELING IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

By

EDWIN ANTHONY PERKINS

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN BUILDING CONSTRUCTION

UNIVERSITY OF FLORIDA

2007

To my family and friends, for all their support and guidance throughout this entire process

ACKNOWLEDGMENTS

I would like to thank Dr. R. Raymond Issa, who has been a great advisor and mentor throughout my studies at the University of Florida. His knowledge as well as enthusiasm toward my studies was extremely helpful in accomplishing my thesis. I would also like to thank Professor John Maze of the college of Architecture at the University of Florida whose knowledge and direction in digital practice was crucial to my research objectives. I would also like to thank Dr. Ian Flood and Dr. Svetlana Olbina for their contributions to this study.

I thank my family and friends for their support and guidance throughout the entire time I was in school. I would like to specifically thank my parents. Without their financial support as well as encouragement, I would not have been able to complete my studies at the University of Florida.

TABLE OF CONTENTS

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Master of Science in Building Construction

BUILDING INFORMATION MODELING
IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

By

Edwin Anthony Perkins

August 2007

Chair: R. Raymond Issa
Cochair: Ian Flood
Major: Building Construction

Advances in telecommunications have flooded us with ever-growing amounts of information, most of which is available to us today in computer-based forms. Current uses of computers in construction include design, planning, scheduling, and cost estimating. Much more could be accomplished on a fully computer-integrated construction site. Building Information Modeling constitutes a cornerstone for any technique that claims to address these growing demands for streamlining information services and management techniques.

Building Information Model (BIM) is a tool used by the architectural, engineering, and construction (AEC) industry as a digital representation of the building process to facilitate exchange and interoperability information in a digital format. It is a dynamic, shared digital knowledge resource of information about a specific building used to develop and communicate all the information required to analyze, design, detail, procure, and construct a building. It can provide accurate information for sequencing and executing the planned documents. Having the ability to keep information coordinated, up-to-date, and accessible in an integrated digital environment gives architects, engineers, builders, and owners a clear overall vision of their

projects. As a result, BIM enhances the ability to make better decisions faster—raising the quality and profitability of every project.

In the United States, the AEC industry is beginning to come under pressure to implement BIM technology. The pressure is coming from building owners who want to make the design, construction, and operation of buildings much more streamlined and efficient. This paper will focus on utilizing the BIM created in the architect's office and implementing it in construction industry. A BIM of the M.E. Rinker, Sr. Hall will be created as a means of simulating how BIM can be used from a contractor's perspective. The purpose of this thesis is to provide a guide that can be used by contractors to facilitate the implementation of BIM. It will focus on all the benefits BIM has for the contractor as well as guidance on overcoming any barriers against implementation. The research will discuss the future direction of BIM technology providing examples of other applications that can follow.

CHAPTER 1
INTRODUCTION

Advances in telecommunications have flooded us with ever-growing amounts of information, most of which is available to us today in computer-based forms. Current uses of computers in construction include design, planning, scheduling, and cost estimating. As our society and technologies become more complex, a parallel increase in the sophistication of the built environment is anticipated. The day of the master builder who was responsible and aware of the entire building process is long gone. A consequence of the new complexity of the built environment has resulted in an increase of specialists needed to be involved with the entire building life cycle process. The number of specialists found in one building project has become inflated and is considered as the only way in which the complexities of the building can be resolved. Organizing the contributions of the various teams of specialists has caused the building process to be much more involved.

The complications of organizing the specialists involved in a project are a result of two main factors. The first factor is that none of the specialists work together or are found in the same office. Each is involved and concerned only with their task. For instance, the mechanical engineer is only concerned with the mechanical aspects of the building and the structural engineer is only concerned with the structure of the building.

The second main factor that causes complications is that each specialist is working on a different part of the design. Complications arise from this process and are usually not caught until the building is in the construction phase and the contractor sees that the drawings are not coordinated correctly. Take the following example of a typical project. The architect designs the building and is about 80% complete with the construction documents when he passes on the AutoCAD plans to the structural and mechanical engineers. After the specialists begin their

work, the client decides that they want changes to the design of the building. However, the changes do not get communicated correctly to the mechanical engineer who has already laid out the HVAC system. The error is not caught by the contractor until the building is already under construction and the HVAC system has already been ordered. This error leads to a costly change order that also slows down the construction process. At the end, the client has to pay for the communications error that could have been avoided with an improved streamed lined system.

With a fully integrated construction project, much more can be accomplished. Building Information Modeling (BIM) constitutes a cornerstone for any technique that claims to address these growing demands for improved information services and management techniques. The Building Information Model is a tool used by the architectural, engineering, and construction (AEC) industry as a digital representation of the building process to facilitate the exchange and interoperability of information in a digital format. It is a dynamic and shared digital resource of information about a specific building, used to develop and communicate all the information required to analyze, design, detail, procure, and construct a building. Building Information Modeling can provide accurate information for sequencing and executing the construction documents. Having the ability to keep information coordinated, up-to-date, and accessible in an integrated digital environment gives architects, engineers, builders, and owners a clear overall vision of their projects. Moreover, it gives them the ability to make better decisions faster, thus, raising the quality and profitability of their project.

1.1 Statement of Purpose

The barriers to implementing BIM technology in the construction industry has hampered the wide spread acceptance of BIM. Although many Architects are currently testing out BIM's capabilities, construction companies find the barriers too overwhelming to utilize the technology. The notion is that there are no guides that are intended for the professional industry that can

explain the basics of ‘what’ BIM can do for the industry and most importantly ‘how’. However, there are currently guidelines and numerous research activities intended to explain the technical aspect of BIM and how an architect can implement BIM into their office.

It is the intent of this study to identify barriers associated with implementing BIM in the construction industry as well as methods for overcoming these barriers. Understanding what BIM is and how contractors can use it will help facilitate the wide spread acceptance of BIM technology throughout the lifecycle of a project.

1.2 Objective of the Study

The objective of this study is to produce a Building Information Modeling guide that can be used by contractors as a reference for implementing BIM technology. The guide will focus on four main components:

- What is Building Information Modeling?
- How can a contractor benefit from Building Information Modeling?
- What are the barriers to its use that contractors need to be aware of?
- Implementing Building Information Modeling.

1.3 Scope and Limitations

The study investigates the need for Building Information Modeling in the construction industry. Research will focus on how BIM is currently being used by the General Contractor as well as the future use of BIM technology in the construction industry. In addition, barriers to implementation will be investigated to come up with solutions that will overcome any conflicts discovered in BIM.

This research will focus only on how the contractor can use Building Information Modeling. This is due to the fact that there are currently extensive research results as well as guidelines for implementing BIM in an architectural / engineering office. Data and information

obtained from this study represents the perception of the respondents to the surveys, as well as research conducted by the author and the author's experience with using BIM.

CHAPTER 2
LITERATURE REVIEW

Building Information Modeling (BIM) is an emerging research area. The concept of BIM has been around since the middle 1990s. However, due to significant improvements in technology, a great deal of research is currently underway in facilitating BIM into the building industry. This chapter discusses various studies currently in progress on BIM focusing on users in the construction industry.

2.1 Building Information Modeling Background

As of today, architects and engineers have been using three-dimensional (3d) technology in the form of renderings for their presentations. These visualization techniques have helped architects and engineers convey their design concepts to owners, who then use the renderings to sell the project and promote fund-raising efforts. Building Information Modeling incorporates the use of 3d visualization techniques with real-time, data driven, object- based imaging as a tool by all facets of the industries (Holness 2006). Building Information Modeling technology has the potential to dramatically change the dynamics of the building industry by improving efficiency, accuracy, and communication.

According to the US General Services Administration's (GSA) Office of the Chief Architect (OCA), BIM is defined as

> The development and uses of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design. (OCA 2006)

The OCA is a strong advocate of BIM and they have been providing extensive research and guidance in the implementation of BIM in the building industry. The purpose of the OCA is to provide national leadership and policy direction in the areas of architecture, engineering,

urban development, construction services, and project management. A study performed for the National Institute of Standards and Technology (NIST) in collaboration with the OCA, estimated that in 2002, $15.8 billion were lost due to "significant inefficiency and lost opportunity costs associated with interoperability," in the capital facilities industry (OCA 2006). Estimates have also suggested that as much as 30% of project costs are wasted through poor management of the design-construction process (Brown and Beaton 1990). Moreover, building owners and operators bore the majority of these costs. The findings provided by the research provoked the OCA to research new methods that will drastically reduce the lost due to inefficiency and interoperability. The OCA evaluated BIM technology and ascertained that a BIM-based approach will make the design information unambiguous, so that the design intent and program can be immediately understood and evaluated. The OCA also established that a BIM-based approach supports on demand generation of documents from a consistent Building Information Model. The documents a BIM can generate include, but are not limited to, drawings, lists, tables, and 3d renderings related to the project. Thereby contributing more to efficiency, and provide superior accuracy than traditional 2d CAD drawings (OCA 2006).

In a study published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the potential savings in construction cost by implementing a BIM technique where found to be substantial. The study concluded that savings in construction cost alone can range from 15% to 40%, as well as reductions in construction schedules and improvements in quality (Holness 2006).

2.1.1 Distinguishing 3D, 4D, BIM

The terms three-dimensional (3d), four-dimensional (4d), and Building Information Modeling have been associated interchangeably with virtual reality. However, each term is

significantly different and a valid understanding is needed in order to understand the principles of the concept of BIM.

In the field of computer graphics, 3d space is defined as three mutually perpendicular lines which intersect at a point called the origin. The three lines are named the X axis, Y axis, and the Z axis. The traditional method of drawing construction documents is using the 2d method based on the X axis and Y axis (Finkelstein 2006). Building Information Modeling technology introduces 3d by utilizing the Z axis. The third dimension is an added depth property that indicates where the point lies on an imaginary Z-axis. The 3d objects are generated and displayed in a two-dimensional space, for instance, a display monitor. A 3d model contains no intelligence, only graphical representation of the building. A BIM contains the 3d model as intelligence that can provide information used by other, non-design applications, such as cost calculation, energy simulation, or building code checking. The main concept behind BIM is the concept contained in the "I" of BIM, which stands for information. The information contained in a BIM is a data rich digital representation cataloging the physical and functional characteristics of design and construction (OCA 2006).

The term 4d represents an input of time to the 3d model, which illustrate phasing activities from the design, procurement, and construction schedules. When the 4d is implemented in the BIM, stakeholders can view the planned construction of a facility over time and review the planned or actual status of a project in the context of a 3d model for any day, week, or month of the project (OCA 2006). Experienced project managers, superintendents, and schedulers often visualize three dimensionally movies in their heads to think about the construction of the project. These professionals have been able to relate to 4d models and use the technology to explore the thoughts in their heads (Fischer and Kunz 2004). The time sequencing in 4d models has been

beneficial when questioning the constructability of a design and related schedule. Building Information Modeling technology linked with 4d technology makes it economical and valuable in supporting a project team's decision making by addressing such questions within a few moments.

A recent example of a successful implementation of 4d technology was the Paradise Pier portion of Disney's recently opened California Adventure in Anaheim, California. Walt Disney's Imagineering found that the 4d model enabled the project team to achieve fewer unplanned change orders, control smaller construction teams, and had a comfortable completion of the project ahead of schedule. Walt Disney Imagineering found that by improving project communications, the 4d models reduced unplanned change orders by 40% to 90%, reduced rework, increased productivity, and improved the credibility of the schedule (Goldstein 2001).

2.1.2 Need for an Effective Implementation Strategy

Traditionally, in an architect's office, a project is divided up among team members by drawing type. For instance, one team member draws the plans, another draws the sections, another draws the details, etc. (Khemlani 2004). However, BIM automatically generates the drawing within the model, as in the case with Revit®. Therefore, the traditional approach to generating construction documents has to be addressed differently. The need for an effective implementation strategy must be researched in order to effectively facilitate BIM.

Khemlani (2004) conducted surveys of several architectural practices that were in various stages of deploying or evaluating a BIM application. According to data received from the research, Khemlani evaluated that most firms not only required learning a new application, but also required learning how to reinvent the work flow, how to staff and assign responsibilities, and what to model and what not to. One approach that was used by various companies was to dedicate one team to creating the objects, and have other teams assemble them into buildings.

Khemlani concluded that most of the firm principals and technology leaders where struggling with the same basic questions of how to best leverage BIM:

- How can the greater design efficiency and better building quality enabled by BIM be translated into more profitability?
- How can the added intelligence in a BIM model of a building, which includes valuable information but takes more time for firms to produce than traditional 2d documents, be priced? (Khemlani 2004)

To facilitate the implementation of BIM, new rules that will provide guidance to participants of a BIM project must be established. These rules create a common language amongst the industry which will harmonize work between all organizations involved in the building industry.

This method of creating standardization is nothing new. It was first implemented when the industry started using AUTOCAD in which CAD standards where created. The purpose of the CAD Standards was to ensure consistent 2d drawings, accurate source of spatial data, and uniform requirements for contractor design deliverables (Hall 2006). These standards provided accurate space assignment and rent billing data, drawings suitable for client agency use, maintenance and operation data, and record drawings for management and future renovations of GSA's Public Building Services (PBS) buildings (Hall 2006).

Today, the National Institute for Building Sciences (NIBS) is creating standards for BIM. The goal is to knit together the broadest and deepest constituency ever assembled for the purpose of addressing the losses and limitations associated with errors and inefficiencies in the building supply chain (Davis 2006).One of the most important tasks for NBIMS is to coordinate these efforts and harmonize work between all organizations with similar products and interests.

The OCA is also inputting their knowledge by developing a BIM Guide Series to allow the GSA project teams and users to understand BIM technologies. The GSA is responsible for

meeting the space requirements of federal agencies. They provides national leadership, policy direction, and standards in the areas of architecture, engineering, urban development, design, fine arts, historic preservation, construction services, and project management (GSA 2006). Any contractor who is involved in a federally funded government project must follow the rules set forth by the GSA.

The building industry can all benefit from a clear set of guidelines outlining an effective strategy and methodology of implementing BIM. Support is needed from both industry leaders as well as government entities. For example, in Singapore, the government has developed the Building and Construction Authority (BCA) to develop and regulate the construction industry. The key factors of the BCA are to:

- Improve quality and productivity through high standards of excellence and the use of innovative construction technology.
- Raise skills through training and testing to develop a professional construction workforce.
- Ensure building works are designed to comply with regulations and built to high safety standards.
- Support industry growth through resource and information management. (Chew 2001)

2.2 Barriers to Implementing BIM in the Building Industry

Information technology in recent years has seen substantial support in many industries. The manufacturing, agricultural, and other modern enterprises have embraced information technology for competitive gain and efficiency. The new approaches utilize a model based digital design process based on data supported by cost modeling, supply-chain integration, and computer driven fabrication (Bernstein and Pitmann 2004). Yet, the building industry has fallen behind in the transfer of technologies, lowering productivity in comparison with other industries within the past thirty year period (U.S. Census Bureau, 2002). Researchers need to consider that the building industry is not a “perfect world” environment. Bernstein and Pitmann (2004)

concluded in an information technology research that every project is unique, building project teams rarely work together more than once, and project delivery is driven by the least cost effective method. The question becomes, how do we input this “perfect world” solution, into a dynamic industry? Implementation barriers must be studied and solutions must be found before BIM receives an overall acceptance in the industry.

2.2.1 Implementation Challenges

One of the biggest obstacles found when companies try to implement a new strategy are the employees resistance to change. Researchers have found that a primary barrier to implementing BIM is the lack of commitment from employees who are resistant to learning something else in the midst of trying to do their jobs (Khemlani 2004). The survey conducted by Khemlani found that the resistance is not limited to employees, but across all levels and positions. The overall feeling of management is that the projects that their companies are involved in are too complex for a BIM system. Therefore, trying to implement the technology will take too many resources. However, to contradict everything stated above, Khemlani’s research also found that the companies who stated that their projects are too complex for BIM have used 3d modeling on various projects for presentation purposes to try to win projects. It is observed that 3d modeling technology is being used in the commercial construction industry, but not to its full potential.

The challenge of how to implement BIM technology also presents a barrier to its support. The OCA is currently working on standardization procedures for BIM to reduce implementation challenges. Within the standardization are guidelines to help project teams evaluate whether or not it is feasible to utilize BIM technology. According to the OCA (2006), when analyzing feasibility, project teams should take into account:

- The experience of the project team.

- The maturity of the technology.
- The resource availability (e.g., funding).
- How BIM information will be exchanged between team members.
- How to procure BIM services.
- When during the project life-cycle should BIM technology be adopted?

2.2.2 Legal Exposure

BIM has not yet been implemented because of the fear of addressing legal exposures. The idea of Building Information Modeling as a design and construction database is a difficult one to examine from practice and insurance-coverage perspectives. Construction companies will face increasing challenges as they realize that they are moving from a physical model with hard-copy plans and specifications, to the primary information generators for a digital database. Construction companies will have to deal with new business rules and possibly unknown liability exposures as they move to a "super-integrated" future system (Davis 2006).

According to Bernstein and Pitmann (2004) of Autodesk, there are many uncharted territories that lie ahead for the building industry in adopting BIM.

- What is the relationship between design intent represented in preliminary design and the responsibility for singing and sealing the final design documents?
- What is the design team's additional obligation for coordination when integrated information becomes fluid and malleable as a result of design document production?
- When design and fabrication data are inextricably intertwined, how are the duties and responsibilities of the parties allocated?
- What is the predicted lifespan of digital design information and how are creators compensated? (Bernstein and Pitmann, 2004)

Building Information Modeling eases the flow of information, yet lacks clearly delineated work flow and data interactions currently not blurred with the paper- based method. To allocate from the apparent risk, Bernstein and Pitmann (2004) suggest distributing risk across the entire team, including the owner and all engineers. However, teams that offer BIM design strategies

will require larger fees and commensurate risk distributions in their contracts. (Bernstein & Pitmann 2004)

2.2.2.1 Professional liability insurance

As the different contributors add their scope of work to a BIM, the boundaries of their responsibility and work product become blurred, thus increasing the risk of professional liability claims. As the construction industry unites around the use of BIM, there will be a need for professionals to take the lead as project information integrators. This can be in the form of a licensed professional who will control the overall process and create the database of design, procurement, and construction information provided to or managed on behalf of the client. The coverage provided by professional liability insurance has been defined through policy language and court decisions and is based on the question: was a cost, loss, or damage to another party the proximate result of negligent professional services by the policyholder (O'Shaughnessy 2003)? However, professional liability coverage is not meant to cover technology-based risks such as lost data, virus corruption, or general software glitches. Yet it does cover broadly defined design services, regardless of the means of communication (O'Shaughnessy 2003). On a project, insurance coverage exists for an architectural project team. A basic premise of BIM is the collaboration by different consultants at different phases of the life cycle of a building to insert or modify information in the BIM to support and reflect the roles of that consultant. Tracking responsibility for design input can be possible. The United States legal system requires that parties rectify harm caused by their negligence, and any party providing negligent design input should be liable if that negligence causes harm to end users or other project stakeholders (Bedrick 2006). This system exists today in which contractors and others to whom design responsibility is distributed can be insured for their negligence in creating or furnishing design

information. Any party involved with the BIM process should have design liability coverage to pay on their behalf and it should be a requirement set in the contract prior to the start of project.

Professional liability insurance coverage covers services such as visualization studies, cost analysis, energy audits, scheduling, and post-construction advisory (O'Shaughnessy 2003). The integration consultant's role, focused on managing the information model, involves professional services but also includes exposures for security breaches and other technological risks that may be outside its scope. One insurance company offers a liability coverage known as *TechVantage*, designed for technology firms and professionals such as custom programmers, system designers, web designers, and internet service providers (Bedrick 2006). This policy offers errors and omissions coverage, coverage for copyright and trademark infringement, unauthorized access, and introduction of a computer virus by firms developing specialized software products (Bedrick 2006). Projects that are considering utilizing BIM technology would now be faced with adding this expense to their bids as insurance overhead. In an industry where pricing models are based on established legal precedents and claims statistics developed over decades, policies covering design exposures and digital communication problems for all parties should be considered.

2.2.2.2 Copyright

There is a concern throughout the construction industry associated with copyright laws in utilizing BIM. Copyright of the project becomes an issue since there are now many parties involved with the design of the documents. The current Architectural Works Copyright Protection Act (AWCPA) defines an "architectural work" as "the design of a building as embodied in any tangible medium of expression, including a building, architectural plans, or drawings" (Copyright 2006). The protection act does not prevent a consultant from using components of the building imbedded in the BIM on a subsequent project. To understand this issue, we first have to investigate why Architectural Works where protected in the first place.

Prior to the AWCPA of 1990, copyright protection generally did not include the right to prevent others from using copyrighted architectural works. Anybody that had access to plans or drawings could construct a building and escape liability if the plans and drawings themselves were not copied. The AWCPA significantly altered the scheme for protecting architectural works, and infringement may now be found even though access to the 3d work is obtained from its 2d depiction. According to the AWCPA, architectural works are explicitly recognized as the eighth form of copyrightable subject matter under 17 U.S.C. §102(a). The definition of this category is "the design of a building as embodied in any tangible medium of expression, including a building, architectural plans, or drawings" (Copyright 2006). Protection includes the overall form as well as the arrangement and composition of spaces and elements in the design, but does not include individual standard features.

2.3 Impact on Business Practice

BIM can positively impact business practices when a company successfully implements the technology. Lin (2001) in his book about construction technology for highrises, describes the basic resources for any building as money, materials, and machinery. According to Lin, the overall economy of a building project are affected by the manner in which materials are incorporated in the fabrication and structure of a building at the design stage and in which materials are handled and deployed on site. The basic resources described by Lin are essential to a construction company's success. Building Information Modeling can provide real-time information and data essential to maintain the basic resources of any building thereby benefiting the business practice.

A recently published research on emerging construction technologies found BIM to impact business practices as follows:

- IMPROVE PROJECT SCHEDULES. When schedules are verified prior to construction, crew productivity may be increased.

- IMPROVE CONSTRUCTABILITY. Workflow for contractors can be identified as well as potential conflicts by minimizing interferences onsite.

- IMPROVE MATERIAL MANAGEMENT. Material databases can be automatically populated, eliminating the need for manually creating spreadsheets for materials management. The database produces material takeoffs, minimizing the need for wasted materials.

- IMPROVE RESOURCE MANAGEMENT**.** With BIM, the placement and staging of scaffolds and cranes can be simulated for optimal performance.

- IMPROVE CHANGE ORDERS**.** Change orders can be greatly reduced by simulating work versus rework and creating new material takeoffs automatically.

- IMPROVE COMMUNICATION**.** All involved with the project can rely on accurate visualization that can create a complete set of information from which to plan and build. The improved communication may reduce the need for Request for Information (RFI) and rework. (Wood and Alvarez 2005)

2.3.1 Project Organization

Currently, information flows sequentially to each party in the process, from the time the design was conceived by the architect, drawn, scheduled, specified, and issued through the bidding process. The information is then transferred to contractors and suppliers, where quantities are taken and bid through a vendor, distributor, etc. Then, it is issued for construction with material takeoffs completed and shop drawings processed, again through vendor, distributor, subcontractor, and general contractor, until the component is finally delivered and installed in the field. Each step has its own associated handling and processing costs, time delays, and the potential for error, as the information is translated from format to format. Electronic communications can speed up the process, but unless the basic format is changed and unnecessary steps eliminated, the cost, delays, and potential for errors still exists. By using real-time, object based imaging and building information modeling data base techniques, the architectural/ engineering (A/E) drawings can facilitate the direct, seamless, and simultaneous

flow of information to all parties in the construction process: owners, program managers, consultants, code officials, general contractors, trade subcontractors, suppliers, distributors, vendors, and manufacturers. The potential exists to significantly reduce the number of communication steps, eliminate the need to translate or transfer information, thereby, reducing time and cost while increasing accuracy and quality (Holness 2006).

2.3.2 Impact on Owners and Architects

Current research in the architecture industry has found positive attributes about implementing BIM in their business practice. For instance, a 300 staff firm reported that for several projects on which BIM was used, they had used only half the number of staff that had been originally budgeted and completed the work twice as fast. Another firm that employs 150 people found that one key benefit of using BIM in a tenant fit-up project is the ability to provide the building owner with more accurate data on square footage as well as construction estimating (Khemlani 2004).

At an AIA National Convention and Design Exposition, building owners expressed their perspective on BIM. William Tibbett of Johnson & Johnson spoke on behalf of the building owners and stated that clients are no longer tolerating mistakes, delays, and team members not being able to share their networked information (AIA 2005). Owners want the project teams to develop a new method for working together and BIM is a solution to the apparent problems.

2.3.3 Cost Integration

A BIM system allows the user view the cost data associated with the 3d design data. This would enable the original cost estimating proposal to be done much more rapidly and accurately since it will be accounting for every object represented in the model. For example, Webcor Builders in San Mateo, CA, experimented with the use of 3d models for automated quantity take-off and found that estimators could build a BIM and perform take-offs in less than half the time

than they would need for the same process using 2d drawings (Bedrick 2003). In addition, the model-based quantity takeoff reduces the inconsistency of take-off numbers between different estimators and increases the speed of re-estimating a project when design changes occur.

2.3.4 Construction Coordination

Contractors are now experimenting with the construction phasing ability found in BIM. Coordination models in BIM generate workflow sequencing that can be used for organizing subcontractors, site logistics, and to validate early on the project's overall sequencing. For example, BIM was used for the construction of the Walt Disney Concert Hall as a method of improving the construction schedule and for communication. According to Fischer and Kunz (2004), the project's general superintendent, Greg Knutson, estimated that for every hour he spent working on the schedule he needed about six hours to communicate the schedule. Integrating the schedule with the BIM allowed him to reduce that time while increasing the amount of subcontractor feedback and buy-in. The BIM was also used extensively during pre-planning subcontractor coordination meetings to review the sequence of work and related logistics and improve the constructability. While in the construction phase, the BIM was used to preview the scope of work for the upcoming 90 days during their monthly subcontractor coordination meetings (Fischer and Kunz 2004).

The Walt Disney Concert Hall team found BIM to be a key tool for site logistics. They were able to place cranes into the BIM and to analyze the placement of the cranes throughout construction to minimize crane movements and to ensure that the cranes could reach all areas of work as required by the schedule. The team also found the site logistics tools very beneficial when they tried to obtain a permit to proceed with construction from the County. The County did not approve the desired steel erection plan that was presented in form of a detailed step by step plan of action. It was a battle that lasted several weeks and it was not until the BIM model was

presented to the County officials that they where able to understand the erection plan and within fifteen minutes approved the strategy (Fischer and Kunz 2004). Construction coordination is where contractors will discover the benefits of a BIM system. More research is currently underway in facilitating construction coordination in BIM. The research is being driven by industry leaders that notice the benefits of how technology can change the way we think, plan, and build.

CHAPTER 3
METHODOLOGY

The objective of this thesis is to determine the optimal approach necessary for implementing BIM in the construction industry. The data analyzed for the research was collected by means of a survey sent out to industry professionals as well as a BIM case study. The research was aimed at assessing BIM usage in the building industry as well as comparing the traditional methods of planning with a BIM method. It is noted that the research will focus only on how the contractor can use BIM. This is due to the fact that there is currently extensive research as well as guidelines for implementing BIM in an architectural/engineering office. Data and information obtained from this study represents the perception of the individuals surveyed, as well as the author's research and experience.

3.1 Survey

The survey was sent out in the form of a questionnaire to industry professionals in construction. Construction companies targeted for this research were those ranked amongst the top ten according to a listing provided by the *Engineering News Record* of the top 400 Contractors for 2006 (ENR 2006). Rankings were established by construction revenue in 2005. Large construction companies had been selected since they have the capital and the means to be able to experiment with new methods and they are usually more amenable to implementing new technologies. There were no specifications towards the types of projects the companies built. Project types ranged from all sectors of the construction industry including commercial, industrial, and residential.

3.1.1 Design of the Survey Questionnaire

The survey was developed with a series of open-ended questions in which the respondents described, in their own words, the types of technologies they were using as well as the benefits

or constraints in implementing technology in construction. For this research, the term "Virtual Reality" is used to define BIM or any other technique used to give real time visualization of the built environment. This survey entitled “Analysis of the Use of Virtual Reality within the Building Industry” can be found in Appendix B.

This survey targeted upper level management, Project Managers, and Project Engineers. Data was analyzed by job title in order to determine their perspective as well as their experience with construction technology. Some of the data for the survey was collected as a result of interviews by way of telephone conversations and others were sent the survey by email to be filled out and returned.

3.1.2 Explanation of Survey

The survey was developed to collect responses to the following types of questions:

Personal and Company: This section included a series of questions pertaining to the respondent’s personal information as well as their company’s background. The purpose of this section was to gather information pertaining to the respondent’s circumstances that could be used in the analyses to determine any variations in their perspective.

Fundamental Understanding of Virtual Reality: This section was used to analyze how the respondent would define Virtual Reality. Once they gave their perception of what Virtual Reality meant to them, they were given a definition of what the term Virtual Reality meant for survey purposes. The term was defined as BIM or any other Real Time visualization of a computer generated model.

Strategy of implementing Virtual Reality: This section explored the methods of Virtual Reality being used by the respondent or the respondent’s company. The intent was to ascertain the respondent’s perception of whether they saw any benefits or opportunities in using BIM technology in construction.

Actual Experience in Virtual Reality Implementation: This section was only answered by those respondents that have used BIM technology or any other virtual reality method in a construction project. The structure of the questions addresses the respondent's experience with BIM as well as the barriers and benefits of using BIM on a construction project.

Reflection on Virtual Reality implementation: The series of questions in this section pertains to the respondent's recommendation, if any, for implementing BIM technology in the construction industry. Respondents were also asked to reflect on whether there is a place for Virtual Reality in the construction industry and recommendations for a widespread adoption.

If there is no Virtual Reality usage in the company; Why? The series of questions were only answered by respondents that had no experience with any Virtual Reality technology in a construction project. The intent of the questions were to analyze the respondent's perception as to why they have not utilized the technology and what circumstances would need to change to implement a widespread acceptance of Virtual Reality technologies.

3.2 BIM Case Study

The research involved creating a BIM of M.E. Rinker, Sr. Hall at the University of Florida. The BIM of M.E. Rinker, Sr. Hall was created as a means of simulating how BIM can be used from a contractor's perspective. The BIM was generated from the original AutoCAD® plans and specifications provided by the architect. The BIM model integrated multiple databases that simulated scenarios to identify potential problems, generate "what if" scenarios, and visualize what components needed to be installed. The data plugged into the BIM included:

- Material specifications from the construction documents.
- Costs of the components provided by the estimate.
- 2d plans will be used to generate 3d plans.
- Construction schedule for sequencing analysis.

3.2.1 Analyzing the BIM

The purpose of selecting an existing building was to make sure that all the data necessary to develop a BIM that resembles the actual project with real data was available. Once the BIM was completed, analyses of problems encountered in the project pertaining to conflicts in the plans were compared to a BIM approach that could have avoided the issues. The focus of the construction document analysis was to find problems as a result of:

- Information required by general contractor that were not incorporated in the plans.
- RFIs due to interoperability conflicts in the plans.
- Fallaciously interpreted information in the plans by general contractor.

3.2.2 Selection of Software

The Rinker Hall BIM was created with Autodesk® Revit® software, an innovative design and documentation software built for BIM. Revit® was chosen as the BIM software because it is considered the product of choice in the construction industry. Although there are many other BIM software applications currently in the market, Revit® was developed by Autodesk® whose AutoCAD® system has been widely used in the building industry for many years. Therefore, many clients trust the Autodesk® name and are switching from an AutoCAD® system to a Revit® system.

CHAPTER 4
WHAT IS BIM

There are many misconceptions about BIM in the construction industry. Some industry leaders feel that BIM is just a phase and it will be done with soon. Others understand the importance of the BIM movement, yet are waiting for others to try it out first. The imperfect perception of BIM has caused the greatest barrier for implementing this technology. A survey was sent out to construction companies across the United States to understand their perceptions on BIM and the ways to overcome the barriers. The analyses of the survey led to the determination of best practice methods for implementing BIM on a project.

4.1 Industry Perception

For the purpose of this study, six (6) construction companies were interviewed to determine the extent of technology being used by contractors. The perceptions of BIM in the construction industry were analyzed as a means for assessing BIM usage in the building industry as well as comparing the traditional methods of planning with a BIM method. By understanding the perceptions of industry professionals, solutions for overcoming barriers in implementing BIM technology can be derived. The questions used in the interviews can be found in Appendix A.

4.1.1 Interview Results

As mentioned in Chapter 3, the construction companies selected were those ranked amongst the top ten according to a listing provided by the *Engineering News Record* of the top 400 Contractors for 2006 (ENR 2006). Figure 4-1 illustrates the types of projects the six (6) companies commonly engage in. Even though each one of these companies had a stronger reputation for a different sector, the commercial sector was the common link amongst them. The project type plays a vital role in the understanding of BIM implementation because the industrial

and infrastructure construction companies have different methods of building compared to those that are strictly commercial and residential. This is due to the fact that industrial projects are designed and constructed in the same office by the same company. In essence, communication becomes a lot more efficient in building a project. It was found that because of this ease of communication, the companies involved in industrial or infrastructure work have greater successes in implementing BIM technology. Figure 4-2 shows the companies that have taken a formal decision that BIM should be used throughout the company's projects. However, these same companies have not had success with using BIM technology when the construction division is coordinating work for a commercial project designed by a different company.

Construction technology is nothing new in the construction industry. In fact, every company interviewed was using some sort of streamed line method for efficiently completing tasks. Figure 4-3 is a summary of the different applications construction technology is being used for by these companies. The respondents where not provided with a list of technology applications. Instead they were asked to list the technologies they were using at the time. It was found that many of the companies were using the same techniques for productivity enhancement.

Within the six (6) companies that were interviewed, at least three (3) employees responded to the survey. Figure 4-4 illustrates the different job titles that were interviewed. Upper management responses focused on how BIM technology affected the company as a whole. Whereas project managers focused more on how projects can be affected by BIM technology. For the purpose of this research, upper management includes: Vice President, Chief Executive Officer, Senior Vice President, and Chief Information Officer.

The listing below illustrates specific responses to questions in the survey. The job title of each respondent is noted in order to distinguish the perception of BIM for upper management

versus project managers. For the purpose of this research, the term Virtual Reality was used throughout the questionnaire to define BIM and any other 3d or 4d technique.

When, how and why did you/your company start to use VR technology?

- With the invention of the computer, we found that computers gave the added value we where looking for and there were no limits to the things we can do with them. We brought together computer programmers, software developers, and contractors to share ideas and knowledge. *Upper Management*

- We used it for cutting cost on labor. We felt that by preplanning the construction, we would not have to spend time reworking items on the plans that were not planned well. *Upper Management*

- We saw BIM as an important movement in the construction industry and saw a need for it. *Upper Management*

Has your company taken a formal decision that VR should be used in the company's projects?

How was this decision formulated?

- We created a Steering committee compromised of the IT Department and upper management in mapping out the progress of using BIM. *Upper Management*

- The use of BIM is included in all project contracts that can benefit from the use of it and is included as a separate line item. *Project Manager*

- The company's decision to use BIM on a project depends on a client's needs. We educate our clients on the need for BIM on the projects, but at the end, it is up to the client since they are paying for it. *Upper Management*

Based on your experience, what have been the greatest barriers to the introduction and use of VR technology in your company?

- The greatest barrier has been trying to get full support from top management. In order for BIM to be used throughout the company, everyone in top management must be on board. *Project Manager*

- Trying to get architects involved in BIM technology from the initial phase of a project has also been a hurdle. *Project Manager*

- Trying to get all the programs working together has also been an issue. Example, transferring an AutoCAD® document to ArchiCAD®. *Project Manager*

- Adaptation. The barriers are the workers who have been in the construction industry for many years and feel that they have been able to perform their jobs without it, so they do not see the need for it. *Upper Management*

- The greatest barrier is cost. Trying to convince the client to buy into using it for their projects. *Upper Management*

What do you see as the greatest advantages and benefits of using VR today?

- It cuts labor costs since they are not as many change orders due to preplanning. Building Information Modeling enables the client to visualize how their building will look like, which eliminates change orders also. *Upper Management*

- Building Information Modeling allows the laborers and management to visualize the task at hand. This way they all understand what needs to be done, so productivity increases. *Project Manager*

- The ability to solve the collision of voids through the overlaying of systems. *Project Manager*

- There are too many times that we receive construction documents form the architect/owner who wants us to begin work without 100% complete documents. The owner/architect says that the documents are 80% complete. But how can you measure 80% complete? *Upper Management*

- It puts the company in a niche market by providing a service that their competitors might not offer. *Upper Management*

What would you consider to be major contributors towards the advance of VR into mainstream building activities?

- Outside contributors are needed to advance VR into the mainstream. These outside groups are educational institutions, computer software companies, and societies like the AES or ABC. *Upper Management*

- The industry coming together creating standards that will underline legal issues concerning roles and responsibilities in the development of a BIM. *Upper Management*

If there is no VR usage in the company, what do you see as the most important reason why you have not introduced VR in your company's projects?

- We question the value of virtual reality because so far we have been able to get the job done without it. *Upper Management*

- COST. The cost of training, the cost of IT support, and the infrastructure needed to support it. *Upper Management*

- There is not just ONE program in the market; there are various programs whether it is ArchiCAD, Revit, etc. So as a company, which do they use? We have had clients who require using a certain management program, then another client who asks for a different management program. It is difficult to train our employees on every program out in the market. *Upper Management*

- Documentation is also a concern. Currently, buildings are built using the signed documents given to them from the architect. Those documents also change as the project progresses. Yet all these documents are signed and dated, so it is easy to manage what was on the old drawing versus the new drawings. This will be hard to manage with a BIM system. There is no hard dated, signed and sealed document to build off. *Project Manager*

4.1.2 Conclusions from Results

The responses to the last question listed above, regarding companies that have not implemented VR technology, demonstrates the four main perceptions currently in the industry regarding implementing BIM technology. Research in implementing BIM in the construction industry needs to be focused on providing solutions for these four primary perceptions about BIM technology. It is concluded from the questionnaire that contractors are aware of BIM and are aware of the benefits they can gain from BIM. However, currently the risks are too great for contractors. All respondents agree that standardization is needed so that communication is the same throughout every project. A widespread acceptance into the mainstream will be evident once standardization is implemented that offers solutions to the four primary complexities involving BIM. This study will offer recommendations of how construction companies can overcome the barriers in implementing BIM.

4.2 Impact on Business Practice

The more you plan, the more you reduce risk. This is a principal benefit of BIM. It is not about the ‘wow’ factor as some of the interviewees responded to the survey. Building Information Modeling technology does not provide all the answers to the problems encountered

on a job site. Many researchers in the area of productivity in construction compare the construction industry and the manufacturing industry as if they are alike. However, the two industries do not share the same characteristics. The difference between the construction industry and the manufacturing industry is that in the construction industry, you can not control everything on a job site because there are too many unknowns. Some of the unknowns found in a construction project include:

- Construction Documents being coordinated correctly
- Weather conditions
- Every project is a custom design
- Underground site conditions
- Whether or not the entire crew will show up for work

In construction, the obstacles that can be planned for should be accurately planned for so that they do not become part of the unknown conditions. Building Information Modeling is a tool that allows those who are involved with the decision making to formulate better solutions faster, thus providing adequate control over the problems associated with the construction sequence. For a construction company, this means time saved on decision making as well as accurate predictions of the construction process. In turn, these benefits result in cost savings to the owners as well as faster project completion times. A satisfied owner will result in repeat business. Construction companies utilizing a BIM system will see an increase in productivity by their staff because decisions are made with illustrations and simulations that support their findings. By using BIM to explore options, an employee will not be afraid of investigating other options that will better correspond with the projects needs.

4.3 Initiation of a BIM Project

This section will describe the many ways in which a contractor can initiate a BIM system for a construction project. It is to be noted that the following suggestions are based on the

author's experiences in utilizing a BIM system and take into consideration that every construction project is different and may be organized differently. These suggestions can be used as a guideline for organizing a BIM project.

4.3.1 Development Method I

The first method is the optimum method for implementing BIM in a project. It involves utilizing BIM at the origination of the project. For organizational purposes, the project is broken down into three (3) phases; Preliminary Design Phase, Design Phase, and Construction Phase.

4.3.1.1 Preliminary design phase

This is the phase in which the project's intentions and goals are outlined by the client, architect, and construction manager. It is within the pre-design phase that the program for the building is defined as well as the budget. This phase today is usually compromised of just the architect and owner. However, BIM is all about collaboration. Thus, the construction manager needs to be involved as early as the pre-design phase to ensure adequate planning and budgeting.

The architect becomes the original author of the BIM. During the pre-design meeting, the architect can start designing the layout of the program. Cost databases are automatically inputted into the BIM and that allows us to see in real time the cost of the building as functions are added. This enables the project team to estimate the project budget and optimize the value of the building by analyzing design alternatives. For example, Figures 4-5 and 4-6 illustrate the cost of a metal panel wall system compared to the cost of a concrete wall. By using a BIM system early on in the project, a clear understanding of the building's functions as well as an accurate project budget can be established.

4.3.1.2 Design phase

The design phase is where the approved conceptual design is finalized. In this phase, the BIM is undergoing architectural detailing and consultants are brought in to ensure an integrated

building design. The architect's BIM is still the master model. However, the consultants are also presented with the BIM to integrate their systems. Figure 4-7 illustrates the organization of the BIM. It is important that the master BIM is constantly updated to reflect all the components integrated by the consultants.

The construction manager can use the master BIM for conflict detections early on to avoid Requests for Information (RFI) or change orders during the construction phase. As the BIM is further enhanced, the construction manager can effortlessly keep up with the automated quantities list to ascertain the project is still within budget. The construction manager can begin the construction schedule based on the BIM and analyze different alternatives for sequencing the project.

4.3.1.3 Construction phase

During the construction phase, the construction documents have been finalized, the cost of construction has been approved, and construction is underway. At this point, the construction manager has already used the BIM for conflict detections, therefore reducing future need for change orders or RFIs. The BIM at this stage will be used by the construction manager for coordination meetings with the subcontractors. Any conflicts that are detected are better analyzed during the RFI process because it is easier to visualize the problem in the model three-dimensionally. Conflicts that need to be changed by the architect are uploaded to the principal model automatically, which can then be tested for interoperability with the structural or mechanical systems.

4.3.2 Development Method II

The second method is when the construction manager is brought in after the construction documents have been created and the BIM has not been created by the architect. The BIM will be created by the contractor from the information provided by the construction documents. Even

though this method is not recommended as the best practice for utilizing BIM, it can still provide many benefits to the contractor. There are only two phases within Method II; BIM Development and Construction Phase.

4.3.2.1 Building Information Modeling development

The BIM development phase begins once the contractor has been awarded the project and is delivered the entire 2d construction documents. The contractor would need someone in-house to develop the BIM from the 2d construction documents. This person should be one of the project managers or project engineers who would be involved with the entire construction of the project. The duration of developing the BIM can be one week up to a couple of months depending on the complexity of the project. A good time to begin the BIM development would be during the mobilization of the project. In doing so, construction time is not wasted on developing the BIM and the contractor can still receive payments for work performed during mobilization. As the BIM is developed, conflicts will be detected before construction begins. Detecting conflicts early on will reduce the amount of change orders later on, saving time and money, thus resulting in a satisfied client and increase in worker productivity.

4.3.2.2 Construction phase

The construction phase of the first method is very similar to the second method. The only difference is that the master BIM is developed by the contractor, not the architect. Therefore any changes in scope need to be updated to the master BIM file by the contractor.

4.4 Software Selection

Building Information Modeling is not a program. It is a concept describing a new approach to architectural CAD. There are many software applications that market themselves as BIM compatible. The selection and training of the software becomes an important process in the

implementation of BIM technology. The wrong software selection can waste time as well as money.

The same software must be used by all the parties involved to ensure accurate compatibility. If two non-compatible programs are being used within one (1) project, data will be lost when trying to transfer information. Therefore, it is imperative that the software selection amongst all parties involved be discussed prior to the implementation of the BIM.

Within the past couple of years, the BIM concept has been widely accepted by the AEC industry. Numerous software vendors have developed BIM compatible software to profit from the growing market. From the survey conducted for this research, the construction companies all agreed that standardization in software selection is imperative. Construction companies do not want to pay for training employees all the different software nor do the employees want to undergo the training. An industry standard program needs to be established just as AutoCAD® was when it was implemented as a standardized program. Even though there are several BIM programs, there are currently two that are being widely accepted in the AEC industry; Autodesk's Revit® and Graphisoft's ArchiCAD®.

4.4.1 Autodesk's Revit®

Autodesk's Revit® is made by the same company that produces AutoCAD®. Therefore, many industry professionals have accepted this program due to the fact that Autodesk is a reliable name. Autodesk also offers extensive in house training to those companies seeking support and is compatible with AutoCAD® files. The compatibility allows for any document that was created in AutoCAD® to be imported into Revit® as well as a Revit® file being imported back to AutoCAD®. This becomes very important when you are working with a consultant who is not using any BIM program. If this problem does occur, the Revit® BIM can be exported as an

AutoCAD® file for use by the subcontractor. Once they are complete, the AutoCAD® file can be imported into the Revit® BIM file.

Since Autodesk's Revit® has become a popular option, there are other applications that can be synchronized with the BIM. E-Specs® is an application that integrates the BIM with the specifications document. It automates and synchronizes the insertions of the specifications section based on the object in the BIM. Once specifications have been created in e-Specs®, they are imported into Revit®. E-Specs® automatically detect the assembly codes of the objects in Revit®. This way, when a wall is selected in the Revit® BIM, you are provided with all the specifications for that division.

4.4.2 Graphisoft's ArchiCAD®

Graphisoft's ArchiCAD® is targeted at architects who want to explore 3d forms with modeling freedom. The 3d model can then be generated into a construction document set very easily. The 3d graphical model also contains non-graphical information about the object that can be used to extract information for cost estimated and scheduling. AutoCAD® files can be imported into the ArchiCAD® software. However the ArchiCAD® file must be exported as an AutoCAD® DWG file if the file is to be given to a subcontractor who is not using ArchiCAD®.

4.4.3 DProfiler®

Beck Technology developed BIM software called DProfiler for accurate 3d cost-based modeling. The program is used during pre- construction services to produce cost estimates in real time while modeling the concept of the project. The cost data base can be associated with either RSMeans or the contractor's own data. DProfiler® for pre-construction services produces conceptual estimates very easily, yet the 3d model produced in DProfiler® does not have the

capability to be used for construction document purposes. Therefore it is only a good estimating tool for pre- construction services.

4.4.4 Final Analyses of Software Selection

The best method in selecting what software application would best benefit the company is to contact the vendors and have them demonstrate what the product has to offer. Besides cost, it is important to compare the type of support the venders are offering. When implementing a technology as complex as BIM, it is advisable to have a representative of the software company provide a presentation to the users. Being part of the decision making process will boost employee moral and they will be eager to learn the new software. From a contractor's perspective, it is advisable to have some knowledge of both the Revit® application and the ArchiCAD®. This way projects will not be lost due to software compatibility. As mentioned previously, as of 2007, all federally funded projects will require spatial program BIMs as the minimum requirements for submission to OCA for final concept approvals by the PBS Commissioner and the Chief Architect (OCA 2006).The construction industry must be ready for the BIM movement or companies can loose business due to inadequate technology.

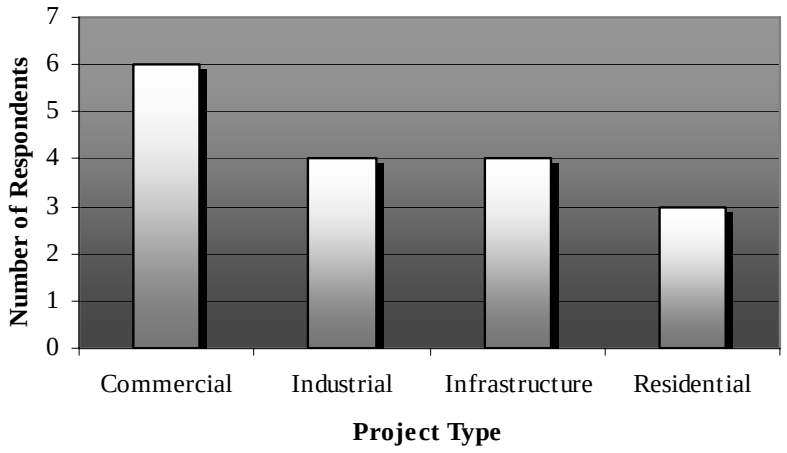

Figure 4-1. Types of projects most commonly engaged in.

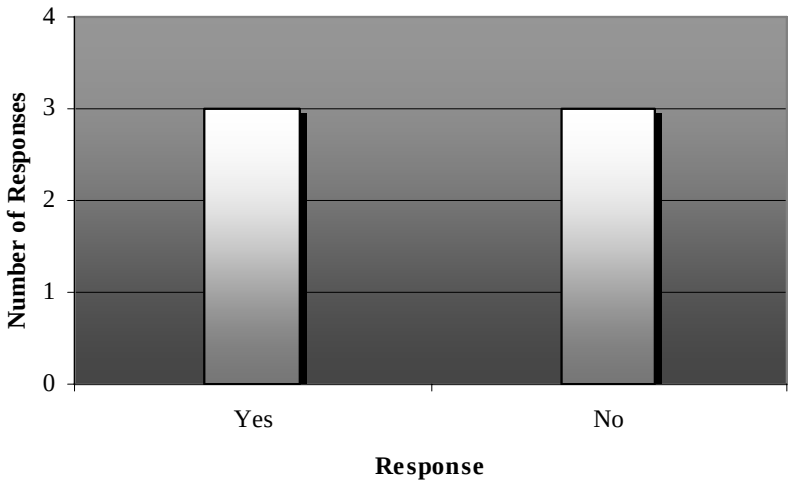

Figure 4-2. Has the company taken a formal decision in using BIM technology?

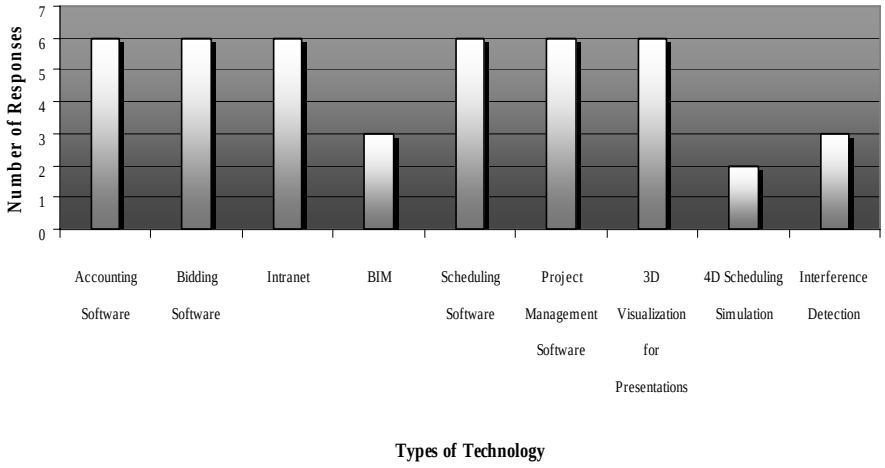

Figure 4-3. What types of technology are you currently using?

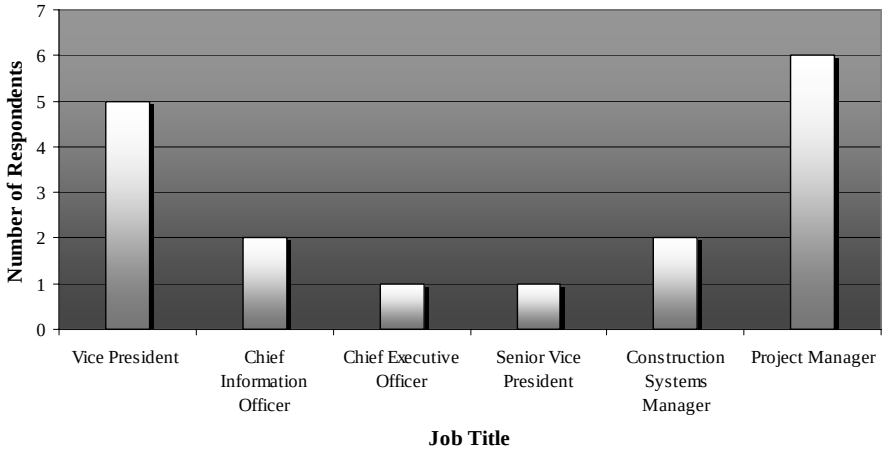

Figure 4-4. Job titles of the employees that were interviewed.

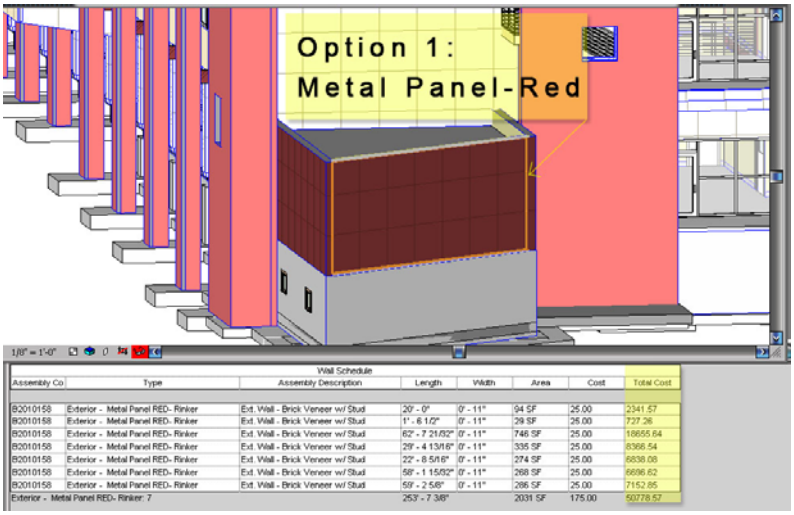

Figure 4-5. During the pre-design phase, design alternatives are investigated during owner/architect/ construction manager meeting.

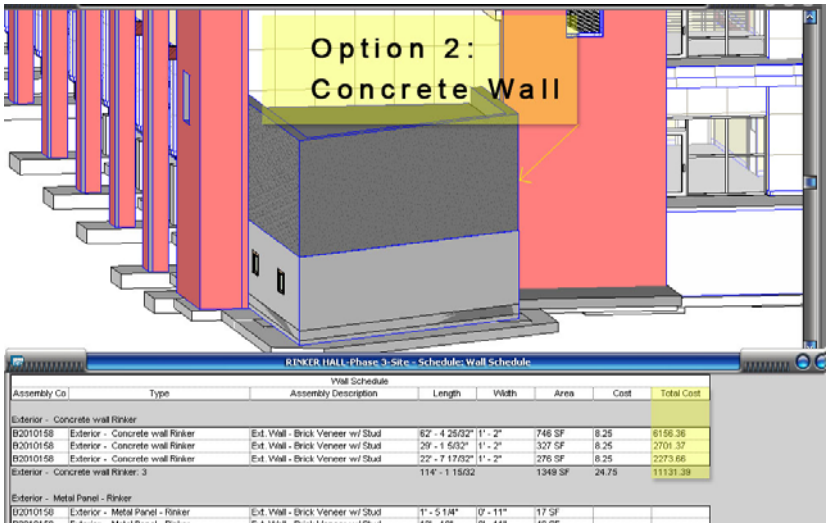

Figure 4-6. During the pre-design phase, design alternatives are investigated during owner/architect/ construction manager meeting.

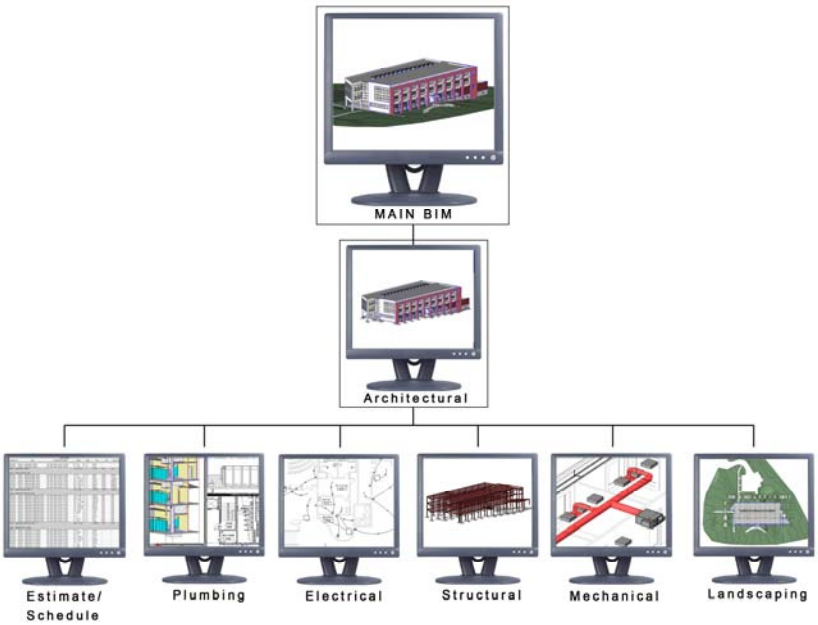

Figure 4-7. Proper organization of a BIM project to ensure adequate updates.

CHAPTER 5
BENEFITS FOR THE CONTRACTOR

The Building Information Model (BIM) is represented by the development of a model-based design supported by data used throughout the lifecycle of a building. A misconception determined from the respondents of the survey discussed in Chapter 3 was that contractors perceive BIM as a tool that benefits the architecture industry more than the construction industry. This is due to the uncontrollable nature of the construction industry as a result of too many unknown factors. Using BIM technology, all critical information is immediately available so that decisions can be made quickly and effectively. The following section demonstrates some of the potential benefits of BIM for use by the contractor. It should be noted that as BIM is gaining wide spread acceptance into the construction industry, advances in BIM technology are changing the AEC industry on a daily basis. In the next section a few contemporary examples of how BIM benefits a contractor are listed.

5.2 Pre-Construction Services

5.2.1 Estimating

Building Information Modeling supports 3d cost-based modeling that provides real time estimating data as the building is designed. The estimating feature in BIM can be used during the preliminary design phase of a project as a tool to effectively price and define the scope of work within hours instead of days. One method for effectively utilizing the 3d cost-based BIM modeling features is during the preliminary design meeting with the owner and architect. As the owner defines the functions of the building for the architect, the architect begins to model the building in terms of those building functions. At the same time, the contractor can input a cost database that produces real time data of the building costs while building objects are being added. The 3d cost-based modeling enables the project team to estimate the project budget and

optimize the value of the project by analyzing design alternatives very early in the project and within a few minutes.

The 3d cost-based modeling in the BIM is tracked in a material schedule which can be customized to the contractor's preferences to include the item, dimensions, costs, as well as classification system such as CSI. The material schedule can then be uploaded into the contractor's estimating software if they prefer to do so. However, it should be noted that the estimating capabilities in BIM vary among software packages. Figure 5-1 illustrates the material schedule capabilities in Autodesk's Revit® that parametrically gets updated as components are added. As a means for comparison, Beck Technology's DProfiler® can be used for accurate 3D cost-based modeling during pre-construction services to produce cost estimating in real time while modeling the concept of the project. The cost data base is associated with either RS Means' data or the contractor's own data. However, as mentioned in Chapter 4, DProfiler® is only a good estimating tool for pre- construction services because it does not have the capability to be used for construction drawing purposes.

5.2.2 Scheduling

Construction scheduling in BIM is an effective tool for the project team to visualize the construction of the building over time. Each object in the BIM is assigned a phasing code that is automatically linked to the schedule simulator. Playing the simulator in real time displays the building objects constructed over time. The simulation assists the scheduler with developing different phasing strategies that can improve the plan and improve communicating the plan to the project team. By simulating the construction process before hand, you can avoid complications which will save time and money.

5.2.3 Site Utilization

The BIM can be used to analyze the most efficient strategy for locating cranes, scaffolds, and material deliveries. For example, the simulation capabilities may be used to plan the path and loads for each crane, as well as test for any interference with the radius of the boom. Simulating resources can be tied back to the schedule and analyzed for optimal use as well as constructability.

5.2.4 Interference Detection

Detection of interferences during the pre-construction stage is another valuable feature of BIM. The BIM contains all the divisions of a project including the architectural, structural, mechanical, plumbing, and electrical. However, all of these components are inputted by the different consultants involved in a project. In the traditional 2d method, the problem of having different consultants inputting their data into the architect's original plans usually causes overlooked interferences with other components. The interference detection tool in BIM allows the contractor to run a report that lists every component that is interfering with another object and illustrates them in 3d. The BIM detects the functional relationships between the building components and understands how they should react to one another. The walls, floors, ducts, and pipes all have set parameters that understand how to relate to another object. The interference report can then be given to the architect to correct all conflicts prior to construction. Figure 5-2 illustrates the report discovering the interference of a door positioned on the railings of a stair, highlighted in red. The ability to analyze the BIM for interferences early on helps avoid RFIs and COs during the construction phase saving both time and money.

5.3 Job Site During Construction

5.3.1 Visual Communication

The vast amount of construction documents necessary for the construction of a building generates delays in communication when answers are needed right away on the field. BIM streamlines the process of accessing information through the ability to navigate to any view in the 3d model. The contractor does not need to rely only on the 2d plans the architect has provided. Instead, the contractor can navigate the 3d model generating their own views of the building. The visual communication abilities in BIM make project coordination amongst the project team efficient since 3d visualizations offer a better representation of the project. For example, the subcontractor responsible for installing the interior ceiling notifies the contractor that they are having trouble understanding how the ceiling is to be constructed from the 2d plans. The contractor and the subcontractor analyze the BIM cutting their own sections, elevations, 3d views, and create photorealistic images to better understand the ceiling installation (Figure 5-3). Streamlining the information gathering process through visualization can increase the productivity of a project since time will not be wasted waiting for answers. Perhaps most importantly, the BIM visualization capabilities would substantially reduce cost overruns in construction inaccuracies due to misinterpreting the construction documents. Coordination between the project team can be easily planned and by seeing the process, the project team members will each know their role.

The BIM visual communication abilities can also facilitate the Request for Information (RFI) process for a contractor in the field. An RFI serves as a communication tool between the contractor, architect, and engineers for clarification or additional information regarding conflicts in the construction drawings. They are usually typed in a word processor attached with an image describing the conflict. The attached image usually involves photocopying the portions of the

construction drawings that are affected by the conflict then scanning them into the computer to be sent as an attachment or sent as a fax. The process, although effective in communicating the conflict, is time consuming.

Instead, using BIM, the contractor can drag and drop the plans into a blank sheet while adjusting the display to focus on the conflict. The contractor can also make notes on the sheet to clarify the cause of the conflict and suggest a solution to the conflict if necessary. This sheet can then be saved as an image and sent as an attachment to the architect as an RFI. Figure 5-4 illustrates the ability to create an image that could be sent as an RFI about interference.

5.3.2 Material List

The material list is another component of the BIM that enables the contractor to generate an inventory of all the materials associated with the project. As mentioned previously, the scheduling feature in BIM is bidirectional associated with the 3d model. As a result, data correlated with a building element will be automatically generated in the schedule. The material listing capabilities can help the contractor keep track of all the materials they need to order as well as the dimensions and specifications of that list. The list can be also used for estimating as mentioned previously in the estimating example in Figure 5-1.

5.3.3 Parametric Objects

Parametric objects in the BIM are components that combine data specifications with geometric representations. The objects provide an integrated system that can be used to simulate the behavior of a real-world system. The information found in the parametric objects is gathered from sources such as the manufacturers' specifications or designers' instructions. Figure 5-5 shows an example of a parametric door. Once selected, the properties of the door's specifications, size, cost data, fire rating, etc. are displayed.

Having the ability to view data driven parametric objects in an integrated digital environment gives contractors a clear overall vision of the project, as well as the ability to make better decisions faster. For example, the project manager on a construction site with a tablet PC viewing the BIM, can select the installed door they are currently standing in front of to determine whether the correct door was installed. Parametric objects also benefit the project engineer who is in charge of coordinating shop drawings. When looking at the structural steel shop drawings from the steel manufacturer, they no longer have to flip through pages of documents just to find the specifications they need to insure the right steel beam is being installed at the right location. For example, in the traditional 2d method, the plan sheet shows the location and type of beam, the elevation shows the height of the beam, the details sheet shows how the beam is connected, and the specification sheet shows technical information related to the steel. Once the search is complete, then all of the mechanical, plumbing, electrical, and architectural sheets need to be checked to verify that there are no interferences with the steel beam. Parametric modeling facilitates the shop drawing coordination process with just one click of a mouse button. Once the steel beam is selected in the BIM, all the specifications and requirements are displayed as well as automatic interference checks performed (Figure 5-6). The ability to access this information quickly and efficiently increases worker productivity, raising the quality and profitability of every project.

5.3.4 Interference Detection, Estimating, Scheduling

Section 5.2 discussed how BIM can be used for pre-construction services. However, the estimating, scheduling, and conflict detection abilities can continue to be used on the job site during construction. As previously mentioned, there are many unknowns within a construction project that effect cost and schedule. Utilizing BIM can greatly reduce the complications associated with a construction project through better communication and collaboration.

However, problems will always arise and the schedule and estimate will always need to be adjusted. The plans will be changed, either by change orders or additions. As a result, the interference detection must be used to insure the constructability of the project. Therefore, the interference detection, estimating, and scheduling features would be in constant use by the contractor for project coordination throughout the duration of construction.

5.4 Post-Construction

5.4.1 Lifecycle

In today's practice, contractors usually issue a warranty for a specified time on installed construction components after the building has been completed. The warranty covers all materials, facilities, workmanship, and equipment as being free of defects and of specified quality. Trying to backtrack through sets of documents and specification in order to find out what went wrong can be time consuming. Building Information Modeling has the ability to retain accessible information such as drawings, specifications, instructions, estimates, and schedules within one file. For example, two years after the project has been completed, the contractor receives a phone call from the building owner who states that the roof, which is still under warranty, has been leaking. Within moments, the contractor can verify whether or not the roof was installed correctly and materials met the specified quality by just selecting the roof in the BIM file. Once selected, the specifications for the roof along with all warranty information can be effortlessly accessible for informed decision making.

The amount of documents created during a construction project can be a gruesome task to keep track of. Especially if the building owner wants to make changes to the building fifteen years after the project has been completed. The information that is created throughout the life of the project is vital to the management of the building's lifecycle. This information is again utilized when the building goes through its natural changes – renovations, upgrades,

maintenance, etc. A BIM can provide a digital record of renovations and improvements to the building throughout the existence of the building, facilitating the search of information.

5.4.2 Facility Management

Facility management is described in the simplest terms as the management of the people, places, and things that make up a facility. What sets BIM apart from today's practices is that with the new methods and technology, management of the building can be kept for the life of the building within the BIM. Physical information about the building, such as finishes, tenant assignments, equipment inventory, and financially important data about departmental cost allocations can be stored and managed. Much more information can be generated to provide the building's owners, occupants, and visitors with data to help them through their daily lives. For example, the BIM can be used by security personnel in case of any emergency to have immediate access to information regarding an electrical panel, or even the fire rating of a wall. The BIM can also be used by maintenance personnel to facilitate the information gathering process for repairs on mechanical systems.

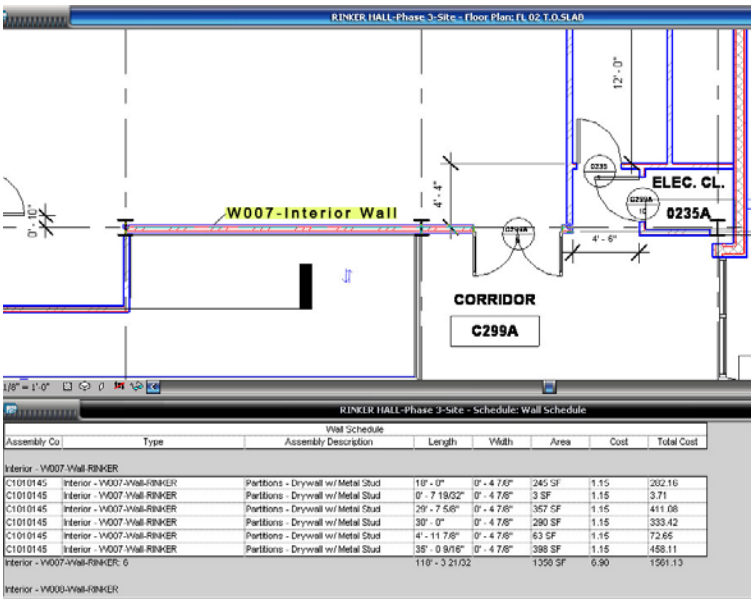

Figure 5-1. Autodesk's Revit® parametric material schedule.

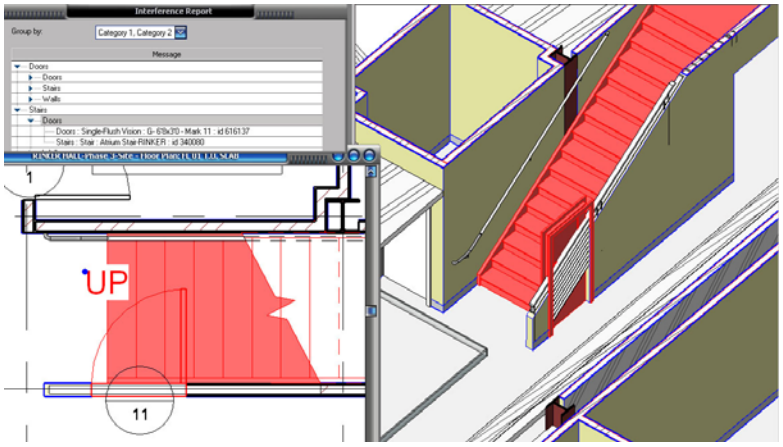

Figure 5-2. Interference report detects a door positioned on the railings of the stair.

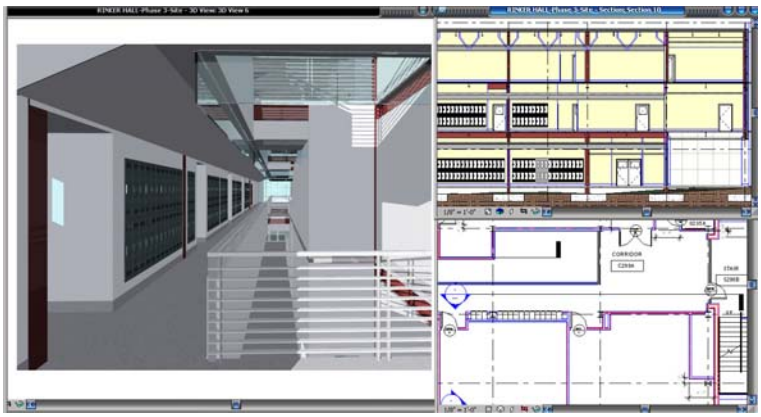

Figure 5-3. Visualizations offer better communication on the field.

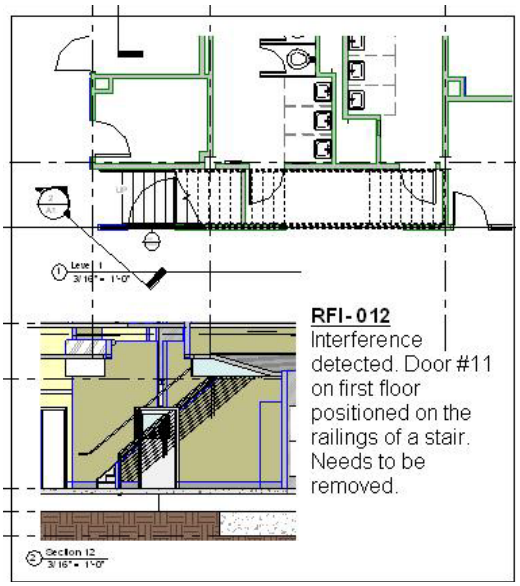

Figure 5-4. Request for information coordination image

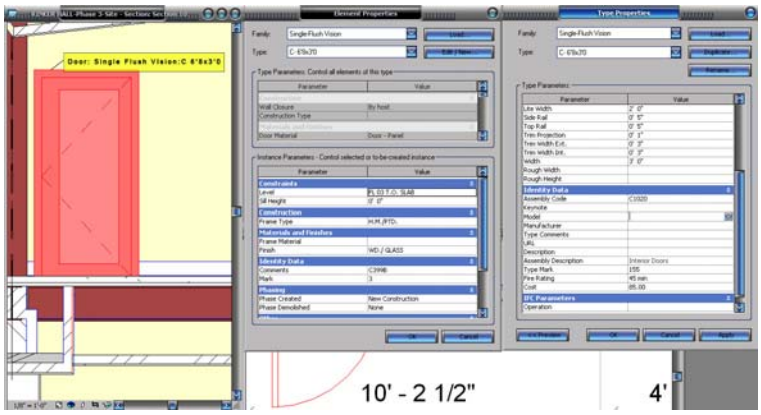

Figure 5-5. Parametric door

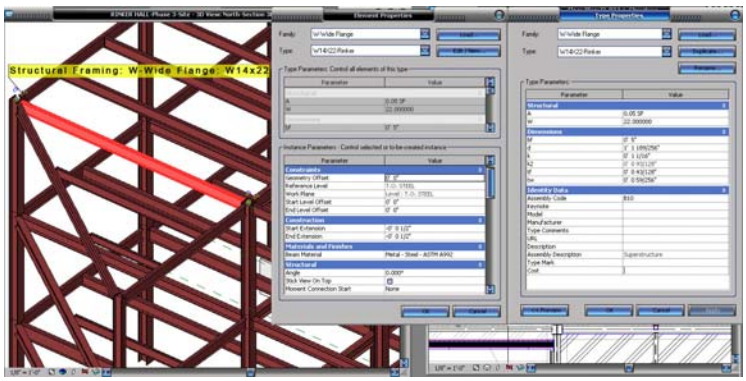

Figure 5-6. Parametric structural steel

CHAPTER 6
BARRIERS TO IMPLEMENTATION

Like with any other new technology, there are always going to be barriers to implementation. These barriers can be caused by the cost associated with implementation, miss-conceptions and legal complexities. The interviewees and respondents to the survey on the use of Virtual Reality, as discussed in Chapter 3, felt that there was an overall concern about legal exposures utilizing BIM. The concern comes from there being too many unknowns in terms of copyright protection of the BIM as well as who would be liable for the data inputted into the BIM. The concerns also come from the costs associated with implementing BIM on a project and trying to get the client to pay for the services. This next section discuses provisions that should be included in the project contract prior to the project commencement as well as paying for the cost associated with integrating BIM within a project.

6.1 Provisions to Include in Your Contract

An advantage of a BIM is that it serves as an information database for the life of the building. However, the difficulty in developing a BIM for a collaborative and multidisciplinary project arises due to the diverse task involved with the individual specialist being integrated into one shared representation. This has created a concern throughout the construction industry associated with copyright laws in utilizing BIM. Copyright of the project becomes an issue since there are now many parties involved with the design of the documents. The fear is who would have control of the model. Architects have always had control over the building documents thanks to the Architectural Works Copyright Protection Act. However, they are not the sole authors of a BIM and there are significant challenges in determining who has the role of BIM manager. The model manager is the individual responsible for the organization and implementation of the entire BIM.

The current Architectural Works Copyright Protection Act (AWCPA) defines an "architectural work" as "the design of a building as embodied in any tangible medium of expression, including a building, architectural plans, or drawings" (Copyright 2006). Protection includes the overall form as well as the arrangement and composition of spaces and elements in the design, but does not include individual standard features. Article 1 general provisions, AIA A-201 the general conditions of the contract for construction between owner and contractor, states that the copyright and ownership of the documents, drawings, and specifications remain with the architect. These provisions should remain the same for a project utilizing BIM because all of the inputs from the engineer or contractor are additions to the architect's original documents. Therefore, the architect should have full copyright to the BIM as well as ownership. This is further emphasized in the AIA B141, standard form of agreement between owner and architect, Article 1.3 in which the architect shall be deemed the authors and owners of their respective instruments of services (AIA 1997). The provisions regarding the instruments of services between the owner and architect need to be revised for a project involving BIM. Since the BIM can be used throughout the lifecycle of the building for facility management and other purposes, the owner of the building will need to have ownership of the BIM. This way, the owner can distribute the BIM to consultants that will need the BIM for facility management or performance. Provision within the contract documents should state that the architect will have full copyright of all the instruments of services and the building owner will have full ownership of the BIM. However, it ought to be clearly noted within the contract documents that the building owner needs to obtain written agreement of the architect for any distribution of the BIM as stated under Article 1.3.2.3 of the standard form of agreement between owner and architect. Changes in

the Architectural Works Copyright Protection Act will have to take into account BIM systems to eliminate copyright law suits in the future.

Since the architect owns the rights to the BIM, they assume the role as BIM manager. This means that the architect will be responsible for making sure the BIM is free from discrepancies from any party involved with contributing data. Provisions under the general conditions Article 1.2.3 should include a line item that protects the contractor from any discrepancies within the BIM and the architect should be responsible for managing the BIM. There are concerns with tracking responsibility for design input in a BIM system. The United States legal system requires that parties rectify harm caused by their negligence, and any party providing negligent design input ought to be liable if that negligence causes harm to end users or other project stakeholders (Bedrick 2006).

Article 1, AIA A201, under the general conditions of the contract for construction between owner and contractor ought to include a statement with the aim of permitting the contractor to build off of any view generated from the BIM. The BIM allows a user to view three dimensional details of the building and also allows the user to cut additional sections of the building that provide the user with more information of how the building comes together. The views are additional information that may perhaps not be found in the signed and sealed construction documents provided by the architect. Figures 6-1 and 6-2 illustrate how the contractor can generate their own views of the building by drawing a section line through the plan. Once the section line has been created, a new window appears that automatically cuts a section through the building. This section can also be generated as a three dimensional view that provides even more information to the builder about how the building comes together. The ability to generate views is a great tool for builders to comprehend the design of the building. However, contractors need

protection in the contract as a preventative measure for being responsible for discrepancies within the BIM. Precautions can be set by including the BIM as part of the contract documents within the standard form of agreement between owner and contractor, AIA Form A101, under article 8 “Enumeration of contract documents”.

6.2 Who Should Pay for the Service?

Respondents from the survey discussed in Chapter 4 established that convincing the owner to pay for the services involved with BIM implementation imposes a barrier. The respondents cited that they already have trouble trying to convince the owner to pay for items such as fax machines, printers, cell phones, and computers used for the project. One upper management personnel responded, “The greatest barrier is cost. Trying to convince the client to buy into using BIM for their projects will be an unavoidable situation.” The building owner is ultimately responsible for paying all cost associated with a building project. These costs include everything from the design, consultant fees, construction, jobsite trailer, faxes, and all costs associated with printing the construction documents. Consequently, every time the construction documents need to be changed due to poor communication, interoperability conflicts, or inadequate specifications, it is the building owner who ends up paying for all inconsistencies. It is the responsibility of the architect and the contractor to educate their clients on the potential of BIM. Clients need to know how BIM can ultimately save them time and money through enhanced project collaboration and pre-planning.

As BIM technology continues to gain widespread acceptance, owners are also realizing the benefits of utilizing BIM technology and are requesting it to be used. Therefore, the conception that building owners will not want to pay for the services of using BIM technology will be inadequate in the near future. Instead it will be the building owners who will ultimately drive BIM adoption. One of the first owners that have mandated the adoption of BIM within all of

their projects has been the Federal government. This came after a recent report by the National Institute of Standards and Technology, entitled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry," which quantified the annual cost of waste due to inadequate interoperability among computer-aided design, engineering, and software systems in the construction industry to be $15.8 billion. Due to this report, as of 2007, every federally funded project must utilize a BIM system (OCA 2006). Research collected for this thesis has shown that many building owners are also following this approach and have mandated that BIM be used for the design and construction of their projects.

Neither the owners nor the architects need to drive BIM adoption nor do they need to pay for the services. Contractors can decide to implement BIM within a project and still save money as well as benefit from all the advantages of BIM technology. The developers of the BIM program ArchiCAD noted that the development of a BIM for the use of the contractor was estimated to be 0.1% of the total cost of a project (Khemlani 2006). Listed below are the many different ways in which a contractor can make back that 0.1% expense and perhaps gain more profit.

- The project may be finished earlier than expected.
- Mistakes caused by the contractor can be avoided, eliminating the need for rework at contractor’s expense.
- Estimates can be more precise, eliminating the need to pay for items that were not accounted for in the bid.
- The project schedule can be planned more accurately, decreasing delays in the project due to poor scheduling and eliminating the need to pay for liquidated damages.
- The client will be satisfied with the project performance due to the contractor catching errors in the plans prior to construction as well as the enhancing communication.
- Client recommendations for future projects will be inevitable.

The cost of BIM should not be a barrier to implementation for any party involved with a project. The initial cost of developing the model will be justified at the end of the project when the project team realizes how much time and money they were able to save due to all of the advantages of BIM previously listed. Those who do not see the advantages must be educated on BIM. Contractors need to realize that in the near future, it will be the owners who will mandate that a project is to be designed, constructed, and delivered utilizing BIM technology. This is due to owners being tired of having to pay for the costs of inadequate drawings, oversight, and communication failures. Research conducted for this thesis concluded that owners view BIM as a method for reducing all the previously stated problems. The initial expense of implementing BIM on a construction project will pay for itself in the long run.

Figure 6-1. Image on the left is of a BIM floor plan. The image on the right illustrates the section tool being used to generate a section view.

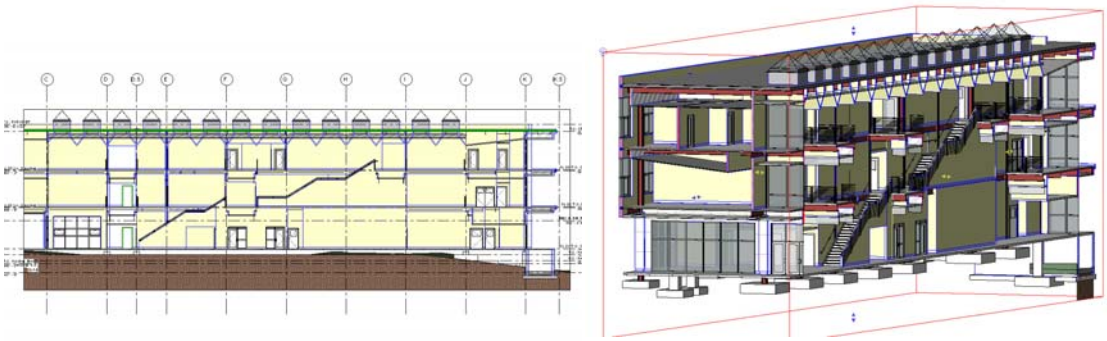

Figure 6-2. Image on the left illustrates the section view generated by the section tool. The image on the right illustrates the section viewed in 3d.

CHAPTER 7
IMPLEMENTING BIM

The following section discusses methods for implementing BIM technology within a construction company. This section is a reflection of the author's personal experience with BIM as well as the recommendations from construction industry professionals as discussed in Chapter 4. This section should be taken as a guide. Technology changes on a day to day basis. For an accurate guide to implementing BIM technology, consult with software venders for their input on the appropriate methods of implementing BIM technology.

7.1 Purchasing Equipment

BIM software selection as discussed in Chapter 4 will depend on the clients needs. One of the misconceptions from the respondents of the survey was that they would have to upgrade all their hardware and networking requirements to work well with a large BIM project. Although this is true to some extent, a majority of the large construction companies that build large projects already have the recommended hardware requirements.

Work-Sharing Networks: In the case of most projects, the work will be done remotely. A remote project is a project in which the participants involved in the collaboration process are located in different areas. For instance, the contractor is located on the job site whereas the architect is located in their office. It is recommended that one server be set up for the project. Participants in the project BIM, from architect to engineers, need access to the remote server in order to update the master BIM. Project teams located in the same office are networked together in a local area network (LAN). The server can be accessed via the LAN by all project participants, streamlining data transfers. However, this is not the case on a typical construction project. Especially a BIM project that requires the collaboration of various project teams spread out in different locations, even countries. A Wide Area Network (WAN) is needed to streamline

data across a wide geographic area (Figure 7-1). According to an article published in the Cadalyst, improvements in WAN technology have allowed for faster transfer speeds and have caused a reduction in WAN traffic by 95% (Rundell 2006). Many construction companies before the improvement were reluctant in utilizing a WAN network because of the slow transfer speeds. Companies that have implemented BIM technology have had success with Riverbed's technology Steelhead application. The Steelhead application provides faster WAN data transfer and reduces the risk of hacking, viruses, and data theft (Rundell 2006).

Distributing the BIM over a network which links to the master file is a barrier which has industry professionals concerned with how it will be monitored. The survey discussed in Chapter 4 found that the respondents were concerned with the liability of changing the wrong component and even changing the plans without the consent of the architect. Software companies have solved this issue by providing work sharing capabilities. The work sharing software allows for work to be distributed based on systems.

The systems are monitored and distributed by the author of the master BIM, usually the architect. For example, the mechanical engineer can only enter information pertaining to their discipline and cannot modify anything else. The architect can only modify components that pertain to the architectural discipline and not the structural or electrical. The work sharing application keeps record of who entered what on what day and to what model, reducing the possibility of editing conflicts.

7.2 Training

The first stage of training is to plan a strategy for training. Careful planning is crucial to the success of the training. Planning the training for BIM should take careful consideration of all the individuals the change will affect. This is especially difficult for construction companies since all of their employees are spread out across different jobsites and jobsites can not be closed

down for training. The company's culture and ages of employees can create a significant barrier to the overall implementation process. Respondents to the survey discussed in Chapter 4 established that the older generation gave the most difficulty whenever the company tried to implement a new technology. Superintendents were found to be the most reluctant to any new methods in construction technology. The common conception is that they have been in the construction industry for many years and feel that they have been able to perform their jobs without it, so they do not see the need for it.

It is for these reasons that training is so crucial to implementing BIM technology. Employees and management need to understand that BIM is not the answers to every problem and it will not do the job for you. It is a tool, just like a drill that allows a user to perform their task faster or a backhoe that can dig a ditch faster than a man with a shovel. The decision to train is a decision that affects the entire company. This is why it is important to get the input off all the staff members that will be affected by the decision to train and be willing to adjust any implementation plans to accommodate the company's employees. Accommodating the staff will make them appear as if they are a part of the decision, therefore, they will be more acceptable to the change and training process. Listed below are different training methods for implementing BIM technology in a construction company.

7.2.1 Training Strategy I: Pilot Project Approach

The first training strategy is the pilot project approach. The following strategy is for a project in which the BIM is created by the architect or engineer. The construction team is concerned with extracting information for viewing purposes, scheduling, estimating, interference detection, etc. The strategy involves selecting one project team to be trained on the BIM software before any work is begun on the project. A project team is required to be involved with the entire sequence of a project; estimating, planning, mobilization, and construction. The team will spend

5 days during working hours, generally four (4) hours out of the entire working day, in training. By allowing only four (4) hours a day, the team can still have the rest of the day to perform any billable work required for the project. The training should be organized and tailored to cover specific project issues. The issues that should be covered are those only necessary to the construction industry as described in chapter five. Little time should be spent on the overall basic tools such as drawing walls which would be done by the architect. As the project is underway, an on going training process will occur throughout the length of the project. It is important that the project team be provided with information of who to contact for support. It is a good idea to familiarize the trainer with the project so that they can serve to answer specific questions that pertain to the project as they arise. This method is considered an on-call method and has been successful to many companies that are implementing BIM technology.

The pilot project approach can also be used if the construction company takes on the responsibility of creating the BIM from the construction documents. However, training would be more extensive and must cover the basics of the program. Both aspects of the pilot project approach serve as a great method for the entire company to see whether BIM will benefit them. This method can serve as a learning curve which can then be used to develop a proper strategy for implementing BIM training throughout the company.

7.2.2 Training Strategy II: Tailored training

The second training strategy is recommended for those companies that have decided to implement BIM training throughout the entire company. Construction sites cannot be shut down due to training and employees do not want to spend their weekends in training. Method two involves dividing the training into task specific groups. Listed below are the three groups.

- GROUP 1. Schedulers and Estimators
- GROUP 2. Superintendents

- GROUP 3. Project Managers, Project Engineers and Field Engineers

The groups should be trained on specific task that pertain to their job requirements. Splitting into groups also creates an interactive training environment in which the employees will be able to ask specific questions and have specific discussions pertaining to their job descriptions. It is also advisable to split each group into two so that not all the superintendents or project managers involved in a project will be away from the job site. After the initial training stages, employees should be provided with the contact information of a dedicated support person who can answer questions as issues arise on the job. The dedicated support needs to be made easily accessible and must respond to any issues in a timely way to not allow any frustrations amongst the employees. This will ensure an adequate implementation process amongst the staff.

7.3 Case Study Results

As previously mentioned in Chapter 3, research involved in creating a BIM of the M.E. Senior Rinker Hall, School of Building Construction at the University of Florida. The BIM of Rinker Hall was created as a means of simulating how BIM can be used from a contractor's perspective. All BIM images seen throughout the thesis were produced from the BIM created of Rinker Hall. The following section analyzes the experience of developing a BIM from a novice user's perspective.

7.3.1 Case Study Development

The BIM was created from the original 2d construction documents and specifications. It took one person 149 working hours to produce the BIM with very little knowledge of the software. Table 7-2 shows the working log which kept track of the task being performed as well as the level of experience in using the BIM software. It is noted that only the architectural, structural, and landscaping divisions of the construction documents were included in the BIM. The software selected to create the BIM was Autodesk's® Revit® Architecture which does not

have the capabilities to model the mechanical, electrical, and plumbing divisions. Autodesk's® Revit® MEP needed to be used in order to incorporate the mechanical, electrical, and plumbing divisions into the Rinker Hall BIM. Autodesk® provides a free student version of Revit® Architecture that was used to generate the Rinker Hall BIM for the thesis. However, Autodesk® does not provide a free student version of Revit® MEP. The author notes that for the purpose of this thesis, the divisions that were included in the Rinker Hall BIM were significantly sufficient to sustain the overall objective of the thesis.

7.3.2 Case Study Training

Training on the software was being performed as the BIM of Rinker Hall was being produced. This method proved to be very successful in developing the necessary skills needed to produce the BIM. A total of 37 hours of training were spent prior to the commencement of the Rinker Hall BIM. During this initial stage, training focused on the basic functions of the software. Then a total of 27 hours of training were utilized throughout the duration of the Rinker Hall BIM which focused on solving problems that arose during the BIM development. Figure 7-4 illustrates the training log kept throughout the creation of the Rinker Hall BIM.

The level of experience illustrated in Figure 7-4 demonstrates the increase in software comprehension while working on a pilot project at the same time as training. The scale ranged from a level of one to a level of ten. A level 1 experience signified very insignificant knowledge of the software. Mastering the software was signified by a level 10 experience. By the end of the Rinker Hall BIM development, an experience level of seven was attained which proved the theory that working on a pilot project while training enables the user to learn and comprehend the software more rapidly since the user is practicing what they have learned in the training.

7.3.3 Case Study Analyses

The expectations for creating the Rinker Hall BIM were to test whether BIM technology would be suitable for a contractor. In all, the overall development of the Rinker Hall BIM was found to be a success. The original 2d plans and specifications were able to be used to compose a data driven BIM.

However, one of the major outcomes of the Rinker Hall BIM was the ability to reduce by 40% all the recorded RFIs. Prior to the construction of Rinker Hall, the contractor kept a record of all the subtle ambiguities and interferences associated with the construction drawings, as illustrated in Figure 7-5. The Redicheck log was compared to the Rinker Hall BIM created for this thesis. It was discovered that out of the132 items listed in the Redicheck log, 52 could have been avoided if the original project utilized a BIM system from the inception of the project. Reducing the number of ambiguities prior to construction can eliminate the need for additional rework during the construction process, as well as additional costs and schedule delays. Figure 7-5 illustrates the 52 items discovered in the Redicheck log along with the BIM solution. Blunders associated with the construction drawings were characterized into three main solutions, listed below. The solutions were derived from the capabilities of a BIM system.

- BIDIRECTIONAL ASSOCIATION. An advantage of BIM is that is serves as one model that generates every plan, elevation, section, detail, and schedule. Therefore, a change in one drawing is a change everywhere. When a detail is called out in a plan, the page number associated with that callout will be accurate. Bidirectional association also signifies that if a wall is moved in one drawing, that change will be reflected automatically in any drawing associated with that wall. In comparison, in the traditional AutoCAD method of drawing, there is no automatic association between the drawing files. Therefore, the change of a wall placement may not be reflected in any other drawing associated with that wall unless the user remembers to do so. Bidirectional association eliminates human errors constantly correlated with inaccurate drawings.

- INTERFERENCE CHECK. The interference checking tool automatically scans the entire model for collisions between objects that should not have association. For instance, a mechanical duct interfering with a structural beam, one needs to be moved. The interference of such circumstance are detected in the BIM which then prompts the user to reposition the object

- VISUAL COMMUNICATION. BIM allows a user to explore the 3d model generating views necessary to understand the project. It also provides a material representation to distinguish the different components of the projects. The visual communication of a BIM project can reduce the need to ask the architect to provide further clarification or additional drawings.

System Recommendations for Revit® by Autodesk® (Autodesk 2007)		
	Small Projects	Large Projects
Operating System	Microsoft Windows 2000 or later	Microsoft Windows XP or later
Processor	Intel Pentium 4 1.4 GHz	Intel Pentium 4 2.8GHz
Hard Drive (RAM)	1GB	2 GB +
Free Disk Space	1 GB	1 GB +
System Recommendations for ArchiCAD® by Graphisoft® (Graphisoft 2007)		
	Small Projects	Large Projects
Operating System	Microsoft Windows XP or later	Microsoft Windows XP or later
Processor	Intel Pentium 4	Intel Pentium 4 2.8GHz +
Hard Drive (RAM)	1GB	2 GB +
Free Disk Space	1 GB	1 GB +

Figure 7-1. Hardware recommendations provided by BIM software companies

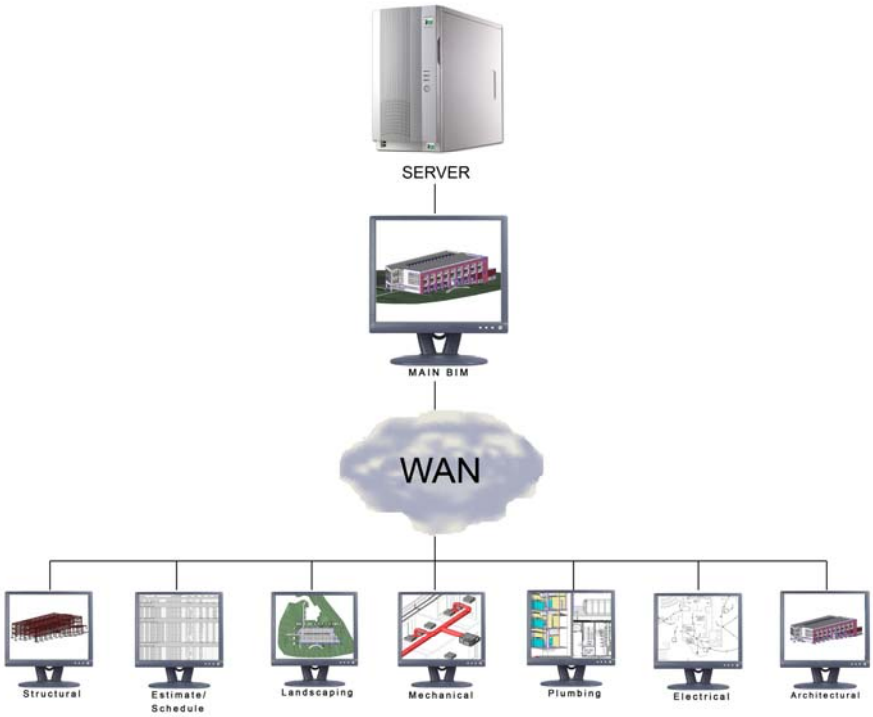

Figure 7-2. Illustration of a Wide-Area Network linking the project teams to the master BIM.

Rinker Hall Time Sheet	
Date	Date of work period
Hours	Total number of uninterrupted work hours for the given date.
Division	**A**rchitecture/ **M**echanical/ **S**tructural/ **C**ivil/ **E**lectrical/ **P**lumbing/ **L**andscape
Task	Brief description of work performed on the given date
Percent Complete	Percent complete of work of the given task item.
Level of experience	The modeling of Rinker Hall in Autodesk's Revit® was the first time the user had ever used Revit®. The level represents the users understanding of the program.

DATE	TIME	DIVIS-ION	TASK DESCRIPTION	PERCENT COMPLETE %	LEVEL OF EXPERIENCE
10/1/06	10	A/S	Modeling foundations / structural steel	80 / 50	1
10/2/06	8	A/S	Modeling structural steel / ext. wall	80/ 20	1
10/3/06	4	A	Modeling floor slabs / glazing system	100 /60	1
10/19/06	8	A/S	Modeling & detailing ext. walls	70	2
10/20/06	8	A/S	Modeling & detailing ext. walls	90	2
10/21/06	8	A	Modeling & detailing of brick screen wall	90	2
10/25/06	4	S	Modeling & detailing Structural Steel/ brick wall	100/100	2
10/26/06	10	A	Modeling & detailing of roofs/ 1st flr plan	80 /70	3
10/31/06	8	A	Modeling & detailing of doors/ 1st flr plan	30/100	3
11/6/06	8	A	Modeling & detailing of doors/ 1st flr ceilings	100/100	3
11/11/06	6	A	Modeling & detailing glazing system	100	3
11/12/06	5	A	Modeling skylights / ext doors	50/100	3
11/19/06	3	S	Modeling west entrance canopy	90	4
11/22/06	5	A	Modeling west entrance canopy/ all stairs	100/100	4
11/24/06	9	A	Modeling & Detailing of 2nd flr plan / ceiling	70/10	4
11/28/06	8	A	Modeling & Detailing of 2nd flr plan / ceiling	100/60	4
11/29/06	3	A	Modeling & Detailing of 2nd ceiling	85	4
11/30/06	4	A	Modeling & Detailing of 2nd flr ceiling / 3rd flr plan	100/10	5
12/1/06	4	A	Modeling & Detailing of 3rd flr plan	80	5
12/2/06	4	A	Modeling & Detailing of 3rd flr	100/20	5
12/3/06	7	A	Detailing of 3rd flr ceiling/ skylights	100/100	5
12/5/06	2	A	Modeling & Detailing of Mechanical Room	100	6
12/5/06	4	A/S	Detailing of Ext Walls / Foundations/ Roofs	100/100/100	6
1/5/07	6	L	Modeling & Detailing of Ext Landscape	70	7
1/6/07	3	L	Modeling & Detailing of Ext Landscape	100	7
1/10/07	4	A	Material Schedule	100	7
TOTAL WORKING HOURS				**AVERAGE LEVEL OF EXPERIENCE**	
149				**3.81**	

Figure 7-3. Rinker Hall BIM development log

DATE	TIME (hour)	TRAINING	DESCRIPTION
9/24/06	6	Introduction	Intro to the Revit application: menus, toolbars, interface
9/25/06	7	Modeling	Creating generic walls/ windows/ doors
9/26/06	6	Sheets/ Views	Creating sheets and views: elevations, section, plans
9/27/06	4	Structural	Modeling structural beams/ columns
9/28/06	8	Structural	Modeling foundations, structural framing
9/30/06	6	Modeling	Creating wall and window families
10/3/06	4	Floors/ Roofs	Detailing and creating specialized floor systems
10/18/06	8	Walls	Detailing and creating specialized wall systems
10/21/06	5	Brick Walls	Detailing brick walls and adding wall sweeps
10/25/06	4	Interior Walls	Creating specialized families of walls types/ wall schedule
11/12/06	2	Skylights	Creating skylight family
11/20/06	2	Tapered Beams	Creating parametric tapered beam system
1/5/07	2	Site	Creating site and landscaping
TOTAL	**64**		

Figure 7-4. Building Information Modeling software training log.

ITEM	SHEET	DESCRIPTION	DRAWING TYPE	BIM SOLUTION
1	A201	Elevation 3 might be the East Elevation	Architectural	Bidirectional Association
2	SU-2	Location of stair, bike racks, & entrance AVW C4.0	Civil/ Landscape	Bidirectional Association
3	SU-3	Location &routing of structures for storm lines AVW C4.0 &C5.0	Civil/ Landscape	Interference Check
4	A101	S-1 Drainage structure in construction yard AVW	Civil/ Landscape	Interference Check
5	A404	Sloped Cantilever beam shown on section 1 is AVW S2.0	Structural	Bidirectional Association
6	A202	West End canopy on elevation 4, might want to reference detail 1/A404	Architectural	Bidirectional Association
7	A104	Roof drain location near F-1.75 AVW S4.0 Beams	Mechanical	Interference Check
8	A201	Handrail not shown on stairway	Architectural	Bidirectional Association
9	A701	Wall types W001 & W002 show fire safing- Could not locate Fire Rating for wall type	Architectural	Bidirectional Association
10	A102	Cuts 4/A402 & 5/A402 might be reversed	Architectural	Bidirectional Association
11	A201	Mullions not shown on elevations 2 & 3 AVW A103	Architectural	Bidirectional Association
12	A803	Is the Building glass or metal panels at the lowest row between col lines E & D?	Architectural	Visual Communication
13	A152	Skylight locations AVW Structural openings S4.0	Architectural	Interference Check
14	P-3	Align roof plan and 3rd floor plan left to right	Mechanical	Bidirectional Association
15	M-2	Ceiling height, exterior, interior glass, and glazing shown on A102 is AVW ductwork shown on M-2 in room 125	Mechanical	Interference Check

16	P-2	Roof leader riser location @ Column line F3 AVW drywall chase A102	Mechanical	Interference Check
17	P-2	Storm & sanitary lines AVW with footings on S1.0	Mechanical	Interference Check
18	M-3	Exhaust fan & return ductwork AVW required ceiling height	Mechanical	Interference Check
19	A152	Ceiling height AVW ductwork & fans- See M-3 & 1/A405	Mechanical	Interference Check
20	S2.0	W 14x12 beam in between col line S 2 & 3 & H & I AVW P2, W14 X 30 beam in between E & F running from 1 to 2 is AVW P2	Mechanical	Interference Check
21	E103L	Size of lighting fixture D-2 AVW schedule. One calls for 2x2 & other calls for 2x4	Electrical	Bidirectional Association
22	E103L	Most Electrical Fixtures on plans do not coordinate with fixture schedule	Electrical	Bidirectional Association
23	E004	Location of Fans AVW M-4	Electrical	Interference Check
Note: AVW signifies "does not correspond with"				

Figure 7-5. Rinker Hall RFIs that could have been avoided utilizing a BIM system.

CHAPTER 8
FUTURE DIRECTION

Although Building Information Modeling is a relatively new term being used throughout the AEC industry, the technology has been around since the early 1990's. It is due to recent advances in technology that BIM is beginning to reach its potential in the AEC industry. It is without a doubt that with the recent popularity of the technology, more improvements and additions to BIM technology will be inevitable. The following section illustrates how BIM technology can impact the construction industry in the future.

8.1 Building Information Modeling Within the Next Five Years

Within the next five years, the major impact in the direction of BIM will be the widespread acceptance throughout the AEC industry. Building Information Modeling will replace the traditional AutoCAD method of designing and new standards that are currently being created will be finalized. Contractors will be brought into the design development phase early on instead of after the construction documents have been created. Bringing in the contractor early on has already been a realization because owners are realizing the long term savings in a well coordinated project. However, within the next five years, the architect, contractor, and owner will be utilizing BIM technology for design development, estimating, and scheduling for pre-construction.

Mobile Technologies: Building Information Modeling will be used in every construction site by project managers and project engineers to facilitate project collaboration. Besides utilizing the BIM for construction management tasks, the way in which we view the BIM will have a significant impact on construction jobsites. The desktop and laptop computers currently found in jobsite trailers will be replaced by mobile technologies like tablet PCs and PDA telephones that will allow for portability of the BIM. Mobile technologies can allow a contractor

or field worker to access the project information needed to complete a task without ever leaving the point of work, improving production efficiency. The contractor can walk around the jobsite with the BIM displayed on the mobile technology answering any questions from the subcontractors without having to go back and forth between the jobsite trailer and building (Figures 8-1 and 8-2). Currently, mobile technologies are being created to be more durable in the rugged conditions of a construction site. Within the next five years, durable mobile technologies will be available at a reasonable cost with the ability to handle a BIM file on site. The user would be able to maneuver in 3d the BIM model with the touch of a finger and will be able to write notes on the screen that could be saved for future use.

8.2 Building Information Modeling in the Future

We are becoming an information based society that has developed countless programs that produce and manage huge amounts of data throughout all sectors of our economy. Building Information Modeling is one of those tools with the main purpose to produce and manage data to facilitate the construction process. As a result, BIM will evolve to be an integral part of every new technology produced for the construction industry. There are endless possibilities with BIM technology. The following section explores some of the futuristic applications of BIM in the construction industry.

8.2.1 Developing a True Paperless Office

Construction projects generate enormous amounts of data in paper format, which are then filed away. Many construction companies today are taking control of this by using electronic means to document information instead of printing every document. Yet the plan room is still filled with mounds of construction drawings that are constantly being reproduced every time there is a change in scope.

In the future, the plan room will be replaced by large durable multi-touch screen monitors that display the BIM (Figure 8-3). Multi-touch sensing will enable users to interact with a system with more than one finger at a time. The technology enables a user to zoom in and out by opening and closing two fingers, grab plans and position them somewhere else on the screen, and glide through programs without ever using a mouse or keyboard. If it seems impossible, the technology is currently being used in the new iPhone developed by Apple. Even though the technology exists today, the cost associated with providing each project team member with a large multi-touch screen is currently too expensive. However, with advancing in technologies, the cost will be greatly reduced in the future. The cost of supplying each project team member with the screens will be cheaper than the printing and delivery charges currently associated with paper form construction plans.

The project teams' desktop computer will be replaced by a workstation. The workstation will consist of a large multi-touch screen monitor built into the desk connected with two smaller display monitors (Figure 8-4). The BIM can be viewed and maneuvered with the multi-touch screen monitor. Selected views can be dragged by hand motion to the other monitors for viewing purposes. The other monitors can also serve to run additional applications besides the BIM such as project management software or email. For example, a project engineer can have the BIM model displayed on the multi-touch screen while accessing the shop drawings in the BIM on one of the dual monitors. The other monitor displays a live video feed of the construction project for communication purposes with the field engineers. The project engineer can access the necessary views from the BIM by touching the view to open it on the screen. They can then grab the view to move it to on side of the screen where they then double touch the section call out to open the section. Once the project engineer has made notes for adjustments on the shop drawings, they

then drag and drop the file to the email program to be sent to the architect for final approval. The project engineer receives a phone call from a field engineer who needs clarification of the construction drawings. The project engineer zooms in on the project webcam displayed on the other monitor to the specific area of question. They access the BIM locating the area on the model and clarify the drawings to the field engineer by emailing the clarification view to the field engineer's mobile PDA. In the example, productivity has been increased due to:

- Delivery packages do not need to be prepared for shipping the drawings to the architect or engineer.
- Piles of drawings do not need to be searched to find the necessary information.
- Photocopies of the plans for writing notes to be sent as an RFI do not need to be made.
- Changes by the architect or engineer to the plans are updated to the main shared BIM. Eliminating reprinting all the drawings associated with the plan.
- The project engineer does need to walk to the site, see the problem, walk back to the office to search the construction plans for the answer, and then walk back to the site to clarify the situation to the field engineer.

8.2.2 Construction Automation

Construction automation aims to develop remote control robots capable of construction works to remove dangers, reduced the need for labor, and increases the productivity of a project. In the future, the automation systems will be able to be controlled within the BIM. For example, the Surf Robo is a finishing robot that automatically finishes concrete floor surface, eliminating the need for laborers (Takenaka 2001). The robot is equipped with two sets of rotary floats and is currently controlled by a wireless remote control. However, the future BIM will allow a user to set predetermined path of the floor to be finished. Another example of an automated system is the steel welding robot. Automated welding enable construction projects to be executed in a short time, eliminates the shortage of skilled welders required, and is 40% more efficient than

using welders (Takenaka 2001). The path of the robot can also be set and controlled within the BIM.

Perhaps the most significant automation tool currently in use today is the SMART system. The SMART system closely resembles the production process of the manufacturing industry. It consists of a roof equipped with a lifting mechanism, machines erecting structural steel frames and curtain walls, automatic welding machines, and a control system. Construction takes place in stages; the roof is raised a level, the steel structure is erected and outer panels are attached, then the process is repeated. The roof also helps eliminate construction delays due to inclement weather. The upper floor is assembled first and becomes a *Sky Factory* or a building production plant. The SMART system has been found to reduce labor cost by 50% and shortened construction periods by 30% *(R&D* 2002). In the future, the SMART system will be able to be designed and controlled in the contractor's BIM. The BIM will allow the operator of the SMART system to maneuver the erecting machines in a 3d environment which can keep track of all the installed components. The list of installed components can be accessed by the project manager who can use the data for creating progress payments.

The future possibilities of technology associated with BIM are endless. Building Information Modeling will never replace the human factor in designing and managing the constructing of a building. But the tools developed will make the building process more efficient, saving time and money.

Figure 8-1. Building Information Model viewed on a tablet PC.

Figure 8-2. Building Information Model viewed on a mobile PDA.

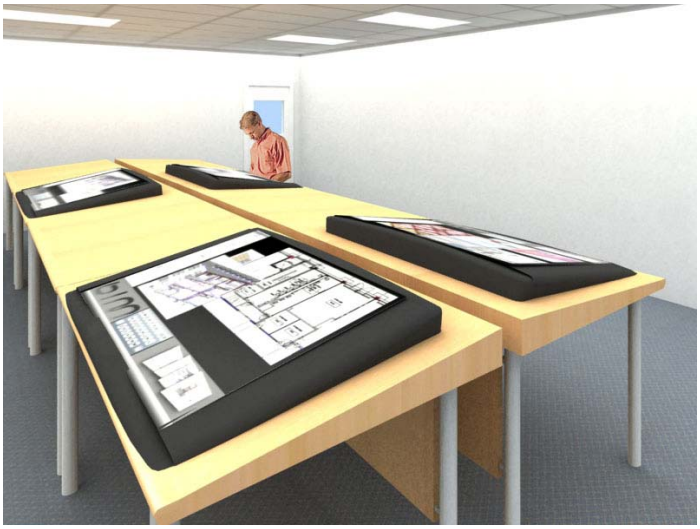

Figure 8-3. Multi-touch screen monitors in plan room.

Figure 8-4. Work station

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

Building Information Modeling (BIM) is the wave of the future and will revolutionize the AEC industry as AutoCAD did in the late 1980's. However, it is not until we solve the challenges involved with implementation that we will see BIM be utilized to its full potential. This study identified barriers associated with implementing BIM in the construction industry as well as methods for overcoming these barriers. Understanding what BIM is as well as the benefits to the contractor will help facilitate the wide spread acceptance of BIM technology throughout the construction industry.

Both the survey and the case study developed for the research highlighted significant facts correlate with BIM realization. First, despite current implementation challenges, all of the respondents indicated that they do see the benefits of BIM technology in the construction industry. Second, standards that will provide guidance to participants of a BIM project must be established. In addition, education and awareness about BIM technology are critical to counter the resistance to change.

Addressing legal exposures must be resolved before the standardization of BIM in the building industry becomes a reality. Research is currently underway by various organizations to eliminate any legal exposures by providing rules that will guide participants of a BIM project. These rules will create a common language amongst the industry which will harmonize work between all organizations involved in the building industry. The rules will have to deal with significant issues including defining professional services, regulation of revisions to the model, and define ownership of the BIM.

The technology is here and the potential opportunities are too exciting to ignore. The BIM created for Rinker Hall proved that even in these early stages of BIM development, the

technology shows significant benefits to the contractor. However, the potential for BIM can only be realized if software companies come together to provide a true BIM program that combines all the capabilities into one program. This problem was noted during the Rinker Hall BIM development produced for this thesis. In the analysis, Revit® was used to create the 3d model which generated data to be inputted into the scheduling, estimating, animation, and specification programs. Using one program to manage all the necessary components of a project will facilitate the widespread adoption of BIM because companies would not need to worry about training their employees in all the different BIM programs as well as compatibility conflicts between the different programs. Software companies need to realize that information sharing between the different BIM applications is essential to achieve better interoperability between the different software.

The lack of interoperability amongst the software applications is one significant barrier of implementation. However, the research concluded that it is also the lack of BIM knowledge within the construction industry that is impeding the implementation process. This thesis establishes best practice methods for implementing BIM within the construction industry. Incorporating these best practice methods can facilitate the implementation process by providing the reader with the necessary knowledge to make informed decisions.

The BIM case study developed for this study was generated from the construction documents of an already completed building. The completed building served as a basis for comparing the traditional method of construction with a BIM method. It is recommended that BIM be used for a new project throughout the complete life cycle process for further studies. In addition, the future study should analyze user involvement with the BIM software recording any

difficulties that reduce worker productivity. The solutions to the difficulties can be added to the best practice guide eliminating any barriers that can impede the BIM implementation process.

APPENDIX A
LIST OF TERMINOLOGY AND ABBREVIATIONS

- AEC. Architecture / Engineering / Construction
- BIM. Building Information Modeling
- BUILDING. In BIM, it is the building that is required to be managed.
- CO. Change Order
- INFORMATION. The Information / data that is obtained from the building.
- LIFECYCLE. Describes all the phases of the building process: design, construction documents, procurement, construction, maintenance, additions, and demolition.
- MODELING. The model that houses, maintains, and controls the flow of information needed to manage the building
- NBIMS. National Building Information Model Standards
- NIST. National Institute of Standards and Technology
- OCA. Office of the Chief Architect
- PDA. Portable Digital Assistant
- PROJECT TEAM. All entities involved in delivering a project; architect, engineer, contractor, subcontractor, etc.
- RFI. Request for Information
- TABLET PC. Mobile computer with a touch screen technology allowing the user to operate the computer with a digital pen or fingertip instead of a keyboard and mouse.

APPENDIX B

ANALYSIS OF THE USE OF VIRTUAL REALITY WITHIN THE BUILDING INDUSTRY

1. Personal and Company Questions:

a) Name of the Interviewee:

Please confirm they give consent to use their names?

b) Age*:*

c) Job title:

d) Name of the Company:

e) Number of employees in this company:

f) Type(s) of projects your company is most commonly engaged in (check all that apply):

Commercial

Industrial

Infrastructure

g) How many years have you been working in the built environment industry?

2. Fundamental understanding of Virtual Reality (VR):

a) How do you define Virtual Reality?

b) For the type(s) of projects your company most commonly engages in, what type(s) of visualization techniques do you use?

3. Strategy of implementing VR:

a) When, how and why did you/your company start to use VR technology?

Explore whether outsourcing to a third party company was considered.

b) Has your company taken a formal decision that VR should be used in the company's projects?

c) If yes: how was this decision formulated?

d) What benefits and opportunities did you think you would have by using VR technology *before* you started using it?

4. Actual experience of VR implementation:

a) How do your initial expectations compare with the actual experience?

b) Based on your experience, what have been the greatest barriers in the introduction and use of VR technology in your company?

c) Has a business case concerning VR been evaluated?

d) Approximately what proportion of your company building projects involves VR use?

e) Which type of building projects involves VR use?

f) Is VR being applied to the

i. project initiation (collaborative decisions)

ii. Design

iii. Procurement

iv. Construction

v. Maintenance

5. Reflection on VR implementation:

a) What do you see as the greatest advantages and benefits with using VR today?

b) What do you see as the greatest disadvantages or the greatest difficulties with using VR today?

c) What would you consider to be major contributors towards the advance of VR into mainstream building activities?

d) Would you recommend the more widespread adoption of VR technology in the Building Industry?

e) What are your reasons for this recommendation?

f) Do you use computer models in other ways than real time visualization?

g) What, if anything, could instigate your company to use VR-models in projects to an even larger extent than what is the case today?

h) Can you provide us with the names of TEN people in your company who could complete an on-line questionnaire for this research?

6. If there is no VR usage in the company:

a) What do you see as *the most important reason* why you have not introduced VR in your company's projects?

b) What are your concerns in using virtual reality tools in your projects?

c) What do you think the benefits would be?

d) What circumstances would need to change in order to enable the introduction of VR into your company's building construction projects?

e) Would you consider implementing these techniques in your company? Why?

f) Do you use computer models in other ways than real time visualization?

LIST OF REFERENCES

Alpert, S. R., Karat, J., Karat, C.-M., Brodie, C., and Vergo, J. G. (2003). "User attitudes regarding a user-adaptive eCommerce web site." User Modeling and User-Adapted Interaction, 13(4), 373–396

Brown, C., Beaton, H. (1990). “Looking back at design, looking forward to construction,” Journal of Management in Engineering, 6 (3), 342–349.

Bryan, Tony (2005). Construction Technology: Analysis and choice, 1st Ed.,Blackwell Publishing, Malden, MA.

Bedrick, James R, AIA (2006) “The Architect’s Handbook of Professional Practice”. John Wiley & Sons, New York, N.Y.

Chau, K.W. (2005). “4D dynamic construction management and visualization software.” Automation in Construction, 20th International Symposium on Automation and Robotics in Construction: The Future Site, 14(4), 512–524.

Chew, M.Y.L. (2001). Construction Technology for Tall Buildings, 2nd Ed., Singapore University Press, Singapore.

Davis, Dianne (2006). “BIM Update.” <http;//www.aia.org/tap_a_0903bim> (October 2, 2007)

Elvin, G. (2003). “Tablet and Wearable Computers for Integrated Design and Construction.”<http://www.comitproject.org.uk>(Jan. 20, 2007).

Engineering News Record. (2006). “The Top 400 Contractors for 2006.” Engineering News Reocord, <www.ENR.com> (November 3, 2006)

Finkelstein, Ellen. (2006). AutoCAD 2007 and AutoCAD LT 2007 Bible. Wiley Publishing, Hoboken, N.J.

Goldberg, Edward H. (2004). “The Building Information Model.” CADalyst, 21(11), 56.

Goldberg, Edward H. (2006). “BIM Update 2006: How complete is the building information model?” Cadalyst, 23(11), 49–51.

Goldstein, Harry. (2001). “4D: Science Fiction or Virtually Reality?”<www.Construction.com> (Jan 29,2007).

Hall, Dennis (2006) “The Architect’s Guide to the U.S. National CAD Standards”. John Wiley & Sons, New York, N.Y.

Holness, Gordon. (2006). “Building Information Modeling.” ASHRAE Journal, 48(8), 38–46.

InterSpec. (2007). “E-SPECS Software Solutions.” E-Specs, <www.E-specs.com> (March 14, 2007)

Junge, Richard. (1997). CAAD Futures 1997: Proceedings of the 7th international conference on computer aided architectural design futures, Kluwer Academic Publishers, Dordrecht.

Khemlani, Lachmi. (2004). “Autodesk Revit: Implementation in Practice.” Arcwiz, <http://www.arcwiz.com> (Feb.2, 2007)

Khemlani, Lachmi. (2006). “The AGC's BIM Initiatives and the Contractor's Guide to BIM.” AECbytes, <http://www.Aecbytes.com> (Oct.11, 2006)

O’Shaughnessy, Christopher (2003). “Your architectural works are protected by the Architectural Works Copyright Protection Act.” Construction Professionals’ Legal Update, 1(1).

Rundell, Rick. (2006). “BIM on a WAN.” Cadalyst, <www.Cadalyst.com> (March 15, 2007)

Stubs, S. (2005).“Interoperability panel warns get it or quit it.” Proceedings, National Convention and Design Exposition, AIA, Las Vegas, NV

Tah, Joseph H.M. (2005). “Toward an agent-based construction supply network modeling and simulation platform.” Automation in Construction, International Conference for Construction Information Technology, 14(3), 353–359.

Takenaka. (2001). “Concrete Construction Robot.” Developed Technologies, <www.takenaka.com> (April 08, 2007)

U.S. Copyright (2006). “Copyright Claims in Architectural Works.” Library of Congress. < http://www.copyright.gov/circs/circ41.html> (October 20, 2006)

U.S. General Services Administration (2006). “3d Building Information Modeling.” U.S. General Services Administration. <http://www.gsa.gov> (October 25, 2006)

Watson, G.H., Tucker, R.L., Walters, J.K. (1993). Automation and robotics in construction X: proceedings of the 10th international symposium on automation and robotics in construction, Elsevier, Amsterdam, The Netherlands.

Zhu, Y., and Issa, R.R.A. (2003). “Viewer controllable visualization for construction document processing.” Automation in Construction, 12, 255–269

Office of the Chief Architect. (2006) GSA Building Information Modeling Guide, 1st Series, Washington, D.C.

BIOGRAPHICAL SKETCH

Edwin A. Perkins earned his master's degree from the M.E. Rinker, Sr. School of Building Construction at the University of Florida in Gainesville. He interned for Centex Construction as Project Engineer working on one of the biggest development projects in South Florida, where he was exposed to key issues in the building process. While pursuing his master's in building construction, he worked as a graduate teaching assistant for the school of architecture, teaching various digital programs, including BIM technology. Prior to earning his master's degree, he attended the University of Florida School of Architecture, where he earned a bachelor's of design in architecture. During this time, he interned at Zyschovich Architects, as project designer, where he gained the background and experience with various large-scale urban projects.

Edwin's research interests are in the areas of design and construction technology, with emphasis on the implementation of technologies in the building industry. He has also served as President of Spacial Visionz, a visualization studio providing 3D renderings and animations for architects, developers, and construction managers.