RETURN ON INVESTMENT ANALYSIS OF BUILDING INFORMATION MODELING IN CONSTRUCTION

By

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To my parents

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LIST OF ABBREVIATIONS

BIM	Building information modeling
VDC	Virtual design and construction
AEC	Architecture/ Engineering/ Construction
ROI	Return on investment
RFI	Request for information
COR	Change order request
CO	Change order
GMP	Guaranteed maximum price

Abstract of Masters Thesis Presented to the Graduate School
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RETURN ON INVESTMENT ANALYSIS OF BUILDING INFORMATION MODELING IN CONSTRUCTION

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Building information modeling (BIM) signifies the creation and use of a three-dimensional virtual model that replicates the design, construction, and operation of a building. This technology's recent emergence and the evolution of virtual design and construction (VDC) in the architecture, engineering, and construction (AEC) industry is fundamentally changing the process by which buildings are designed, constructed, and used for future generations. However, BIM's high initial cost has deterred many industry professionals from putting the technology to practice. In many cases, an owner's acceptance of BIM is crucial to the success of a company's capacity to finance VDC goals. In order to persuade stakeholders to see the potential benefits of paying additional fees, this study presents the possible cost savings of BIM's implementation. The research objectives were to justify the high initial investment of BIM, to encourage a greater commitment to technological advancements in the AEC industry and to convince the general public of BIM's cost savings.

A comprehensive literature review was performed to define BIM and its history in the industry, present its quantitative and qualitative benefits, and find similar case studies that have been conducted on the return on investment (ROI) of using BIM. Using a sample of past project

data from a medium-sized commercial construction firm, two case studies of varying project types were conducted. In each study, a recently constructed BIM-assisted project was compared to a similar project constructed without BIM. The potential savings to an owner choosing to invest in BIM as an additional service were estimated based on the measurable cost benefits associated with reduced schedule overruns, fewer requests for information (RFIs) and reduced change orders.

This research confirmed that BIM is a worthwhile investment for owners. In the two case studies presented, the ROI of BIM varied greatly from 16% to 1654%. Though an owner's decision to invest in BIM should be weighed heavily against the scale and complexity of a project, this research suggests that vast savings may be realized regardless of a project's size.

CHAPTER 1
INTRODUCTION

The advent of building information modeling (BIM) and virtual design and construction (VDC) has allowed the architecture, engineering, and construction (AEC) industry to radically transform the process in which buildings are designed, constructed, and utilized. To many construction professionals the reduction of change orders, requests for information (RFIs), reduced project delay, and accelerated discovery of construction conflicts is great enough incentive to invest in the software, manpower, training, and time required to implement BIM. However, BIM's high initial cost, in addition to a genuine lack of understanding and fear of change that exists within the industry has resulted in its relatively gradual adoption by contractors. One of the greatest obstacles facing contractors when deciding whether or not to implement BIM is the subject of cost. As owners and developers are the "economic drivers" of a project, their acceptance of BIM is crucial to the success of company's ability to finance VDC initiatives. In order to persuade stakeholders to see the benefits of paying additional fees, data on the potential cost savings of BIM's implementation must be collected and analyzed.

Statement of Purpose

This research aims to justify the pricey initial investment of BIM and a greater commitment of funds toward improved technology within the construction industry. Through the use of a comparative case study, two construction projects of varying scales completed without the benefit of building information modeling were compared to two unique "BIM-assisted" projects. Through a cost benefit study and a return on investment (ROI) analysis, conclusions were made about the potential cost savings of BIM to an owner. Recommendations were made for future contractors interested in recording and calculating their own return on investment.

Scope and Limitations

This study used statistical project evidence such as the number of RFIs, the number of days a project was delayed past its original contract period, the number of change orders, and the total change in contract price in order to estimate the potential cost savings from a significant reduction in time overruns. For the purpose of this study, it was presumed that all of these factors were in direct correlation with BIM's execution, when in actuality it is likely other variables also contributed to each project's success or failure. As each project is unique in terms of staffing, location, productivity, client, architect etc., it was very difficult to quantify which benefits were directly associated with BIM and which were merely the result of improved work ethic, better relationships with owners and architects, and additional variables.

In addition, as BIM is still a relatively new undertaking of the company used for this study, little data was available on the cost savings produced by identifying construction design clashes. Therefore, the savings documented mainly consist of the indirect savings related to reduced schedule overruns and are likely a gross understatement of the actual savings produced by this technology. The metrics produced by this research are specific to the company studied and should not be assumed as an industry standard.

For the purpose of this study, a BIM- assisted project was matched against a similar previous project constructed without the use of BIM in order to demonstrate the improved results of BIM's utilization. However, it should be understood that no two projects are exactly the same and multiple variables contributed to the improved success of the BIM- assisted projects studied.

Lastly, analysis of BIM's return on investment is best understood from a comprehensive standpoint. Thus, the most significant savings are likely to be realized when utilizing BIM in a design-build delivery method. Though savings can be achieved by multiple parties, this thesis only presented the potential savings produced by BIM to an owner.

Organization

This chapter is the first of seven in total. It will serve to define and overview the purpose and rationale for this study. The literature review in Chapter 2 will present all prior research that is related to the topic, exhibiting a brief overview of BIM, its history, its quantitative and qualitative benefits, as well as other similar case studies that have been conducted on BIM's ROI. Chapter 3 will present a discussion of the research objectives and methods and describe the specific procedure that was followed. Chapter 4 will serve to present two comparative case studies conducted on four projects produced by a medium sized construction management firm and to interpret the data uncovered for further analysis. Chapter 5 will analyze the results of the findings. Chapter 6 will summarize conclusions that were made as a result of the study and Chapter 7 will list recommendations for future research.

CHAPTER 2
LITERATURE REVIEW

Introduction

In recent years, building information modeling (BIM) has been a subject of great interest within the construction industry; opening the doors to a world of innovation, technology and possibility. Numerous studies have been conducted to show the potential benefits of BIM and its applications. In addition, the improvement of technology and virtual design and construction (VDC) processes is consistently the subject of countless publications. Software companies are constantly reinventing current technology to resolve issues of interoperability and facilitate a standard set of practices and procedures to be implemented by BIM users. However, amidst this plethora of buzz worthy research, little information has actually been published about the cost savings that BIM may result in or how those savings are measured.

This literature review presents an overview of the current information available on building information modeling within the construction industry. It defines BIM in its entirety and presents a brief history of its development. The potential benefits associated with its implementation are discussed as well as the potential risks and roadblocks that may arise during its implementation. Lastly, the concept of a return on investment (ROI) analysis is presented and the results of similar case studies are discussed to show how it may be applied within this context.

Defining Building Information Modeling

According to the Construction Management Association of America: *Building Information Modeling (BIM)* is defined as: "The production and coordinated use of a collection of digital information about a building project (Egan 2008)." The National Building Information Model Standard (NBIMS) project, managed by the National Institute of Building

Sciences (NIBS) Facility Information Council (FIC), states that: "A building information model is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle, from inception onward (Madsen 2008)." But perhaps the most accurate definition comes from the United States General Service Administration's (GSA) Office of Chief Architect, who defines BIM 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 (Perkins 2007, p 16)."

Therefore, the revolutionary yet basic concept behind virtual design and construction (VDC) is to design and fully construct projects within the virtual world before construction begins in order to improve *all* phases of a project's conception. Thus, BIM facilitates design and schematics all the way down to project completion and continued operation, maintenance and facilities management throughout a building's usable life (Thomson and Miner 2006). What distinguishes BIM from traditional 3D modeling is its use of smart building components that are intelligent digital representations of actual construction components and its capacity to make changes that are reflected in all views. The associated data that is attached to these components is parametric, reliable and non-redundant, synchronized, and possesses information about how a component behaves to be used for analysis purposes (Eastman et. al 2008).

BIM Applications

Whether used by designers, contractors, or potential owners, BIMs are generated for many purposes unique to each party involved. Applications of this technology include: visualization, fabrication and shop drawing creation, energy and airflow analysis, structural analysis, sustainability analysis, conflict, interference, and collision detection, cost estimating, construction sequencing, code reviews, forensic analysis and facilities management (Eastman et. al 2008).

At its most basic level, BIM provides three-dimensional visualization to owners. Used as a marketing tool for potential clients, designers can employ this technology to demonstrate design ideas. In fact most BIM software platforms already include rendering engines that allow the production of photo-realistic images with little additional effort (Azhar et al. 2008). However, more useful to design professionals is BIM's ability to create an accurate set of construction drawings and supplemental documents rapidly and with reduced error. The ease in which shop drawings can be created for various building systems is also a potential draw for general contractors and subcontractors alike (Azhar et al. 2008). Some BIM platforms even facilitate the direct linkage of building components to specifications and manufacturer's websites, thus providing one universal location for information sourcing.

BIM technology not only aids the AEC industry in advancing traditional methods of production but actually has the capability of improving the process in which buildings are designed. Many BIMs have the power to conduct "constructability analysis, energy and airflow analysis, mechanical and structural collision identification, as well as conduct operations and maintenance reports (Thomson and Miner 2006)." BIM can even validate green design, making it possible to accomplish zero carbon emissions, reduce construction and facility waste, and increase building efficiency through alternative positioning and site-design (Madsen 2008). These capabilities may increase the speed of the LEED certification process and force designers and contractors to make more informed decisions.

In addition to the parametric properties of 3D BIM, the technology also has 4D and 5D capabilities. Recent advancements in software have allowed contractors to add the parameters of cost and scheduling to models to facilitate value engineering studies, estimating and quantity takeoffs, and even simulate project phasing (Holness 2006). These concepts provide limitless opportunities to the AEC industry.

Even after a building's construction is complete, BIM may still be useful to members outside the AEC community. An accurate model may be used by fire departments and other officials to conduct code reviews, improving upon the traditional permit process. Furthermore, facilities management can utilize BIM models to illustrate forensic analysis including potential failures, leaks, evacuation and space plans (Azhar et al. 2008).

Historical Background in the Industry

BIM is certainly not a new concept. In fact, the implementation of three-dimensional design software has been a vision of designers since the late 1970s and early 1980s. However, its growth within the construction industry has been a much more recent endeavor, gaining serious momentum only in the past five years. Within the design industry, the progression of change in construction documentation has been a very slow process. It began with manual hand drafting, transitioned to Computer Aided Drafting (CAD) in the 70s and 80s, evolved with the advent of three-dimensional modeling in the mid 90s and finally moved toward the current process of 4D and 5D modeling that BIM facilitates (Eastman et al. 2008).

Since the mid-1990s, BIM has been utilized predominately within the design industry as a tool to communicate design intention and produce more realistic presentations for clients. Unfortunately, its implementation as a constructive simulation tool is still not being adopted extensively by design professionals. In fact, in a survey of architecture firms conducted by AIA in 2006, it was found that "of the74 % of participants that reported using 3D or BIM, 98 % use the tools for renderings and presentation graphics related to conceptual design…using the technology for simple geometric massing and for adding material elements and details to drawings (Gonchar 2006)." Thirty-four percent of designers surveyed were actually using BIM for intelligent modeling. In another survey conducted in 2006, it was found that the "most frequent use of BIM is in design development (91%), schematic design (86%), and construction documentation phases (81%) (Certo 2007, p 7)." While, many designers recognize the benefits that BIM can provide, they fear the initial loss of productivity that may result from switching from the two-dimensional industry standard of AutoCAD to newer costly BIM software platforms.

Historically the construction industry has been one of the slowest industries to adopt change. Its "productivity has decreased by nearly 25% in the past 15 years, compared to the manufacturing industries, which have increased by 125% , during the same period (Holness 2008)." Therefore, it is no surprise that the implementation of building information modeling has been a very gradual process for most contractors. Just as designers fear the risks of change, contractors are even more hesitant to adopt progressive strategies, siding with more traditional approaches. However, studies show BIM is definitely becoming a more accepted practice and will continue to fuel itself in the upcoming years. In fact, contractors seem to have the most positive view of BIM. In a recent survey conducted by McGraw-Hill, "61% of the construction professionals surveyed felt BIM had a positive effect on their company (McGraw-Hill Construction 2008, p 7)."

A recent survey presented in the 2008 issue of National Real Estate Investor indicated that "more than a third of building owners - about 35% - have been using the building modeling technology for at least a year……Just five years ago, in 2003, only 3% used the technology. Usage rose to 4% in 2004, then 6% in 2005, and 11% in 2006, according to the survey (Egan 2008)." McGraw Hill's 2008 Smart Market survey confirmed the assumption that BIM is being adopted with great enthusiasm industry-wide. "Architects are still the heaviest users with 43% using it on more than 60% of their projects" and contractors are still the lightest users with "only 23% using it on more than 60% of their projects." In addition, it was found that 62% of all BIM users plan to utilize it on more than 30% of their projects in 2009 (McGraw-Hill Construction 2008). Thus, this technology will continue to grow and contractors are expected to see the greatest increase in usage in the upcoming year.

Qualitative Benefits of BIM

Extensive research has been conducted on the multiple benefits of implementing BIM. These benefits can be broken into qualitative gains (the factors that improve upon the actual process of design and construction) and quantitative measures (those factors which measurably contribute directly to cost savings).

Pre-Construction Benefits to Other Parties

From a building's initial conception to final occupancy and operation, BIM has the ability provide different qualitative benefits at different stages of the construction process. During the pre-construction phase when an owner or developer is trying to understand the initial budget and feasibility of design options, a schematic BIM linked to cost data can be an excellent estimating tool. It can also assist in determining whether a particular design option meets functional, sustainable, and budgetary requirements (Eastman, et al. 2008). But perhaps most important, it allows all interested parties to visualize project scope and design intent early in the process.

Design Phase Benefits

As stated previously, in its simplest context, BIM improves the overall visualization of a project. A 3D model generated by BIM software not only aids architects and engineers in conveying design ideas to owners, but assists communication and collaboration between disciplines as well. In the past, this process was inhibited by the archaic 2D documentation system in which "CAD produced drawings, remained essentially dumb images, limited to conveying information only visually to other parties (Holness 2006)."

Earlier collaboration of multiple design disciplines is also facilitated by BIM (Eastman et al. 2008). Instead of working with one or more coordinated 3D models, architects, engineers, and consulting parties alike can view and make changes to the design earlier in the process with reduced error. This continuous collaboration aids continued improvement of design. "BIM software allows architects and engineers to make changes on designs and transfer the changes within files in a much more efficient system (Bennett 2008)." The continued maintenance of one "federated" model with multiple disciplines attached is a more efficient process than redrafting and resubmitting multiple drawings. By using a "central database, with each party to the project effectively inputting or extracting data from the base model as needed", the flow of communication is improved dramatically (Holness 2006).

In addition, the ease in which changes can be made in a BIM is another benefit seen in the design phase of a project. The traditional process of drawing in 2D and redrawing as changes arise leaves great room for error and is extremely time consuming. BIM instead generates 2D documentation directly from a 3D model, creating instantaneous changes in all corresponding views. Design components are controlled by parametric rules, assisting the rapidity of changes. This facilitates accurate two-dimensional drawings to be produced at any stage of design and improves the overall efficiency of the process (Eastman et al. 2008).

Schematic BIM models may assist evaluating design intent and extracting accurate conceptual cost estimates for designers as well. Traditional unit cost per square foot methods of estimating are being replaced with more accurate detailed cost estimates based on material quantity takeoffs. All parties are aware of cost implications before the bidding process even begins (Eastman et al. 2008). But perhaps the greatest benefit of BIM in this stage is its ability to improve overall design. The ability to link energy analysis tools to a building model in order to improve the quality of design and make more sustainable design decisions is an invaluable tool.

Construction Process and Fabrication Benefits

In the procurement phase of a project, the 4D and 5D capabilities of material quantity takeoffs provide an excellent source of checks and balances for contractors and estimators. In fact, the level of precision and accuracy that models can achieve actually produce better estimates and lead to greater profit potential. This in turn reduces bidding time and effort (Holness 2006). BIM assists the implementation of lean construction techniques as well by reducing on-site material waste and improving efficiency of on-site activities (Eastman et al. 2008).

BIM is an excellent tool for construction project managers as well. It is now possible to simulate the construction process completely in the virtual world. Site layout, space conflicts, crew and equipment organization and safety concerns are all easily understood in a three-dimensional sense. This type of analysis was once inhibited by paper based methods of the past (Eastman et al. 2008). Construction scheduling can also be linked to a model and provide a visual insight to construction phasing. BIM even has the potential to improve issue tracking for project management staff. Thus, the production of RFIs and change orders are greatly assisted by model visualization. Plus, the single database provides a more time efficient manner for communication between architects, engineers and contractors (Holness 2006).

Perhaps one of the greatest benefits to contractors is BIM's ability to build fundamental intelligence into drawings (Holness 2006). Traditional methods of Computer Automated Drafting or AutoCAD platforms are based on a 2D system of lines. Thus, walls are drawn as four inch place holders, carrying no actual properties of realistic construction. They are rarely drawn with finishes and the nominal stud dimensions are rounded for readability in the field. In contrast, BIM models contain walls that are editable objects with parametric properties that can be changed as needed. These "smart objects" incorporate the actual structure of a wall type with exact dimensions, allowing contractors to build to the nominal dimensions of the wall and distinguish its actual materiality. One of the greatest obstacles arising between design documentation and physical construction occurs in the process of rounding dimensions within AutoCAD. This creates numerous dimensional discrepancies and results in increased RFIs during framing. BIM eliminates this issue by allowing designers to represent objects to exact scale, leaving no question as to what its intended size or construction should be. Though it is often perceived that parametric modeling may leave greater potential for error, it is actually an improvement of quality control and quality assurance as compared to traditional delivery methods (Certo 2007).

> "A BIM solution that can coordinate changes and maintain consistency at all times lets users focus on building design versus change management. This built-in change-management capability is critical to the disconnected building process - which is still heavily dependent on construction documentation -providing confidence in drawing deliverables (Autodesk 2007)."

This application is especially helpful to contractors, as the software can automatically generate accurate shop drawings as needed for supplemental information (Holness 2006). In fact, the ability to produce such drawings with ensured accuracy, allows larger elements of the design to be fabricated offsite, reducing construction cost, time, and rework (Eastman et al. 2008).

Within the construction context, BIM is most useful for conflict resolution and clash detection. Special software additions such as Autodesk's NavisWorks have been designed to assess project components for possible structural and mechanical conflicts such as identifying "clashes" between structural, mechanical, plumbing and electrical system designs that occupy the same space (Bennett 2008). Historically, many of the most expensive change orders have been the result of conflicts that were overlooked during pre-construction. For example, it is difficult for contractors to foresee vertical MEP conflicts with structural systems from a set of line drawings that are essentially a diagrammatic source of reference. Consequently, these types of clashes are associated with the highest cost, due to the wasted materials and increased rework that is associated with their delayed discovery. BIM facilitates the discovery of these "clashes" often before construction even begins.

Post Construction Benefits

Even after construction is completed and final punch list items are fulfilled, a BIM model can be utilized to better manage and operate facilities (Eastman et al. 2008). First, it provides a more accurate record of the building. In fact, BIM improves upon the traditional 2D as-built drawings of the past, which often lack the accuracy and detail required by future owners and facility managers. A BIM 3D as-built model can be "loaded with information on every system, product, finish, and fixture, both inside and out (Madsen 2008)."

Models may also be integrated with facility operation and management systems allowing for the continued maintenance of complex systems. Thus, BIM can essentially "support monitoring of real-time control systems and provide a natural interface for sensors and remote operating management of facilities (Eastman et al. 2008)." Though these capabilities are not fully developed to date, BIM is the ideal platform to implement them.

Quantitative Benefits of BIM

While, the qualitative benefits may be sufficient enough to convince most industry professionals that BIM is worth its initial investment, owners and developers seem to respond better to quantitative units of measure such as cost and schedule reductions. It seems all parties in the process perceive different quantitative benefits from BIM. Owners will be most impressed with the potential reduction in time from project handover to turnover. In addition, studies show that BIM can contribute to the reduction of a building's life cycle operation and maintenance costs by as much as 10-40% (Holness 2006).

Besides the many benefits discussed earlier, architects and engineers may see a reduction in design cycle time by 20-50%. The automated 100% accuracy of final procurement package generation is a great motivator and the reduction in RFIs will facilitate improved coordination with contractors. But perhaps, contractors will see the greatest measurable benefits. Studies show contractors using BIM may see a reduction in project time and costs by as much as 20-40% and will appreciate the reduction of rework to nearly zero (Holness 2006).

A recent survey, conducted by Suermann (2008) determined experts' "perceived impact" that BIM has had on construction by using six commonly used metrics or Key Performance Indicators (KPIs) in the industry. It was discovered that BIM had the most favorable responses toward factors like Quality Control, On-time Completion, and Overall Cost, measuring 90%, 90%, and 84% respectively. Factors such as Units/Man-hour and Dollars/unit and safety were voted to be least affected by BIM in the survey.

Barriers to Implementation Within the Construction Industry

Despite the great potential for improvement and efficiency that BIM offers, it is not without flaws. The system is by no means perfect and will continue to advance, as the industry adopts it on a broader scale. First, the information technology required by most BIM software can be straining on current systems, hardware, and staff capabilities, particularly for contractors who tend to be less open to new technology (Holness 2008). BIM software licenses can cost anywhere from $8,000- $12,000 per seat and the additional costs associated with training staff and upgrading dated IT platforms can be a very pricey investments. In a 2008 survey, "15% of industry professionals saw software costs as the most challenging" aspect of implementing BIM and "another 13% felt hardware upgrade costs to be the most challenging (McGraw-Hill Construction 2008, p 9)." When surveyed, architecture firms utilizing BIM felt that the greatest risk of its execution was the increased initial project costs that would result in a change in traditional "phase-based" billing structures of the past (Certo 2007). The cost of software and staff alone may be a too pricey of an initial investment for smaller firms. In fact, a survey conducted by the AIA in 2006, determined that "around half of all firms with billings over $15 million have BIM software compared to only 15% of firms with billings less than $5 million (Certo 2007, p 7)."

Additionally, the initial loss of productivity in BIM's first phases of implementation is of great concern to architects and contractors. While most designers possess the tech-savvy skills required by BIM software platforms and are exposed to 3D modeling in their education, construction professionals are less familiar with it. Finding qualified professionals to do the work and the initial investment of training for these professionals is an added obstacle for implementing BIM (McGraw-Hill Construction 2008). Traditional career paths within the construction industry for college graduates have leaned toward areas of project management and estimating. However, as the field becomes more specialized it is likely that more students will be entering the industry with the technical knowledge required for virtual design and construction. In addition, a lack of support by upper management is a typical obstacle that may be encountered when firms first decide to deploy BIM.

The issue of interoperability is perhaps one of the greatest barriers that virtual design and construction faces today. BIM software programs have “evolved in pursuit of different solutions” in competition with one another, making it difficult to fully implement all the desired capabilities within one program or software platform (Thomson and Miner 2006). In addition, when data are submitted by different parties in different formats incompatible with the software, the additional time required by project/VDC managers to re-enter data is an issue of concern. The question arises whether initial employment of BIM may actually hinder productivity (Thomson and Miner 2006). The National Institute of Building Sciences’ (NIBS) Facility Information Council (FIC) has recently released the first national BIM standards to facilitate standardization of the process from design schematics to life-cycle process in order to improve these issues (Consulting-Specifying Engineer 2008).

As collaboration is increased in the process of BIM, the traditional lines of responsibility are blurred as well. Problems may arise from multiple parties working from the same data set. In addition, standard industry contracts of the past no longer adequately allocate risk and responsibilities. Thus, contractual language must be perfected to incorporate collaborative risk and additional compensation (Thomson and Miner 2006). This is also a future goal of NIBS and FIC.

There are a number of legal issues that have evolved from the e-transfer of documentation and models. Issues regarding copyright and ownership arise from a shared model that is utilized extensively by different disciplines. The question of who will be responsible for the accuracy of all data entry in a collaborative environment arises as well (Thomson and Miner 2006).

Potential Costs and Savings

Though risks do exist, in 2006 it was estimated that BIM resulted in the potential savings in construction costs ranging from 15-40% (Holness 2006). Research shows that on large industrial projects ranging from 75-150 million dollars, BIM averages roughly 0.25-5% of the total construction cost, comprising around 5-10% of additional design fees (Holness 2008). However, according to Holness (2008), the Construction Industry Institute estimates savings of 3-7.5% in improved coordination and reduced conflicts alone. In addition, researchers expect to see 7.5-10% less waste based on these principals.

BIM has been extremely successful in the automotive industry. A study of automotive plants where BIM was being executed showed the elimination of an estimated 20% of sheet metal waste. It also assisted in “developing programs 15-25% faster, reducing RFIs by 50%, eliminating 25% of all change orders and reducing construction cost by 4-10% (Holness 2008).”

One of BIM’s greatest benefits, conflict detection, has been shown to reduce the number of requests for information (RFIs) and change orders, saving both time and money. A study conducted by Holder Construction demonstrated these principles. Holder used 2D construction documents from an architect to create a BIM model on a small project. Thirty-five conflicts were discovered in the project. “With the $4,000 investment we had in the model on our unplanned experiment, we realized a $135,000 savings in collision detection," states Michael LeFevre of Holder Construction's BIM department (Madsen 2008).

Defining Return on Investment

In interpreting the potential costs savings of BIM, return on investment must be explained in brief. Return on investment (ROI) is one of many ways to evaluate proposed investments, as it compares the potential benefit or gain of an investment to how much it costs. Sometimes referenced as the rate of return, ROI is usually calculated by taking a ratio of profits received as a result of an investment over the price of the investment. That value is then multiplied by 100 in order to establish a percentage that can be used as an indicator of performance. It is important to note that "ROI is a measure of investment profitability, not a measure of investment size (Feibel 2003)." It measures the percent return on an amount of capital expenditure. Some define ROI as a ratio of the net benefits produced by an investment over the cost of the investment times 100 (Feibel 2003). However, in its simplest context, return on investment may be calculated using Equation 2-1 (Feibel 2003):

$$\text{ROI} = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}} \tag{2-1}$$

According to Friedlob and Plewa (1996), "ROI is a comprehensive tool that normalizes dissimilar activities of different sizes, and allows them to be compared." They also noted that management professionals often use ROI analysis as a tool to "measure the performance of individual company segments when each segment is treated as an investment center, evaluate capital expenditure proposals, and assist in setting management goals (Friedlob and Plewa 1996)."

When applied to BIM, it is suggested that ROI be measured as a ratio of net savings to costs because the potential savings that result from this technology are considered profit to contractors, designers, and other various stakeholders. Autodesk suggests one formula for calculating the first year's return on investment for BIM:

$$\frac{\text{Monthly Labor Costs} - \dfrac{\text{Monthly Labor costs}}{(1 + \%\text{ of productivity gain after training})} \times (12\text{-training time})}{(\text{Cost of hardware and software}) + (\textit{Monthly labor cost} \times \textit{Training time} \times \textit{\% of productivity loss})} \quad (2\text{-}2)$$

Equation 2-2 is best applied in an architectural firm setting in which multiple modelers are utilizing the software (Autodesk 2008). As this study is based upon BIM's ROI from the owner's perspective, this method is not entirely applicable.

Example Case Studies

In a survey of industry professionals conducted by McGraw Hill, 48% of respondents indicated that they were actually tracking BIM's ROI at a moderate level or above. From this report it was found that initial ROI values ranged anywhere from 300-500%. In contrast, it was perceived by most respondents that BIM would have an average ROI between merely 11% and 30%. In fact, "one third of respondents reported finding ROI values greater than 100% and many were over 1000% (McGraw-Hill Construction 2008, p 3)." Thus, the potential savings are exceeding most professionals' expectations by a landslide. However, there is still little data available to the general public on such metrics.

Most of the case studies documented similar to this research have calculated BIM's ROI based on clash detection results and the estimated corresponding value that was saved in man-hours and material costs for all construction conflicts discovered by BIM. Surveys show that users who measure ROI focus on six primary areas including: "improved project outcomes such as reduced RFIs and field coordination problems, better communication through 3D visualization, productivity improvement of personnel, positive impact of winning projects, lifecycle values of BIM, and initial cost of staff training (McGraw-Hill Construction 2008, p 27)."

PCL Construction Case Study

In a case study of PCL Construction, it was estimated that the company's VDC efforts were achieving an estimated "500% return on investment with the vast majority of payback coming from clash detection and lower change order costs (McGraw-Hill Construction 2008)." It noted multiple projects in which BIM had been increasingly beneficial. In particular, PCL noted considerable savings on their Silverline project in Telluride, Colorado. By checking their BIM against their original quantity takeoff of excavation and shoring, they were able to save nearly $3 million due to an underestimate. "The combined effort required 560 man-hours, generating expenses well short of its total cost savings (McGraw-Hill Construction 2008, p 11)." In addition, BIM assisted in the discovery of nearly 3,500 total clashes of which at least 500 would have significantly impacted the cost and schedule of their Memorial Hospital Project in Colorado Springs (McGraw-Hill Construction 2008).

DPR Construction Case Study

In a presentation for the teleconference series "Roadmap to BIM 2008," Dean Reed and Atul Khanzode of DPR construction shared some of their experiences using BIM. They noted the successes they achieved particularly in increased productivity, conflict detection, and savings on multiple projects. In a case study conducted on their Sutter Health Lean Project, they saw great savings in terms of schedule and cost avoidance. Some of the project details were as follows:

Project Scope: $96.9 million, 250,000 SF MOB and 420,000 SF parking garage

Duration: Approximately 3 years, 2004 to March of 2007

Delivery Method: Lean Integrated Project Delivery

BIM scope: Design coordination assistance and clash detection

By using an Integrated Project Delivery method versus traditional Design-Bid-Build, the owner saved approximately six months in scheduled time and around $9 million on this project (Construction Project Controls and BIM Report 2008).

DPR noted significant improvements in terms of work flow and productivity of MEP field labor on this project due to utilizing BIM as well. They were able to employ 30% fewer sheet metal workers than estimated and 55% fewer pipefitters. The project also reported 20-37% improvement in productivity as compared to industry standards for HVAC. As a result of this improved coordination, the mechanical contractor reported more than $400,000 in labor savings. Much of this was due to the conflicts that were detected early on in the VDC process (Construction Project Controls and BIM Report 2008).

DPR also found considerable reductions in RFIs, particularly related to mechanical, electrical and plumbing systems on the Sutter Health project. Only six RFIs were reported as a result of MEP and Fire protection systems clashing with other systems and zero RFIS for collisions between MEP systems were reported. On a job of this scale, this was a significantly lower burden on project management staff and a great reduction in scheduled time. They also reported less that 0.2% of hours were spent on rework in this project; much of which was due to using BIM as a means for conflict detection in the early stages of the project. In fact, only 43 total hours of rework were reported out of the total 25,000 man-hours on the job. In DPR's measurements, they reported approximately a 200% return on investment, with net savings of more than $415,000 or 0.043% of the total construction cost (Construction Project Controls and BIM Report 2008).

Holder Construction Case Study

Holder Construction has perhaps been the most public about its active quest to measure BIM's return on investment in recent years. In a presentation given by Michael Kenig in the teleconference series, *Roadmap to BIM 2008*; Holder shared some of its successes in utilizing BIM technology. Since 2003, the company has employed BIM for multiple purposes on various projects of different scale and type. Some of the uses they indicated include: 3D-visualization for scope clarifications, MEP coordination, and construction mock-ups, 4D-phasing and sequencing to assist in assessing site logistics, estimating and quantity takeoffs, value engineering studies, clash detection analysis, trade modeling, and facility management (Construction Project Controls and BIM Report 2008). Though Holder has been utilizing BIM since 2003, they have only actively been measuring its ROI since 2006, tracking more than 30 projects in the past three years. The bulk of their analysis has been based on the tracking of construction clashes. However, they are also "tracking planning stage savings and value analysis options where the model helped them stay on budget (McGraw-Hill Construction 2008, p 26)."

Their initial ROI measurement began with analysis of clashes discovered in NavisWorks. Project teams were assigned to assess the level of severity of each collision discovered by the program. Then unit-cost and crew hour rates were estimated in association with the type of clash, if it had been discovered by traditional means. Through the assistance of a project-specific design coordination visual log, collisions were tracked. From this analysis, they found the average cost per collision fell between $1000-3000 (McGraw-Hill Construction 2008). This magnified on a large project wide scale resulted in millions of dollars in direct potential savings from cost avoidance.

An example of these results can be seen at a project-specific level in a case study of Holder's Hilton Aquarium project in Atlanta, GA. Courtesy of CIFE, some project specific information is indicated as follows (Gilligan 2007):

Project Scope: $46 million, 484,000 SF hotel and parking garage

Duration: 21 months design and construction with 9 months overlap

Delivery Method: Construction Management at Risk

Contract Type: Guaranteed Maximum Price

Design assist: GC and subs on Board at design definition phase

BIM scope: Design coordination assistance, clash detection and work sequencing

BIM cost: $90,000 (approximately 0.2% of project budget ($40,000 paid by the owner)

Cost Benefit: $600,000 attributed to clash elimination

Schedule Benefit: 1,143 hours saved

Courtesy of Holder Construction, Figure 2-1 indicates the breakdown of time and cost savings estimated on their Hilton Aquarium project. It was estimated on this project that $800,000 could be attributed to direct BIM savings and approximately $710,000 net savings resulting in a 780% return on investment, given the $90,000 cost of BIM on that project.

Collision Phase	Collisions	Estimated Cost Avoided	Estimated Crew Hours		Coordination Date
100% Design Development Conflicts	55	$124,500	NIC		*June 30, 2006*
Construction (MEP Collisions)					
Basement	41	$21,211	50	hrs	*March 28, 2007*
Level 1	51	$34,714	79	hrs	*April 3, 2007*
Level 2	49	$23,250	57	hrs	*April 3, 2007*
Level 3	72	$40,187	86	hrs	*April12, 2007*
Level 4	28	$35,276	68	hrs	*May 14, 2007*
Level 5	42	$43,351	88	hrs	*May 29, 2007*
Level 6	70	$57,735	112	hrs	*June 19, 2007*
Level 7	83	$78,898	162	hrs	*April 12, 2007*
Level 8	29	$37,397	74	hrs	*July 3, 2007*
Level 9	30	$37,397	74	hrs	*July 3, 2007*
Level 10	31	$33,546	67	hrs	*July 5, 2007*
Level 11	30	$45,144	75	hrs	*July 5, 2007*
Level 12	28	$36,589	72	hrs	*July 5, 2007*
Level 13	34	$38,557	77	hrs	*July 13, 2007*
Level 14	1	$484	1	hrs	*July 13, 2007*
Level 15	1	$484	1	hrs	*July 13, 2007*
Subtotal Construction Labor	590	$564,220	1143	hrs	
20% MEP Material Value		$112,844			
Subtotal Cost Avoidance		**$801,565**			
Deduct 75% assumed resolved via conventional methods		($601,173)			
Net Adjusted Direct Cost Avoidance		**$200,392**			

Figure 2-1. Holder Construction’s Hilton Aquarium Direct Cost Savings (Source: Azhar et al. 2008).

The ROI values for other projects Holder has undertaken in BIM range anywhere from 140% to 399000%. Figure 2-2 lists the ROI that Holder has achieved on several of its BIM-assisted projects. This spread is partially due to the different methods of measuring ROI and the varying scale and uses in which the technology was implemented. These savings do not account for indirect cost savings seen by other parties and are likely an underestimate of the true savings.

Year	Cost ($M)	Project	BIM Cost ($)	Direct BIM Savings ($)	Net BIM savings	BIM ROI (%)
2005	30	Ashley Overlook	5,000	(135,000)	(130,000)	2600
2006	54	Progressive Data Center	120,000	(395,000)	(232,000)	140
2006	47	Raleigh Marriott	4,288	(500,000)	(495,712)	11560
2006	16	GSU Library	10,000	(74, 120)	(64,120)	640
2006	88	Mansion on Peachtree	1,440	(15,000)	(6,850)	940
2007	47	Aquarium Hilton	90,000	(800,000)	(710,000)	780
2007	58	1515 Wynkoop	3,800	(200,000)	(196,200)	5160
2007	82	HP Data Center	20,000	(67,500)	(47,500)	240
2007	14	Savannah State	5,000	(2,000,000)	(1,995,000)	39900
2007	32	NAU Sciences Lab	1,000	(330,000)	(329,000)	32900

Figure 2-2. A Sample of Holder Construction's BIM ROI (Source: Azhar et. al 2008).

Tocci Construction Case Study

Tocci Building Corporation has also been on the forefront of implementing Building Information Modeling. In their quest to prove their commitment to VDC, they noted three projects completed recently with the benefits of BIM and their resulting savings in terms of capital, schedule and ROI.

Starwood Aloft and Element

The following are some general project statistics noted for Tocci's Starwood Aloft and Element project in Lexington, MA (Tocci Building Corporation 2009):

Project Scope: 147,689SF/ 259 Keys Hospitality Design

Duration: February 2007- July 2008

Delivery Method: Construction Management

On this project, Tocci noted "1.1% capital savings, a 5.7% reduction in schedule and a 1.78:1 return on investment ratio (Tocci Building Corporation 2009)." Much of these savings resulted from the avoidance of a significant change order due to a design document discrepancy. Prior to construction, a significant four inch discrepancy between gridlines on the first and upper floors of the project was discovered. Courtesy of Tocci, an image of the discrepancy is shown in Figure 2-3.

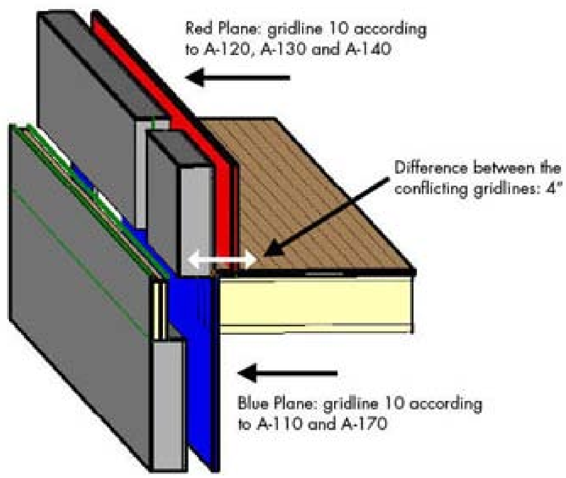

Figure 2-3. Example Gridline Discrepency on Tocci's Starwood Project (Source: http://www.tocci.com. Last accessed on May 15, 2009).

As the drafting error was discovered early, no rework or additional time and material costs ensued. This potential change order was estimated around $57,285, of which a significant $24,000 would have been attributed to five additional scheduled days of general conditions costs. In addition, the cost of additional material and labor estimated around $1,995 and $31,290 was saved in the avoidance of adjusting the lengths of six shear walls, 224 floor joists, and four steel beams (Tocci Building Corporation 2009). An additional $30,854 of savings was also estimated in the discovery of a grease trap located at the wrong elevation. This value includes $21,000 in five days of an additional general conditions and $9,854 of estimated rework (Tocci Building Corporation 2009).

Capital Cove

The second case study from Tocci included the construction of Capital Cove in Providence, Rhode Island. Some of the general project statistics of the project are as follows:

Project Scope: 157,514 SF/96 units Residential

Duration: June 2007 – April 2009

Delivery Method: Construction Management

This project resulted in a "3.5% capital increase, a 6.8% reduction in schedule, and a 4:1 ROI ratio (Tocci Building Corporation 2009)." This project experienced significant savings in terms of virtual coordination and estimating. The design intended for maximum ceiling heights requiring all mechanical, electrical, and plumbing to penetrate through and around the ceiling joists due to limited plenum space. By coordinating all trades exact locations, Tocci anticipated approximately $250 per penetration was saved. It was estimated to total nearly $102,250. In addition, the model was used to communicate design intent and material quantities more accurately to subcontractors resulting in estimated savings of $124,640. This was the difference between the next highest qualified bidder and a preferred mason's bid. It is likely he would not have bid as accurately without the clarity of the 3D model's visualization (Tocci Building Corporation 2009).

Crate and Barrel

Lastly, Tocci cited one final case study of a Crate and Barrel in Natick, MA. General project statistics are as follows:

Project Scope: 32,027 SF/Retail

Duration: July 2008 – June 2009

Delivery Method: Construction Management

On this project, Tocci indicated a “6% increase in capital as a result of BIM, a 5.3 % reduction in schedule, and 5.8:1 ROI (Tocci Building Corporation 2009).” The coordination of underground plumbing conflicts with foundations was greatly assisted by BIM. Tocci estimated around $25,308 of rework was avoided, of which $18,465 was estimated for an additional five days of general conditions. The model also significantly aided in the estimation and preconstruction phase of the project. As the design required high-end materials and finishes, an advanced bill of materials was created to improve the accuracy of the bidding process. “The drawings included model-derived quantity takeoffs and color-coded 3D images which clarified the scope and quantities of material requirements (Tocci Building Corporation 2009).” Tocci (2009) claims: “Both our millwork siding and metal panel subcontractors were able to provide price reductions, based on the accuracy of information.” These price reductions resulted in more than $155,000 in savings and improved coordination and visualization for all trades.

Conclusion

BIM and the ability it provides for implementing VDC has the power to impact designers, construction professionals, and potential owners. It is truly changing the way in which buildings are created, constructed and operated. This literature review illustrates that BIM’s potential advantages far outweigh its disadvantages. The qualitative benefits presented may alone be enough to convince some companies to jump on the bandwagon. However, the quantitative savings are less simply defined and consequently varied greatly based on the size and scope of project and the level of commitment to the process. In the case studies presented in this literature review, there was significant variability in terms of return on investment ratios among companies and from project to project. This is largely due to the fact that the rubric itself is a great estimation. It seems the greater commitment and longer a company was involved in VDC efforts, the more dynamic and significant the savings they realized. In addition, the need for a more standardized method of measuring return on investment was discovered through this process.

CHAPTER 3
METHODOLOGY

This research examined the measurable cost benefits and savings related to reduced time overruns, requests for information (RFIs) and change orders resulting from the implementation of BIM technology. Through analysis of past project data, two case studies were conducted in order to analyze the quantitative and qualitative benefits of implementing BIM. In each case study, a recently constructed BIM-assisted project was compared to a similar project constructed previously without BIM to estimate the return on investment for an owner investing in BIM as an additional service. The projects compared were equivalent in terms of scale, scope, construction type, and contract value.

Division of Project Categories

The two project categories chosen for this study included a small commercial warehouse/office project and a large mid-rise condominium project. These categories were selected based on the specialty of the company used for this study and the greatest amount of available project data. Both studies were analyzed independently because it was anticipated that the quantity of savings would vary greatly in each category based on the scale and complexity of each project type. In order to assess BIM's cost benefits, a project constructed previously *without* the use of BIM was compared within each of these project categories to determine the cost benefits and percent reduction in project delay, RFIs, change orders, and overall savings as a result of using BIM.

Case Study One: Commercial Warehouse

The first case study that was conducted compared two commercial industrial warehouse projects of similar scale, construction type and scope. Both were constructed using concrete tilt-up panels and structural steel. They utilized virtually the same project management staff and were completed in a similar time frame. This project category was selected for its relatively small scope in comparison to the other sample projects studied as a means for testing this research methodology at a smaller scale.

Case Study Two: Mid-Rise Condominium

The second case study that was conducted compared two equivalent mid-rise multi-family urban housing projects. The two projects chosen for the study posed noticeably similar contract values, construction methods, scope, complexity and size. In fact, the two designs were almost identical and utilized the same architect.

Data Collection

The basic quantitative statistics collected for each project, both BIM-assisted and those constructed prior to BIM, included: the original contract value; the total cost of change orders; the total number of requests for information (RFIs); the total number of change order requests (CORs); the original schedule duration, the duration of schedule delay that was/was not experienced; the contract's stipulated cost penalties for time overruns; and the contract's cost bonuses for early completion. In addition, the estimated cost of BIM was also collected for BIM-assisted projects B and D.

For the purpose of this research, the cost of BIM was represented as roughly 0.5% of the initial contract value. This number represents the amount charged to an owner when BIM is included in the contract scope as an additional service. Company X chose to subcontract out the modeling task to an experienced BIM subcontractor and the price of those services was negotiated based on industry standards.

In addition to this quantitative data, qualitative data was also gathered through personal interviews with industry professionals employed by Company X. First, a thorough analysis of the type of conflicts that were resolved by using BIM was performed. This was accomplished through personal interviews with the virtual design and construction manager and careful inspection of Company X's specific VDC RFI and discrepancy logs. These logs provided a running record of issues and conflicts that were discovered in the contract documents in the process of building the model. The most severe of these conflicts were then brought to project management staff's attention and eventually became field RFIs. Interpretation of these logs assisted the researcher in understanding how the technology was being implemented, what it was fully capable of, and what limitations existed. Therefore, when applied to the comparable projects constructed prior to BIM's utilization, it was easier to see what types of conflicts and resulting change orders were likely preventable had BIM been implemented. Second, personal interviews with project management staff from all four projects were conducted in order to better interpret project-specific issues and understand where costly direct and indirect conflicts were encountered.

RFI and COR Analysis

This research was largely fueled by information obtained through each project's RFI and change order request (COR) logs. As there were no available VDC- RFI logs on the projects constructed without BIM, these logs provided the most accurate record of events on each project. The RFI log specifically allowed comparable conflicts on past projects to be pin-pointed and traced to specific change orders with cost data.

All RFIs that related to issues capable of being discovered by BIM were counted and then sorted based on the type of issue. These results were used to compare projects A and B, and C and D respectively. The basic issues discoverable by using BIM fell into five basic categories: dimensional inconsistencies in the construction documents; document discrepancies between disciplines; two-dimensional errors and omissions; grid and column alignment issues; and direct clashes. These issues are explained in full in Chapter 4.

After reviewing all RFIs, the direct change orders that resulted from BIM-discoverable RFIs were studied. For the purpose of this study, the potential cost savings that may have been realized can be considered BIM's potential profit to the owner. Projects A and C that were completed without BIM were analyzed thoroughly in this manner in order to estimate similar savings that occurred on BIM-assisted Projects B and D.

Comparative Analysis

Given the data that were collected on each project and the results of the RFI, COR and change order analysis, comparisons were made between projects similar in scope and size. In each case study, the BIM-assisted project was measured against a similar project conducted without BIM. The percent reduction in change orders, RFIs, and project delay was measured and conclusions were made.

Return on Investment Calculations

Using the collected data, observations were performed to derive the direct and indirect costs that might have been saved by the owner on the projects constructed without BIM had the technology been used. *Direct costs* constituted the sum of all BIM-preventable change orders and any other avoidable costs to the owner that would have been eliminated by using BIM. *Indirect costs* constituted the total cost of schedule overruns when the project was delayed. They include the daily cost of interest on the owner's loan, the cost of the contractor's general conditions, the developer administrative fees and the architect's contract administration fee. Each of these costs was calculated by multiplying the number of days each project was delayed by the daily cost penalties outlined by the project contract. The indirect savings in terms of time and direct savings related to avoidable change orders were then summed for a total estimate of

BIM-related savings. To achieve the net BIM savings the cost of BIM was subtracted from this figure. Then a return on investment value was calculated by dividing the total net BIM savings by the total cost of BIM. These results were then analyzed and applied to the BIM assisted project to get an estimate of what costs were actually saved by the technology.

Case Study Procedure

The methodology of this research was created to meet the objectives of the study. The steps taken were as follows:

I. A literature search was executed to present research material related to BIM and its correlation to costs savings in the construction industry including any case studies that had already been conducted on BIM's return on investment.

II. The past project data that was available for analysis was then identified with the use of Company X's project archives and their assistance.

III. Interviews were conducted with employees of Company X to gain valuable qualitative information about the projects studied.

IV. Past project data including request for information (RFI) logs and change order request (COR) logs and VDC RFI/discrepancy logs were collected and analyzed.

V. Statistics were generated in three phases. Figure 3-1 represents the analysis process used.

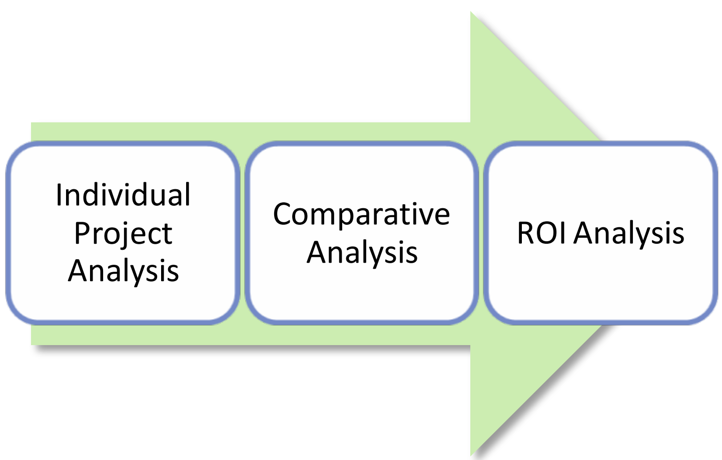

Figure 3-1. Analysis Process

Phase One analyzed each project independently. Phase Two used those results to compare the BIM-assisted projects to a project similar in scope and size that was completed without BIM in order to draw conclusions within each case study. Phase Three utilized the results of Phase One and Two to estimate BIM's ROI.

A. Phase One: Independent Project Analysis

1. Each project's contract price, cost of change orders, number of change orders, amount of schedule delay, number of RFIs and number of CORs were collected and analyzed.
2. The proportion of change orders costs to the initial contract price was derived on each project as a means for comparison in Phase Two.
3. Each project's field RFI log was reviewed thoroughly.
4. The number of field RFIs related to BIM-discoverable issues were counted and cataloged based on the type of issue.
5. On the two BIM-assisted projects, the VDC RFIs were reviewed and analyzed. The issues raised were counted and sorted by type in the same categories developed for the field RFIs.
6. Each project's COR log was reviewed. The number of cumulative change orders that may have been avoided by BIM were counted and analyzed.

B. Phase Two: Comparative Analysis of BIM-Assisted and Pre-BIM Projects

1. In each case study, the BIM-assisted project was matched against the project constructed prior to BIM based on a set of comparable variables.
2. The percent reduction in RFIs was calculated between Projects A and B and C and D, respectively.
3. The percent reduction in change order requests was calculated between Projects A and B and C and D, respectively.
4. The findings of Phase One were compared between Projects A and B and C and D, respectively.
5. An analysis of the timing of field RFIs was compared between BIM- assisted and Pre-BIM projects:

i. The average response time by the architect on all RFIs was calculated on all four projects.
ii. The number of field RFIs that occurred over each month of the project schedule were counted and mapped graphically over the project schedule of all four projects.
iii. The frequency of RFIs over the construction schedule was compared between Projects A and B and C and D, respectively.

C. Phase Three: ROI Analysis:

1. The sum of all direct costs in preventable change orders was totaled for Projects A and C.
2. The sum of all indirect costs in time overruns was calculated based on the amount of project delay attributable to BIM-preventable issues.
3. The total indirect and direct costs preventable by BIM were summed to get the total BIM preventable savings on Projects A and C.
4. The cost of the investment in BIM (to the owner) was calculated by taking 0.5% of the initial contract price on each project.
5. The net BIM savings that might have been achieved on Projects A and C were calculated by subtracting the cost of BIM from the total BIM-preventable savings calculated in step three.
6. These savings were then divided by the estimated cost of BIM on each project to get an estimated percent return on investment.
7. The results were analyzed and measured against BIM-assisted Projects B and D.
8. Projections based on indirect cost savings and ROI were made on BIM-assisted Projects B and D.

VI. Analysis was then conducted based on the statistics derived in steps IV and V to compare the amount of money and time that was saved through the utilization of BIM.
VII. Conclusions were made based on the final results of the comparative case study.
VIII. Recommendations for contractors implementing BIM to use in the measurement of savings to investment ratios for future use were developed based on the lessons learned from implementing this study.

Limitations of the Methodology

As mentioned in Chapter 1, this study only shows the savings related to a reduction in schedule overruns on the BIM-assisted projects. Thus, its results are a gross underestimate of actual savings and ROI for Projects B and D. Since BIM has only been adopted in the past two years by Company X, much of the required documentation of BIM's conflict detection was not available for use as of yet. In order to fully analyze the savings potential of this technology, a commitment from all project staff was required to estimate the value of each clash discovery that took place in terms of labor hours and material costs that were avoided. For the purpose of this study, it was too complex an endeavor given the time restraints.

In addition, it was presumed that a reduction in RFIs, cumulative change orders, CORs, schedule delay and savings seen on the BIM- assisted projects were in direct correlation with BIM's execution. In actuality, it is likely other variables also contributed to each project's success or failure. As each project is unique in terms of staffing, location, productivity, client, etc., it is very difficult to quantify which benefits are directly associated with BIM and which are merely the result of improved work ethic, better relationships with owners and architects, and other outside factors.

This research aims to justify the use of BIM to owners in terms of its potential ROI. It is likely the greatest savings achieved were from the contractor's perspective in improved coordination. However, there was little documentation of such costs. In fact, the best documentation of costs was found in the change orders and COR logs which contained those change orders paid for by the owner. Most costs to the contractor were considered a part of doing business and went undocumented, particularly in the case of rework.

Lastly, it should be noted that analysis of BIM's return on investment is best understood from a comprehensive standpoint. Thus, the most significant savings are likely to be perceived when utilizing BIM in a design-build scenario. As discussed in the literature review, savings can be achieved in all phases of a project from pre-construction to final acquisition and facility management of a building and different savings are realized by different stakeholders. Therefore, though BIM was extremely beneficial to Company X, the implementation of the technology was very limited in the projects studied. It is still a newly adopted platform and therefore only skimmed the surface of what the technology was really capable of accomplishing.

The BIM was only used to solve major coordination issues, create supplemental field drawings when clarification was needed, improve visualization, and catch major clashes/ discrepancies in the 2D documents. On the two projects studied, Company X did *not* use it for scheduling, phasing, quantity takeoffs or as a tool for LEED consultation though the software was equipped with these benefits. Therefore, there are multiple areas from which even greater savings could have been realized. Those are goals of Company X in the future, as they become more equipped to handle VDC endeavors.

CHAPTER 4
CASE STUDIES

Overview

Company X Profile

With the courtesy of Company X, a sample of available past project data was collected and analyzed. Company X is a medium-sized commercial construction management firm, with annual net revenue of over 100 million dollars. It specializes in multi-family residential units, tilt-wall commercial warehouses and offices, assisted-living facilities, and parking structures. With more than 37 years of experience, Company X provides multiple services including general contracting, estimating, value engineering, and virtual design and construction. In addition, it has the capabilities and manpower to self-perform all concrete work and it has partnered with an engineering consultant on several design-build parking structures.

Company X's BIM Approach

In 2007, Company X began offering Virtual design and construction as an additional service to its clients. Their efforts toward implementing BIM have been gradual and continue to improve as time progresses. Due to its relatively recent adoption, they have chosen to outsource the creation of all BIMs to a modeling sub-contractor. Their in-house VDC manager oversees all modeling tasks, assists estimating and preconstruction efforts and communicates with field personnel to create specialized drawings from the models as needed. The chosen software platform used by Company X to date has been Autodesk Revit 2009 Architecture, Structure, and MEP.

To date, Company X has not been able to utilize BIM in an ideal design-build scenario. Rather, they facilitate the conversion of 2D construction drawings to a 3D BIM in order to foresee potential conflicts that may arise in the field. In the BIM-assisted projects described in these case studies, parametric modeling took place after the design phase was completed, when the contract was awarded to Company X. The models were completed in the same sequence as the actual construction process, so that the most time-pressing issues were addressed first. In most cases, the model was 90% complete before construction began and a working model was edited as changes arose in the field throughout the construction process.

Before construction took place, major issues were often resolved during the initial modeling phase. A separate VDC request for information (RFI) log was created to aid communication between Company X's VDC department and the modeling sub-contractor. Questions that could be inferred by Company X were answered. However, larger discrepancies were forwarded to the appropriate parties so that accurate model creation could take place. For the purpose of this study, all "VDC RFIs" reference the communication that took place *before* construction between the modeling sub-contractor and Company X. In contrast, "field RFIs" refer to communication between project management staff and the architect or engineer *during* actual construction.

BIM-discoverable issues cataloged

Analysis of all available project data and documentation revealed that there were a number of similar discrepancies that arose during the modeling process on all projects, regardless of scope or scale. Thus, the BIM model aided in the discovery of multiple types of issues before and during construction, which were critical to the creation of an accurate model. For the purpose of this study, these issues were labeled "BIM-discoverable" and were the subject of both field and VDC RFIs. The major issues discoverable by BIM fell into five basic categories: dimensional inconsistencies in the construction documents, document discrepancies between disciplines, 2D errors and omissions, grid and column alignment issues, and direct clashes.

Dimensional inconsistencies. Dimensional inconsistency due to AutoCAD rounding errors and discrepancies between sheets comprised a large percentage of the issues that using BIM solved for Company X. In fact, analysis of the VDC logs linked dimensional discrepancies to most of the major conflicts discovered on large projects. All four projects studied were designed in AutoCAD. Thus, the 2D representation of walls as lines without finishes caused dimension strings to be inaccurate in the field. It was commonly found that dimension strings on one end of the building would differ drastically on the other end, merely because of the way CAD software rounded. Figure 4-1 shows an example of dimensional inconsistencies that were discovered in a set of construction drawings. This led to multiple RFIs in the field questioning which measurements were to be used, particularly during framing. The accuracy of parametric modeling and the software's accuracy of dimensioning resolved many of these issues before construction began.

Document discrepancies between disciplines. Document discrepancies between sheets and disciplines also comprised a large proportion of issues discovered by BIM. The use of 2D

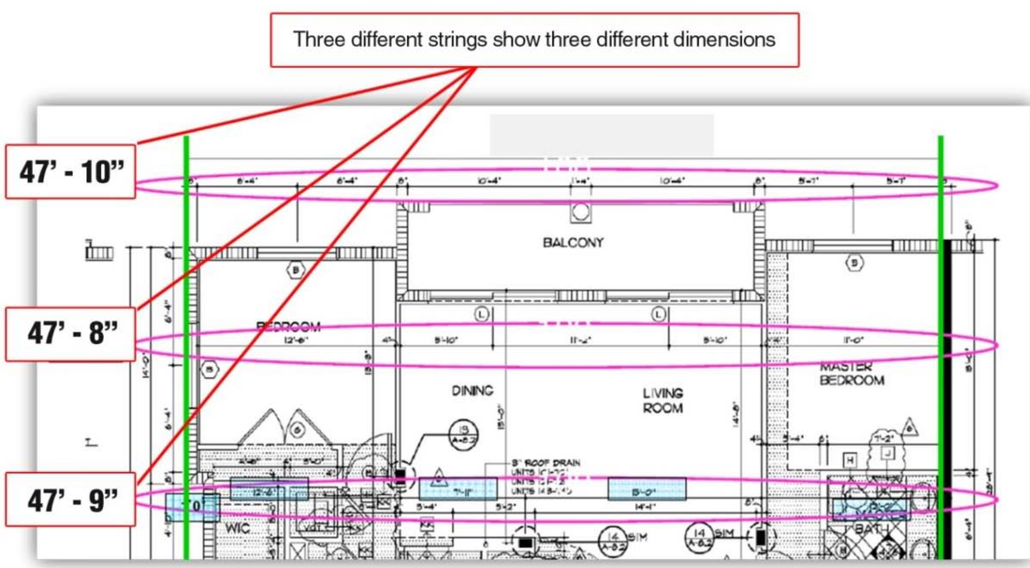

Figure 4-1. Example of Dimensional Inconsistencies in 2-D Construction Drawings

document preparation allows for a greater proportion of CAD errors between sheets. Inconsistencies related to materiality, notations, wall types, and door and window schedules, etc. were often discovered by project management staff late in the construction process. This often led to a number of RFIs and change orders. In addition, the variation between sheets constructed by different disciplines, particularly between architectural and structural drawings, was a major issue that arose in the RFI logs. It was often difficult to discern which discipline's drawings took precedent. Figure 4-2 shows an example of how structural documentation conflicted with what was indicated in the architectural discipline's sheets.

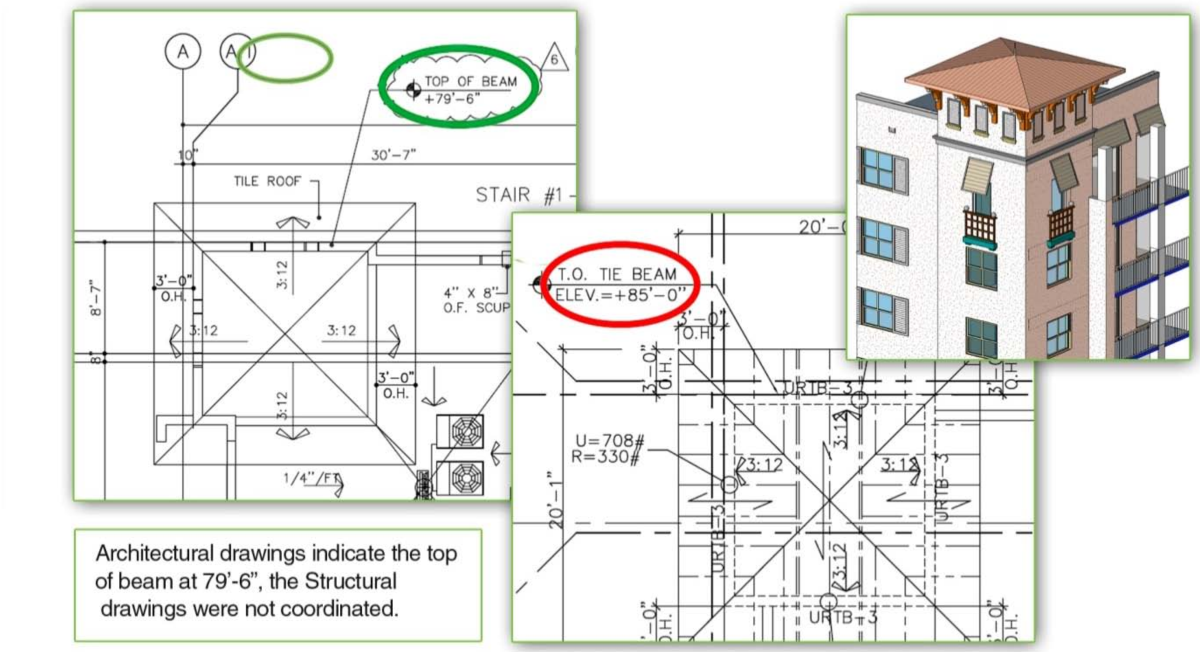

Figure 4-2. Example of Document Discrepancies Between Disciplines

2D errors and omissions. In addition, 2D CAD errors and omissions were also found to be a common RFI issue discoverable by BIM. There was frequently a lack of information indicated on the plans needed to construct the model accurately. For example, there were often door, window and wall types left off the drawings or mislabeled in several cases. Sometimes, there was not enough information indicated in the documents to proceed with building the model, as many design decisions were not finalized. The nature of how construction drawings are created in a 2D system naturally lends itself to greater error. However, by modeling the project virtually during preconstruction, these errors were revealed early in the process and questions were answered without time constraints.

Grid/column alignment issues. Grid line and column alignment issues were a major source of conflict in the projects studied as well, particularly the larger ones. These errors in the documents had perhaps the most profound effect on the projects. There were often major discrepancies between floors and sometimes between disciplines that led to difficulties in placing columns accurately. Figure 4-3 exemplifies a BIM-assisted project in which multiple column locations were revised based on corrected grid alignment.

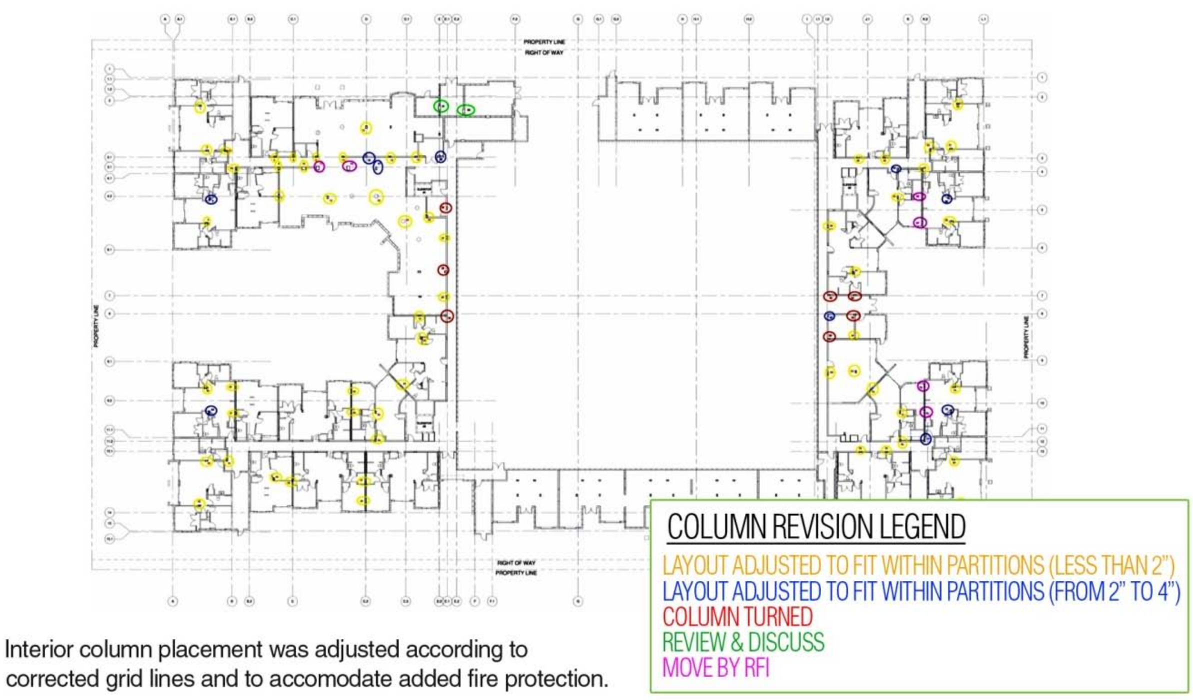

Figure 4-3. Example of BIM-Assisted Column Revisions as a Result of Grid-Line Fixes

BIM's resolution of these issues proved to be one of the greatest cost savings in this study. The resolution of the building grid is one of the first tasks modelers are assigned to during Company X's VDC process.

Direct clashes. RFIs pertaining to direct conflicts between systems and disciplines were also quite frequent such as conflicts between deck openings and ductwork, clashes between architectural, structural, plumbing and mechanical systems. Many of these types of issues resulted in the most costly change orders. Figure 4-4 shows an example of a beam intersecting a mechanical duct. These types of conflicts were often discovered through model analysis and were least likely to be uncovered through mere document review. Their discovery was greatly assisted by BIM's facilitation of visualization.

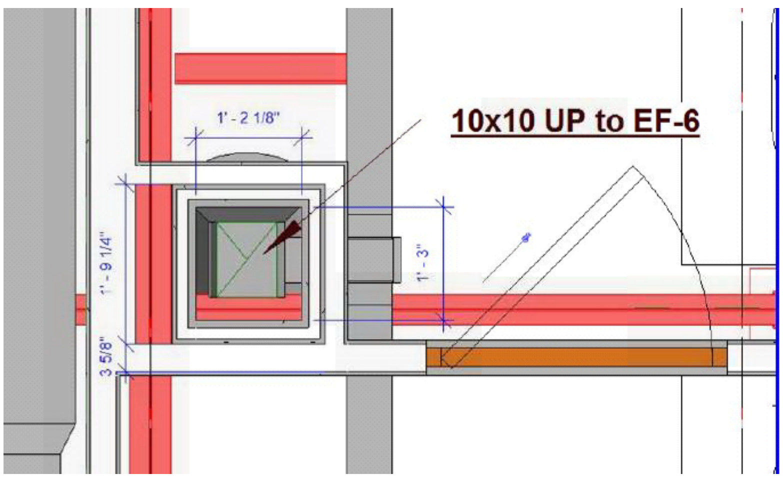

Figure 4-4. Example of a Direct Clash on a BIM- Assisted Project

Other. Lastly, there were a small number of issues that would likely have been discovered by BIM that did not fall into any of the above categories discussed. In particular, there were a number of VDC RFIs between Company X and the modeling subcontractor that did not result in an issue or conflict within the model. Rather, they represented general correspondence between the two parties. These issues were lumped into the "other" category for the purpose of this study.

Case Study One

Project A (Pre-BIM)

Background

Project A is a 123,000 square foot commercial warehouse of tilt-up wall construction that was completed prior to Company X's use of Building Information Modeling. Its delivery method was negotiated bid and its final contract was Guaranteed Maximum Price (GMP). Company X performed full construction management services and complete site development on this project. All concrete work was self-performed by Company X's in-house structural division. Project A's schedule spanned roughly twelve months and its final contract value summed to approximately $7.5 million. Its basic design was formulated by a design firm and then an additional set of detailed tilt-up panel shop drawings were outsourced to a separate subcontractor. An image of the building's basic design is illustrated in Figure 4-5.

Project RFI and change order analysis

A breakdown of the general project statistics that were collected on tilt-up wall Project A is shown in Table 4-1. Project A resulted in $376,837 in change orders to the owner which represented approximately 5.2% of its initial contract price. From these data, it was also derived that the average cost per closed change order request on project A totaled nearly $25,122. Many

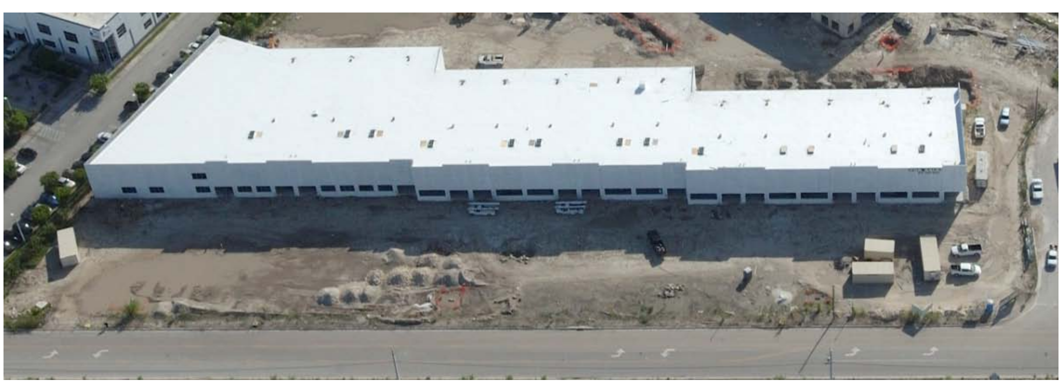

Figure 4-5. Project A: General Design

of these changes resulted in schedule delay and rework for Company X. Of the total 21 change order requests submitted to the owner, 15 were actually granted and resulted in a revised contract price. The other six rejected CORs were resolved by alternative means or became a cost burden of Company X.

Table 4-1. Project A: Contract Information

General Statistics:		Notes
Original Contract Price:	$7,128,000.00	
Total Cost of Change Orders:	$376,837.67	
Revised Contract Price:	$7,504,837.67	
Schedule duration (Days):	334	240 days + 15days mobilization + 30 day grace period for permit
Delay (Days):	7	
Total Number of Change Order Requests:	21	*6 REJECTED & 15 CLOSED*
Total Number of RFIs:	79	

Note: Rejected change order requests (CORs) indicate issues that the owner did not agree to pay for in the revised contract and thus became the contractor's cost burden. Closed CORs indicate those requests that were agreed upon by the owner and resulted in a full cumulative change order and revision in the contract. Most change orders include several closed CORs lumped into one document.

Thorough analysis of RFI and COR logs on Project A determined that three out of the ten total (30%) problems addressed by the cumulative change orders would have been discoverable by using BIM. In addition, the number of requests for information (RFIs) was also relatively high for a project of this scale and complexity.

From the analysis conducted on Project A's RFI log, it was found that a considerable number of RFIs may have been discovered earlier in the project had BIM technology been used. As shown in Table 4-2, approximately 23 of the total 79 RFIs noted construction issues that would likely have been discovered by using a BIM before construction began. This comprised approximately one-third (29.1%) of the total number of RFIs on Project A.

Table 4-2. Number of Cumulative Change Orders and RFIs Discoverable by BIM

Project A: Calculated Statistics:	
Total number of cumulative change orders:	10
Number of cumulative change orders directly preventable by BIM:	3
Total number of field RFIs:	79
Number of field RFIs likely discovered by BIM:	23

Additional statistics were analyzed to breakdown the types of concerns raised in the 23 RFIs based on specific categories. Table 4-3 and Figure 4-6 show the breakdown of the 23 BIM discoverable RFIs. These categories were created based on the known capabilities of Company X's BIM efforts and the types of similar issues that arose in VDC discrepancy logs on later BIM-assisted projects.

Table 4-3. Number of BIM-Discoverable Field-RFIs on Project A by Issue

Issue	# of BIM Discoverable RFIs
Dimensional inconsistencies	5
Documentation discrepancies between disciplines	6
2-D errors and omissions	3
Grid/column alignment issues	2
Direct clashes	7
Total:	23

Direct clashes comprised roughly 30% of the 23 BIM discoverable RFIs. These issues are perhaps the most significant as they resulted in direct costs to the owner when discovered too late in the project schedule. In second place were discrepancies between sheets of different disciplines, which comprised 26% of all of Project A's BIM-discoverable RFIs.

In addition, dimensional inconsistencies and 2D errors and omissions comprised 22% and 13% respectively of the RFIs. These RFIs may have been virtually eliminated all together had the construction drawings been created in some sort of BIM software platform in which 2D errors were minimized.

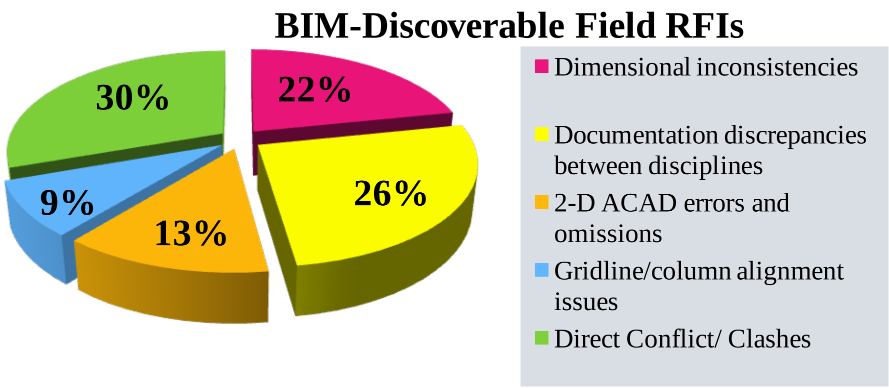

Figure 4-6. Project A: BIM-Discoverable Field RFIs by Category

Project B (BIM-Assisted)

Background

Project B was completed *with* the use of BIM technology after the construction of Project A. It also was constructed using concrete tilt-up walls and structural steel framing. However, the design was comprised of three identical smaller 81,000 square foot warehouses that eventually became commercial offices for lease. Like Project A, the same negotiated delivery method was followed and its contract was also GMP. Project B's schedule spanned roughly twelve months and its final contract totaled approximately $9.1 million after change orders. Though Project B is slightly larger in terms of contract value and overall square footage, the projects are quite comparable for the purpose of this study.

On this project, BIM was used as a tool for coordination, visualization, on-site panel layout, and as a means for checking Company X's concrete estimate. However, the primary function of the BIM on Project B was to facilitate the creation of a more exact set of specialized tilt-up panel shop drawings and eliminate the need to sub-contract that task. As a result, the drawings produced by BIM were much more accurate. It was also much easier to make changes in-house as needed when field conditions arose. Figure 4-7 illustrates the final model that was constructed for Project B.

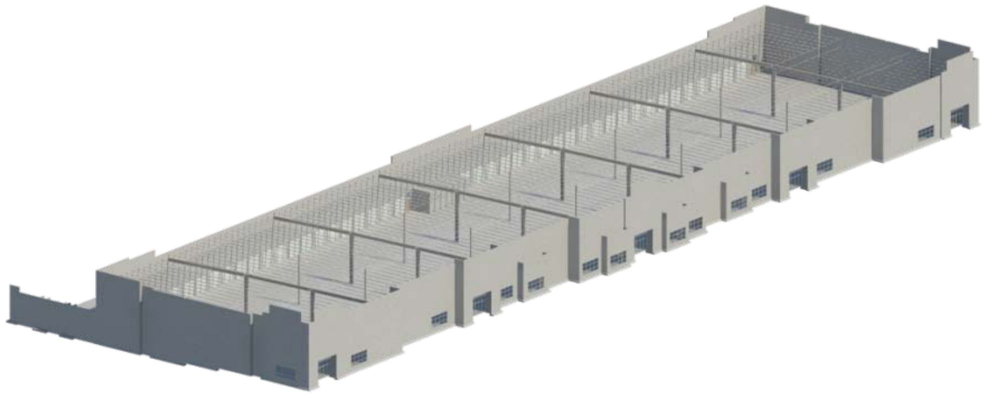

Figure 4-7. Project B: Final BIM

Project RFI and change order analysis

The general statistics that were collected on Project B are indicated in Table 4-4. Project B experienced roughly $271,852 in change orders, representing approximately 3.1% of its initial contract price. Of the total fifteen change orders requests submitted to the owner, eleven were actually granted, resulting in six finalized cumulative change orders. The average cost per closed change order request on BIM-assisted Project B totaled nearly $24,713. It was completed on time and within budget.

Table 4-4. Project B: Contract Information

General Project Statistics		Notes
Original Contract Price:	$8,844,073.00	
Total Cost of Change Orders:	$271,851.83	
Revised Contract Price:	$9,115,924.83	
Schedule Duration (Days):	270	
Actual delay (Days):	0	
Total Number of Change Order Requests:	15	*4 REJECTED & 11 CLOSED*
Total Number of RFIs:	43	

Table 4-5 depicts the breakdown of Project B's cumulative change orders and RFIs in detail. There were a total six cumulative change orders, none of which were attributed to BIM-preventable issues. Project B also experienced fewer field RFIs. Of the total 43 field RFIs, approximately 13 were discovered through BIM coordination during construction. In addition, a total of nine additional VDC-RFIs were submitted by the BIM subcontractor to Company X prior to construction.

Table 4-5. Number of Cumulative Change Orders and RFIs Assisted by BIM

Project B: Calculated Statistics:		Notes:
Total number of cumulative change orders:	6	
Total number of cumulative change orders preventable by BIM:	0	
Total number of RFIs:	52	*43 field/ 9 VDC*
Number of VDC RFIs discovered during conversion of plans to BIM:	9	
Number of field RFIs discovered by BIM during construction:	13	

All of the issues raised in the VDC-RFIs were in reference to the discrepancies between architectural and structural drawing sets needed to furnish accurate tilt-up panel shop drawings and all were resolved prior to the start of construction. Thus, the utilization of the BIM model assisted in the discovery of a total of 22 construction coordination related issues. This comprised roughly over one-third (42.3%) of all of Project B's RFIs.

The 13 field RFIs discovered by BIM *during* construction were analyzed further and broken into categories. Table 4-6 and Figure 4-8 illustrate the breakdown of those BIM-discovered field RFIs by category.

Table 4-6. Number of BIM-Discovered Field-RFIs on Project B by Issue

Issue	# of RFIs Discovered by BIM
Dimensional inconsistencies	2
Documentation discrepancies between disciplines	5
2-D errors and omissions	2
Direct clashes	4
Total:	13

Note: This table only tabulates the number of field RFIs that occurred **during** construction.

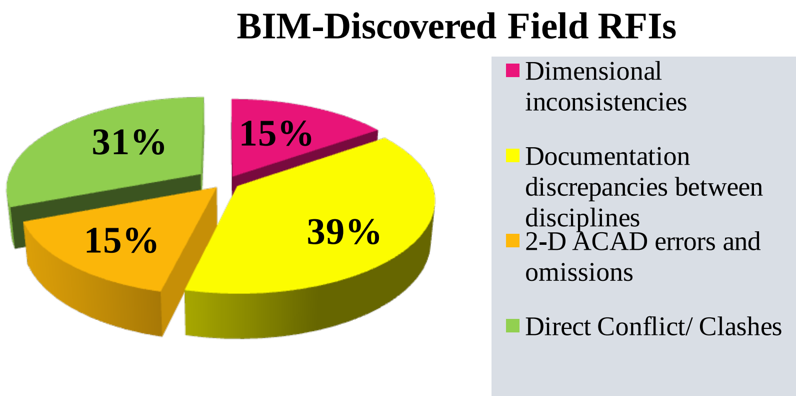

Figure 4-8. Project B: BIM-Discovered Field RFIs by Category

Roughly 39% of all BIM–discovered RFIs related to discrepancies between sheets of different disciplines. This resulted from a lack of coordination between architectural and structural construction drawings and the user error that results from using a 2D system. Direct clashes comprised roughly 31% of the 13 field RFIs discovered by BIM during construction. In addition, dimensional discrepancies and 2-D errors and omissions tied with approximately 15% in both categories.

Comparative Analysis of Projects A and B

Projects A and B were comparable in terms of size, scope, contract value, and construction type. Though there were minor differences between them, it can be inferred that they were roughly equivalent for the purpose of this study. Table 4-7 compares the two projects based on a variety of parameters.

Table 4-7. Projects A and B Compared

	Project A (Pre-BIM)	Project B (BIM-Assisted)
Contract Value:	$7,128,000.00	$8,844,073.00
Contract Type:	GMP	GMP
Delivery Method:	Negotiated Bid	Negotiated Bid
Square footage:	123,000 SF	(3) 81,000 SF bldgs

Table 4-7 Continued.

	Project A (Pre-BIM)	Project B (BIM-Assisted)
Use:	Commercial warehouse with leasable mixed use space	Commercial warehouse of leasable office space
Type of Construction:	Tilt-up wall with steel framing	Tilt-up wall with steel framing
Scheduled duration:	12 months	12 months
Project Management Staff:	Same	Same
Architect/Engineer:	Different	Different
Scope:	Construction Management with all concrete-work self performed	Construction Management with all concrete-work self performed

From the RFI and change order analysis of Projects A and B, it can be concluded that the BIM-assisted Project B showed improved coordination and was more successful. Table 4-8 summarizes the findings of Project A and B's general statistical analysis.

Table 4-8. Project A and B Results Compared

Calculated Statistic	Project A (Pre-BIM)	Project B (BIM-Assisted)
Total number of cumulative change orders:	10	6
Total number of cumulative change orders preventable by BIM:	3	0
Total number of RFIs:	79	52
Number of VDC RFIs discovered during conversion of plans to BIM:	-	9
Number of field RFIs discoverable by BIM during construction:	23	13

It is apparent that Project B had fewer change orders and RFIs and a lower total cost of change orders, despite the fact that is was actually a larger project. In addition, the timely completion of Project B compared to Project A's seven days of delay is also a testament to the impact of BIM on the project. Overall, Project B resulted in an estimated 34% reduction in RFIs and a 29% reduction in change order requests. The change orders on Project A comprised more than 5% of the total contract value, whereas the change orders for BIM-assisted Project B comprised 3% of the total contract price.

Though there was a decrease in the number of RFIs on BIM-assisted Project B, the time in which the RFIs took place was also quite different. It took an average of 7.5 days response time by the architect per RFI on BIM-assisted Project B, while Project A had an average of 7.2 days response time. Figure 4-9 maps the occurrence of field RFIs over each month of Project A's schedule.

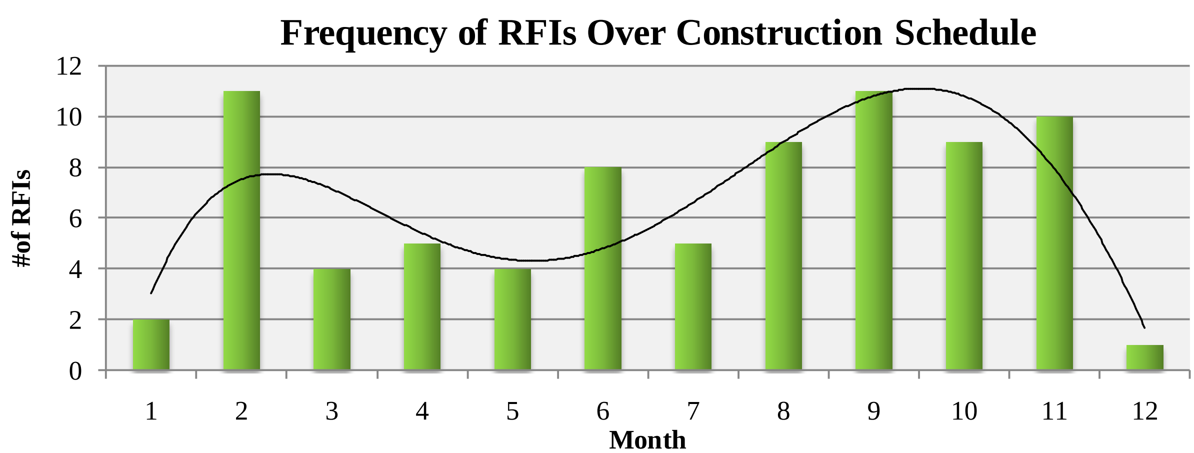

Figure 4-9. Project A: Field RFIs Mapped Over Time

It seems that the greatest concentration of RFIs occurred in the second month of the project schedule and then again in the last five months of the project. As with any conflict, the later that issues arise in the schedule, the more likely that they may affect the cost of change orders and the timely completion of the project. In contrast, Figure 4-10 maps the occurrence of field RFIs over each month of BIM-assisted Project B's schedule.

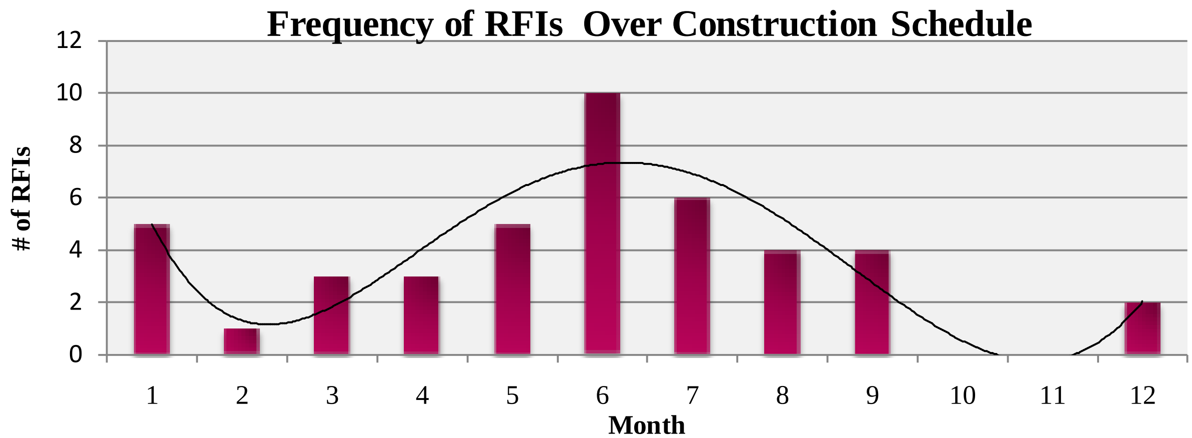

Figure 4-10. Project B: Field RFIs Mapped Over Time

On BIM-assisted Project B, the pattern of RFI frequency resembled more of a bell curve with the greatest concentration of RFIs occurring in the middle of the project schedule. It seems that most issues were resolved by month nine, leaving the last three months almost completely free of construction issues. Whether this pattern is directly correlated to BIM's usage is inconclusive, but the improved organization over time is definitely apparent.

When comparing the types of conflicts discovered by BIM on both projects, it is apparent that the same types of issues arose. Analysis also revealed that a similar proportion of the BIM-discovered RFIs fell into each category. The greatest number of BIM-discoverable RFIs was related to direct clashes and document discrepancies between sheets on both Projects A and B, further justifying their similarities for comparison.

Estimated Return on Investment (ROI)

The estimated return on investment (ROI) that could have been realized by the owner as a result of using BIM was determined based on an analysis of what went wrong on Project A. Therefore, Project A was used as a metric to determine BIM's actual ROI in this case study. The total savings considered in the calculation of BIM's ROI were a function of direct and indirect costs to the owner.

Estimated preventable direct costs on Project A

First, the direct cost of subcontracting out the tilt-up panel shop drawings would have been eradicated if BIM had been used on Project A. There were also three distinct change orders on Project A that would likely not have occurred had a BIM been used. Two change orders cataloged the required fix of the wrong placement of several joist bearing and girder bearing embeds in numerous panels. The accuracy of the shop drawings as well as the large number of embeds make this type of error quite common in this type of construction. On project A, several of the embeds were poured at an elevation two to three inches lower than where the girder or joist was designed to sit. In most cases, a structural member was added to the existing seat in order to allow the joist and beam to sit in the correct location. Figure 4-11 shows a drawing of one of the joist bearing embeds and its proposed fix. The added material and labor cost of these two change orders summed to $9,427 in added steal shims and hardware for several embeds.

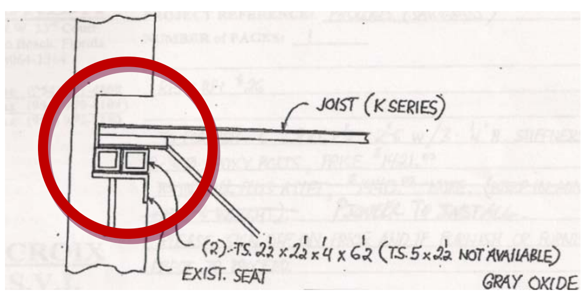

Figure 4-11. Example of Joist Bearing Embed Adjustment on Project A

In addition, there was also a third change order regarding the direct clash of a girder with an overhead door opening. The proposed fix for this issue was to actually move the door opening, re-pour concrete again in the area under the girder, and cut and remove additional concrete to form a new opening. Images of the conflict and its proposed fix are shown in Figures 4-12 and 4-13.

Figure 4-12. Girder and Door Height Conflict on Project A

Figure 4-13. Girder and Door Height Rework/ Resolution on Project A

Estimated preventable indirect costs on Project A

After the direct costs in change orders were analyzed, the indirect costs of time overruns to the owner/developer were estimated. Four major cost categories to the owner were considered in this analysis. First, the daily cost of the contractor's General Conditions was estimated based on the past records of Company X and the scale of the contract. Then the daily cost for developer administration for the project and the architect's construction administration time was also estimated based on the contract size. Lastly, the daily cost of interest on the owner's construction loan was considered. For the purpose of this study, a 5% interest rate was assumed. This is likely an underestimate, as the true interest rate varied on each job based on the scale and the current prime rate that was available when it was constructed. These daily costs were than multiplied by the seven days of delay Project A experienced to calculate an estimated total cost of schedule delay that was experienced. Whether all of this delay was contributed to BIM-preventable issues is inconclusive. However, this analysis assumes the worst case scenario.

Calculated return on investment (ROI) of Project A

Table 4-9 shows the cost breakdown used in calculating the ROI for Project A. The sum of all three direct change orders preventable by BIM, the indirect cost of time overruns, and the cost of subcontracting the panel shop drawings was summed to get the total amount of savings that could have been experienced on Project A. Then the cost of the investment was subtracted from this total to get the net savings that may have been experienced as a result of BIM. The cost of the investment in BIM was approximated to be 0.5% of the original contract price, as that was what was furnished by the owner for BIM services in the contract. To get the final rate of return that may have been experienced on Project A, the total net BIM savings were then divided by the cost of the investment.

From this analysis, the return on investment of implementing a building information model on Project A was estimated to be roughly 36.7%. Therefore, in this case, BIM would have paid for itself almost completely in direct cost avoidances. In addition, it can be seen that 4% of the total cost of change orders on Project A may have been completely eradicated, if BIM technology was used at this scale.

Table 4-9. Project A: BIM ROI

Cost Category		Amount
Direct cost of subcontracting out panel shop drawings:		
	Total:	$16,650.00
Direct costs in preventable change orders:		
Embed Fix Change Order:		$928.00
Girder and Joist Seat Fix Change Order (Figure 4-11):		$8,499.00
Girder and Door opening Conflict Change Order (Figure 4-12 & 4-13):		$5,663.98
	Total:	$15,090.98

Table 4-9 Continued

Cost Category	Amount
Indirect costs in time overruns:	
Estimated daily cost of Contractor time overrun (General Conditions): ($855/day x 7 days of BIM-preventable delay)	$5,983.56
Estimated daily cost of 5% interest on construction loan for time overrun: ($976/day x 7 days of BIM-preventable delay)	$6,835.07
Estimated daily cost of Developer Administration for time overrun: ($446/day x 7days of BIM- preventable delay)	$3,118.50
Estimated daily cost to Architect's Contract Administration for time overrun: ($149/day x 7 days of BIM- preventable delay):	$1,039.50
Total:	$16,976.63
Total Estimated Savings:	$48,717.61
Net BIM savings:	$13,077.61
Cost of BIM (0.5% of contract value)	$35,640.00
ROI:	36.7%

Calculated return on investment (ROI) on Project B

The calculated ROI of Project A was then used as a model rubric for the measurement of BIM-assisted Project B. The comparative analysis conducted previously on these projects demonstrated that Projects A and B were directly comparable based on the type of issues discovered by the technology and the size, scope, and type of construction. As there was not enough recorded information available on the direct costs avoided on Project B, its ROI was estimated based solely on prevented indirect time overruns. Based on Project A’s analysis, it is estimated BIM may have prevented up to seven days of schedule delay on Project B as it was completed on time with improved coordination. Table 4-10 estimates Project B’s ROI solely on indirect costs and the prevented cost of subcontracting out tilt-up panel shop drawings. This analysis was somewhat inconclusive because of the lack of data available for direct cost that were avoided. However, based on prevented schedule overruns alone, Project B’s ROI totaled nearly 16.1%. Though BIM did not pay for itself in indirect costs alone, it should be noted that the software may have still saved the owner roughly $19,769 in delay costs. In addition, it is theorized that BIM may have avoided the direct costs of at least $10,000 to $15,000 in change orders, based on what was discovered on comparable Project A.

Table 4-10. Project B: BIM ROI of Indirect Time Savings

Cost Category		Amount
Direct cost of subcontracting out panel shop drawings:		
$0.13/SF X 243,000 SF	Total:	$31,590.00
Indirect costs in time overruns:		
Estimated daily cost of Contractor time overrun (General Conditions): ($888/day x 7 days of BIM-prevented delay)		$6,213.70
Estimated daily cost of 5% interest on construction loan for time overrun: ($1212/day x 7 days of BIM-preventable delay)		$8,480.62
Estimated daily cost of Developer Administration for time overrun: ($544/day x 7days of BIM preventable delay)		$3,805.85
Estimated daily cost to Architect's Contract Administration for time overrun: ($181/day x 7 days of BIM preventable delay):		$1,268.62
	Total:	$19,768.78
Total Estimated Savings:		$51,358.78
Net BIM Savings:		$7,138.42
Cost of BIM (0.5% of contract value)		$44,220.37
ROI:		16.1%

Case Study Two

Project C (Pre-BIM)

Background

Project C was completed prior to Company X’s implementation of BIM. It is a conventional post-tensioned cast-in-place concrete condominium consisting of 14 stories, 311 units and a 7-story parking garage. The delivery method was a negotiated bid and the final contract was guaranteed maximum price (GMP), with all concrete work self-performed. Project C’s schedule spanned roughly three years with a final contract value that summed to $46.8 million after change orders. The project experienced significant schedule delays resulting in litigation and more than $5 million dollars in change orders at its completion. Figure 4-14 shows an architectural rendering of Project C's basic design.

Figure 4-14. Project C: General Design

Project RFI and change order analysis

Project C resulted in more than $5,097,222 in change orders to the owner, approximately 12.2% of its initial contract price. Its average cost per closed change order request totaled nearly $27,552. Many of these changes were actually delay settlement agreements to compensate for the lost time and rework that Company X experienced during Project C's construction. Of the total 240 change orders requests submitted to the owner, 185 were actually granted and resulted in a revised contract price. The other 55 rejected CORs were resolved by alternative means or became a cost burden of Company X. The general project statistics that were collected on project C are shown in Table 4-11.

Of the 185 closed change order requests on Project C, 15 were found to be directly preventable had been BIM been utilized. Thus, roughly 6.3% of all CORs may have been eliminated as a result of BIM. These CORs resulted in 11 distinct cumulative change orders that may have been eradicated had BIM been used. Project C experienced a great number of RFIs, much of which were due to the extensive delay and extreme conflict.

Table 4-11. Project C: Contract Information

General Statistics:		Notes
Original Contract Price:	$41,757,618.00	
Total Cost of Change orders:	$5,097,222.00	
Revised Contract Price:	$46,854,840.00	
Schedule duration (Days):	1027	*601original duration*
Delay (Days):	426	
Total Number of Change Order Requests:	240	*55 REJECTED & 185 CLOSED*
Total Number of RFIs:	651	

Note: Rejected change order requests (CORs) indicate issues that the owner did not agree to pay for in the revised contract and thus became the contractor's cost burden. Closed CORs indicate those requests that were agreed upon by the owner and resulted in a full cumulative change order and revision in the contract. Most change orders include several closed CORs lumped into one document.

In addition, analysis of Project C's RFI log revealed a large number of BIM discoverable RFIs. As shown in Table 4-12, approximately 210 of the total 651 RFIs noted construction issues that would likely have been discovered by BIM, had the technology been used. This encompassed approximately one-third (32.3%) of the total number of field RFIs on Project C.

Table 4-12. Number of Cumulative Change Orders and RFIs Discoverable by BIM

Project C: Calculated Statistics:	
Total number of cumulative change orders:	49
Number of cumulative change orders directly preventable by BIM:	11
Total number of field RFIs:	651
Number of field RFIs discoverable by BIM:	210

The 210 RFIs that were cataloged as being BIM-discoverable fell into multiple categories. Extensive analysis of Project C's RFI and COR logs revealed that Project C's BIM-

discoverable issues were more evenly split than on the smaller projects analyzed in Case Study One. Table 4-13 and Figure 4-15 reveal the breakdown of these categories. Roughly 29% of all BIM– discoverable RFIs on Project C cataloged issues related to direct clashes, many of which resulted in change orders. Approximately, 21% of the RFIs were categorized as issues related to 2D errors and omissions.

Project C also experienced great incongruity between disciplines, predominantly between Architectural and Structural sheets. This is likely due to its greater size and complexity. Subsequently, documentation discrepancies between disciplines comprised 17% of Project C's 210 BIM discoverable RFIs. In addition, dimensional discrepancies comprised 15%. Another 11% of the BIM discoverable RFIs were attributed to grid and column alignment issues. These issues posed considerable problems on Project C and are discussed further in the change order analysis. It is theorized that most of these issues would have been prevented in the initial modeling phase, had BIM been utilized on Project C.

Table 4-13. Number of BIM- Discoverable Field-RFIs on Project C by Issue

Issue	# of BIM Discoverable RFIs
Dimensional inconsistencies	31
Documentation discrepancies between disciplines	36
2-D errors and omissions	44
Grid/column alignment issues	23
Direct clashes	62
Other	14
Total:	210

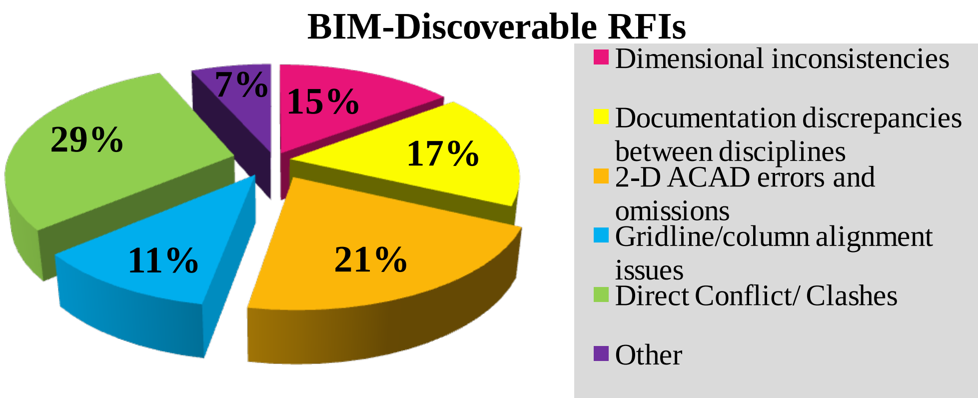

Figure 4-15. Project C: BIM-Discoverable Field RFIs by Category

Project D (BIM-Assisted)

Background

Project D, completed with the aid of BIM, is also a conventional post-tensioned concrete condominium consisting of 4 towers ranging from five to seven stories each and a total of 218 units. The building surrounds a five-story design-build parking garage also completed by Company X. Its delivery method was also negotiated bid and the contract was Guaranteed Maximum Price with all concrete work self-performed as well. Project D's schedule spanned just less than two years with a final contract value that summed to $44.9 million after change orders. This project is anticipated to receive its certificate of temporary occupancy roughly two months ahead of its contracted date of substantial completion. Project D was also the first BIM-assisted project ever attempted by Company X. Therefore, the technology was used in its most basic form, to assist in coordination between disciplines, reduce field error, and aid in visualization. The parking structure was a design-build collaboration constructed of post-tensioned concrete and steel columns. Figures 4-15 and 4-16 illustrate Project D's final BIMs and exemplify its overall similarities in design and layout to Project C.

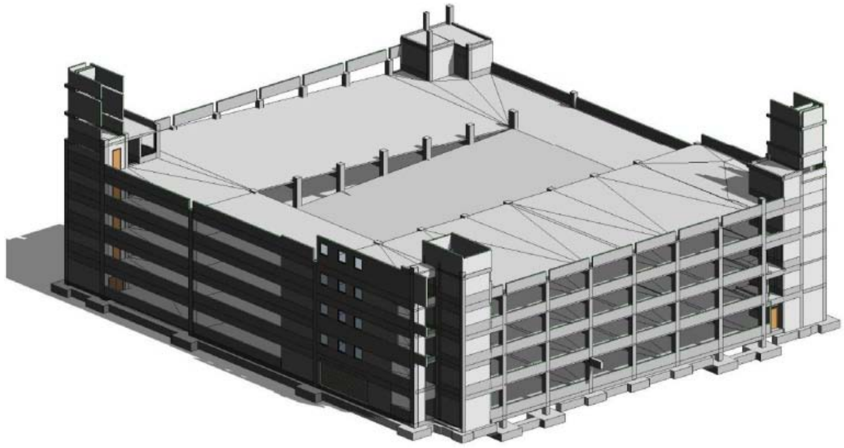

Figure 4-15. Project D: Design-Build Parking Structure BIM

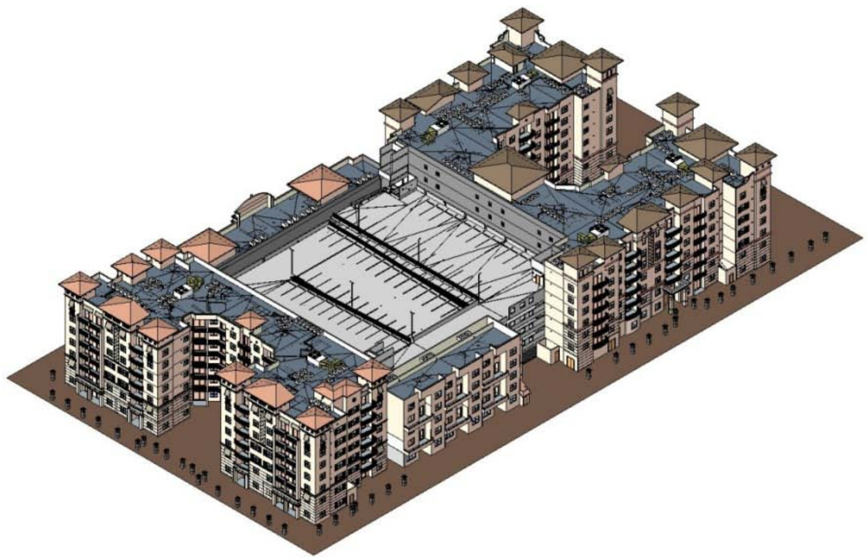

Figure 4-16. 3-Dimensional Axonometric View of Project D's Full BIM

A breakdown of the general statistics that were collected on BIM- assisted Project D is shown in Table 4-14. Approximately 1.2% of Project D's initial contract price was the result of construction changes resulting in $513,632 in change orders. Roughly 31 of Project D's 58 change orders requests submitted to the owner were deemed closed and resulted in cumulative change orders. The average cost per closed change order request summed to nearly $16,569 on Project D.

Table 4-14. Project D: Contract Information

General Project Statistics		Notes
Original contract price:	$44,400,000.00	
Total cost of change orders:	$513,632.00	
Revised contract price:	$44,913,632.00	
Schedule duration (Days):	652	
Actual delay (Days):	0	*60 days ahead of schedule*
Total number of change order requests:	58	*22 REJECTED& 31 CLOSED*
Total number of field RFIs:	315	

Note: Rejected change order requests (CORs) indicate issues that the owner did not agree to pay for in the revised contract and thus became the contractor's cost burden. Closed CORs indicate those requests that were agreed upon by the owner and resulted in a full cumulative change order and revision in the contract. Most change orders include several closed CORs lumped into one document.

Detailed investigation of Project D's RFI and COR logs revealed two of the 31 closed change order requests were attributed to BIM-preventable issues. Therefore, there were two BIM discoverable issues that were overlooked during virtual design and construction that might have been prevented had the technology been used accurately. This is likely due to the fact that it was Company X's first BIM experience ever.

Project D experienced fewer field RFIs than Project C, as shown in Table 4-15. This BIM-assisted project experienced a total of 315 field RFIs, of which approximately 86 were discovered through BIM coordination during the construction process. Thus, 27.3% of all *field* RFIs on Project D were assisted by BIM.

Additionally, a total of 57 VDC-RFIs were submitted by the BIM subcontractor to company X during the conversion of the 2D plans to BIM on Project D. Most of these issues were resolved prior to construction and fueled a more accurate revised set of drawings to be used in the field. Therefore, the utilization of the BIM model assisted in the discovery of a total of

143 construction coordination issues. This comprised roughly 38.8% of all of the RFIs on BIM-assisted Project D.

Table 4-15. Number of Cumulative Change Orders and RFIs Assisted By BIM

Project D: Calculated Statistics:		Notes:
Total number of cumulative change orders:	31	
Number of cumulative change orders directly preventable by BIM:	2	
Total number of RFIs:	369	*315 field/ 57 VDC*
Number of VDC RFIs discovered during conversion of plans to BIM:	57	
Number of field RFIs assisted by BIM during construction:	86	

Table 4-16 and Figure 4-17 demonstrate how the 86 field RFIs discovered through the assistance of BIM were categorized. Like Project C, BIM-assisted Project D's BIM-discoverable RFIs were more evenly distributed among the different categories. Overall, there seemed to be a smaller proportion of RFIs related to direct clashes and grid alignment issues on Project D in comparison to Project C, with 20% and 6% respectively. This is likely attributable to the fact that most grid issues were resolved in the first week of BIM modeling and revised drawing sets were submitted before construction took place. This fact compounded by the earlier discovery of issues during preconstruction by the BIM subcontractor likely resulted in fewer direct clash issues.

Table 4-16. Number of Field-RFIs Discovered by BIM on Project D by Issue

Issue	# of RFIs Discovered by BIM
Dimensional inconsistencies	20
Documentation discrepancies between disciplines	24
2-D errors and omissions	20
Grid/column alignment issues	5
Direct clashes	17
Total:	86

Note: This table only tabulates the number of field RFIs that occurred **during** construction.

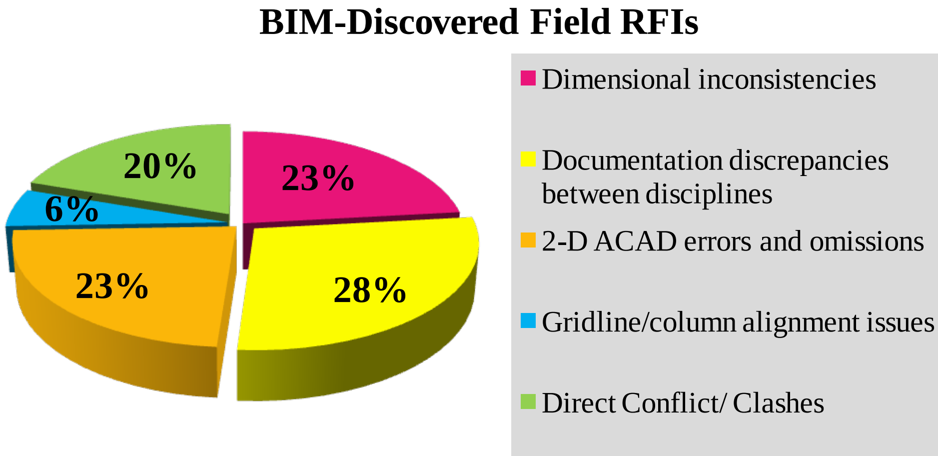

Figure 4-17. Project D: BIM-Discovered Field RFIs by Category

The greatest number of BIM-assisted RFIs on Project D dealt with discrepancies between sheets of different disciplines, comprising approximately 28% of the 86 field RFIs discovered by BIM. Most of these were attributed to inconsistencies between architectural and structural construction drawings. Dimensional inconsistencies and 2-D errors and omissions tied in close second with approximately 23% falling in both categories. Lastly, direct clashes comprised roughly 20% of the 86 field RFIs discovered by BIM during construction.

In addition to the field RFIs discovered by BIM, the 57 VDC RFIs were also categorized by issue. These issues seemed to be more evenly distributed, but were similar to the BIM-assisted RFIs discovered in the field. Table 4-17 and Figure 4-18 describe the proportion of VDC RFIs in each category. The greatest majority of VDC RFIs referenced direct clashes and two-dimensional errors and omissions. Roughly 23% of all the VDC RFIs received referenced direct clashes, mainly between ceiling conditions and mechanical ductwork. An additional 21% of the VDC RFIs were issues regarding errors and omissions in the 2-D documents. Thus, more information was needed by the modeling subcontractor to complete an accurate model.

The 17% of VDC related RFIs that fell into the "other" category were in reference to minor issues in coordination between the modeling subcontractor and Company X. They did not become field RFIs to the Architect. The data revealed a large proportion of grid and column alignment issues, comprising 14% of the total. This is perhaps why this category was much lower in the field RFIs sample. It seems most of the major gridline discrepancies were resolved before construction began on Project D.

Table 4-17. Number of VDC-RFIs on Project D by Issue

Issue	# of RFIs Discovered by BIM
Dimensional inconsistencies	5
Documentation discrepancies between disciplines	9
2-D errors and omissions	12
Grid/column alignment issues	8
Direct clashes	13
Other	10
Total:	57

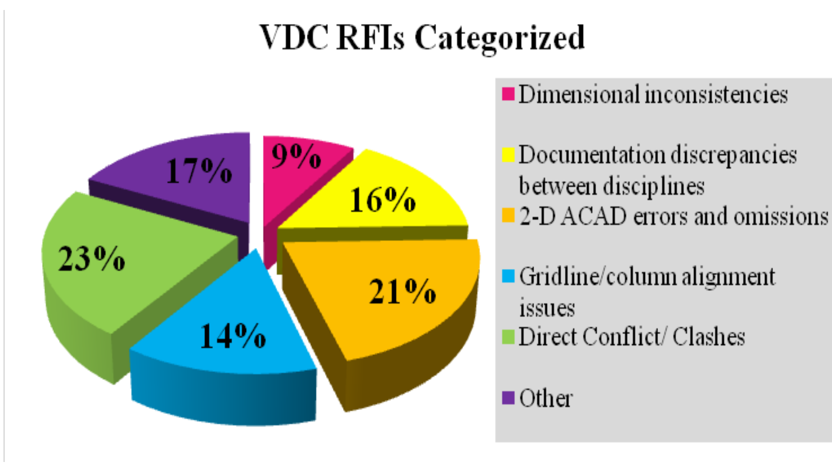

Figure 4-18. Project D: VDC RFIs by Category

Comparative Analysis of Projects C and D

As described, Projects C and D were comparable in terms of size, scope, contract value, and construction type. Though they possess minor differences, it can be inferred that they were roughly equivalent for comparison in this study. Table 4-18 compares the two projects based on a variety of project parameters.

Table 4-18. Projects C and D Compared

	Project C (Pre-BIM)	Project D (BIM-Assisted)
Contract Value:	$41,757,618.00	$44,400,000.00
Contract Type:	GMP	GMP
Delivery Method:	Negotiated Bid	Negotiated Bid
Square footage:	439,760 SF	456,594 SF
Use:	Mixed use- residential condominium	Mixed use- residential condominium
Number of Stories (Garage):	7 Stories	5 Stories
Number of Stories (Towers):	14 Stories	7 Stories
Number of Units:	311	218
Type of Construction (Towers):	Conventional formwork with conventional reinforcing	Conventional formwork with cast in place form tables
Type of Construction (Garage):	Post- tensioned concrete with concrete columns	(Design-Build) post tensioned concrete with steel columns
Original schedule duration:	601 days	652 days
Project Management Staff:	*Different*	*Different*
Architect:	Same	Same
Scope:	Construction Management with all concrete self- performed	Construction Management with all concrete self-performed

From the RFI and COR analysis of Projects C and D, it was found that BIM-assisted Project D experienced improved coordination and success overall as a result of BIM. The results of the statistical analysis of Projects C and D are contrasted in Table 4-19. It is evident that Project D experienced fewer total change orders and RFIs. In fact, its total cost of change orders summed to roughly one tenth of Project C's. This alone is a testament to BIM's role in reducing costs to the owner. Project C experienced almost 2 years of delay which resulted in several settlement disputes. While in contrast, BIM-assisted Project D is anticipated to finish roughly two months ahead of its contracted schedule duration.   From the project data that was collected, it can be estimated that Project D resulted in a 51.6% reduction in field RFIs and a 75.8% reduction in change order requests. There were still a large number of RFIs on the BIM-assisted project; however, the model assisted in resolving and discovering almost 40% of them between pre-construction and construction.

Table 4-19. Project C and D Results Compared

Calculated Statistic	Project C (Pre-BIM)	Project D (BIM-Assisted)
Total number of cumulative change orders:	49	31
Total number of cumulative change orders preventable by BIM:	11	2
Total number of RFIs:	651	369
Number of VDC RFIs discovered during conversion of plans to BIM:	-	57
Number of field RFIs discoverable by BIM during construction:	210	86

Case Study Two revealed a longer average response time per RFI by the architect on both Projects C and D. This is likely due to the greater complexity, scale and scope of this type of project. It took an average of 13 days response time by the architect per RFI on Project C. Whereas, Project D's average response time per RFI was approximately 11 days.   Analysis of the occurrence of field RFIs over the project's schedule was quite different from what was revealed in the first case study.

Figure 4-19 maps the occurrence of field RFIs over each month of Project C's schedule. The results of this graph were somewhat inconclusive. It seems that on Project C there was a steady influx of RFIs through the entire project schedule. However, it is evident that there was a greater concentration of RFIs after the first six months of the schedule had subsided and in the final eight months of the project. This is likely due to the substantial delay claims and extensive rework that was required during its schedule.

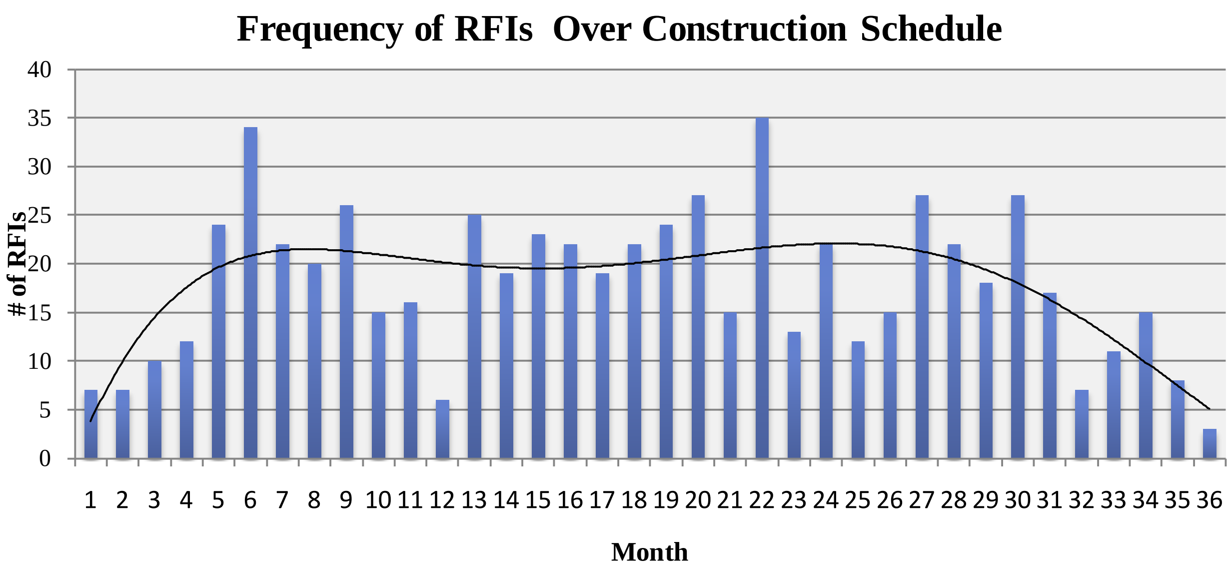

Figure 4-19. Project C: Field RFIs Mapped Over Time

In contrast, Figure 4-20 maps the occurrence of field RFIs over each month of BIM-assisted Project D's schedule. On BIM-assisted project D, the pattern of RFI frequency resembled more of a bell curve with two distinct humps occurring in months seven and eight and in month 12 in the middle of the project schedule. The overall number of RFIs seemed to decrease steadily in the final ten months of Project D. Whether this pattern is directly correlated to BIM's practice is uncertain, but it is apparent that there were fewer RFIs in the last few months of the schedule in comparison with Project C.

Roughly the same types of issues arose on both Projects C and D, regardless of BIM's utilization. In addition, the proportion of RFIs that were either BIM discoverable or BIM-assisted (in Project D's case) proved to be comparable. Roughly 32% of all of Project C's RFIs may have been assisted by BIM had the technology been available and a little more than 37% of Project D's RFIs were in fact discovered through utilizing a BIM model.

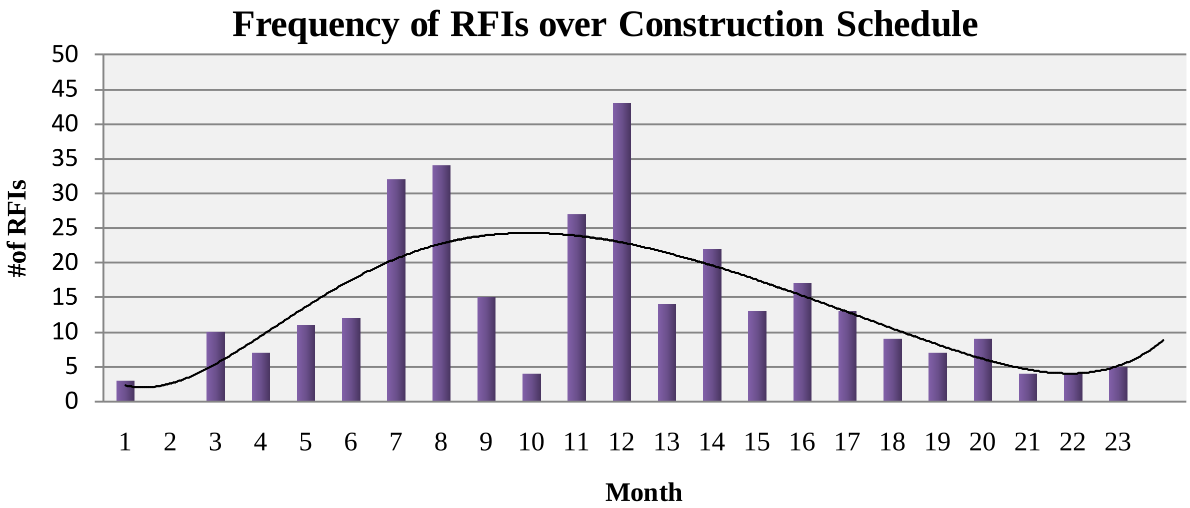

Figure 4-20. Project D: Field RFIs Mapped Over Time

When comparing Project C and D's BIM-discoverable field RFIs within their respective categories, there was a lower proportion of issues related to grid and column alignment. In fact, the data revealed a 5% reduction in gridline discrepancies and a 9% reduction in the number of field RFIs related to direct clashes on Project D. Both projects seemed to experience RFIs in high numbers regarding documentation discrepancies between disciplines and 2D errors and omissions.

Estimated Return on Investment (ROI)

Project C experienced major delay and major construction changes over the span of nearly three years. Many of these issues were the result of extenuating circumstances and outside variables beyond the scope of BIM. However, there were a large proportion of direct costs that could have been prevented had BIM technology been available at that time. Therefore, Project C's return on investment was approached first in terms of the direct costs in preventable change orders and then in terms of the indirect costs related to the delay that was likely associated with issues preventable by BIM.

Estimated preventable direct costs on Project C

There were 185 change order requests (CORs) that were deemed “Closed” by the owner on Project C. Those closed CORs were then lumped into 49 different change orders that eventually became part of the revised contract price to the owner. In the previous analysis, it was discovered that 15 closed CORs were the result of issues that would have been prevented by BIM. The change orders that resulted from these CORs may be considered direct avoidable savings of BIM, had it been used at the time.

Multiple issues arose on Project C. One of the most noteworthy was a major drafting error in the building’s original site plan that resulted in an inaccurate boundary survey. The outcome of this error left the original building’s footprint falling outside the existing property lines. Unfortunately, the 2D error was not discovered by Company X until a month into the project and a substantial amount of foundation work had already been placed. If a BIM had been used, it is expected this type drafting error would have been uncovered during initial modeling before construction commenced. The issue resulted in a 28 day delay time extension and a $24,862 change order including general conditions costs of $13,354, remobilization costs of $10,000, and additional delay damages.

There were multiple change orders that resulted from 2D error in the construction documents. These issues were deemed as BIM-preventable for the purpose of this study. Through interviews with Company X’s VDC staff, it was discovered that dissimilarities between the Architectural and Structural sets were often the first issues to be addressed during virtual design and construction. One such discrepancy which occurred on Project C resulted in a $787 change order which included the addition of link beam, reinforcing steel and labor. Had the issue been discovered earlier in the project schedule, most of the associated costs may have been avoided. There were also a number of issues related to the misalignment of the building grid between floors which caused major issues in the accurate placement of columns (most of which was the fault of rounding errors in the 2D construction documents). This led to a $3,396 change order for the revision of a column on upper floors that fell along a shear wall and a $419 change regarding the movement of two columns that had been poured in the wrong location because of grid line inconsistencies.

In addition, another change order ensued as a result of discrepancies between the plumbing and architectural sets. Sixteen 3” deck drains were left off the plumbing documents but were included in the architectural set and a 4” rainwater leader had to be relocated as it conflicted with an adjacent column. This associated cost as well as the additional labor, materials, tools, and equipment that resulted from this drafting error cost the owner $19,158 in change orders. Had a BIM model been used, it is likely this discrepancy would have been discovered in the creation of the plumbing model. It is anticipated that this issue would have been raised early enough before materials were ordered and construction took place.

There were multiple BIM-preventable direct clashes with the designed ceilings on Project C as well. Several soffits were created to conceal CD and sanitary piping, rain water leaders, and limited space for ductwork that were in direct conflict with the ceiling heights as designed. An increase in the ceiling heights of some units was required to accommodate the direct clash of multiple window heights as well. As a result of these issues, a change order was required to cover the cost to readjust the head heights of five floors of fire sprinklers that had already been placed. It totaled nearly $1,777 in labor and material costs. In another two units, a soffit was required to conceal the washing machine piping from the units above. This resulted in a change order of $1,285 in additional fire sprinkler adjustments as well. In 31 units, soffits were dropped six inches to accommodate the unanticipated scale of the return air ducts. This is an issue BIM could have resolved during preconstruction, so that re-engineering or a similar fix could have been proposed before the mistake was discovered in the field. The cost of additional framing, drywall, texture, repainting and fire sprinkler head adjustment for this issue summed to a $14,115 change order. Lastly, the structural deck of the 14th and 15th floors included multiple unanticipated drop panels. The addition of soffits to conceal these panels resulted in an additional $13,062 change order. All of these coordination issues were discoverable and likely fully preventable by BIM.

Project C also experienced multiple drafting errors that led to the mislabeling of window types on several of the unit layouts. Consequently, many of the mislabeled window types were too large to fit within the openings they had been designed for. A preventable change order costing roughly $2,632 resulted from a direct size conflict with the original windows and the columns that bordered them to each side. In addition, another $2,208 in change orders resulted from mislabeling of multiple window types that were actually intended to be sliding glass doors. This is yet another error commonly discovered by VDC RFIs during initial modeling and was likely avertable had the technology been used.

The mislabeling of wall types and sometimes lack of an accurate partition schedule led to several issues on Project C as well. A wall type that enclosed the roof drain pipes of 36 units was completely left off of multiple drawing sheets. This led to $19,081 in labor and material costs for additional framing and stucco and lath. The inspection of all wall types is a distinct phase of the BIM process that is generally conducted by Company X during 3D conversion to BIM. Therefore, it is likely these issues may have been avoided and the change order prevented.

There were a couple additional major direct clashes that resulted in costly change orders. In one scenario, the supply air and smoke detector duct had been routed in the same wall as an electrical panel causing a direct clash. As a result, a $2,722 change order was processed to include additional ductwork material, two new fire smoke dampers and access panels and the added tools, equipment, labor and supervision cost that was required to re-route the duct. In another instance, it was discovered that a 24" header beam over an elevator door actually conflicted with the head height of the elevator door itself. This error was discovered late in the schedule due to a drafting error in the structural drawings. It resulted in a $66,812 change order that included concrete removal, additional tube steel beams, re-pouring and the doweling in of additional reinforcing. In the process of the proposed fix, multiple concrete lintels and ductwork were damaged in the demolition. Those costs were incorporated in this cost figure as well.

Estimated preventable indirect costs on Project C

In addition to obvious direct costs in change orders, BIM may also have greatly assisted in preventing the indirect costs associated with the extreme delay that Project C experienced. Project C was delayed a total of 426 days past its original 601day duration specified in its contract. This resulted in two different delay claim settlements between the owner and contractor, based upon a detailed schedule analysis by Company X. There were a number of different factors that contributed to this delay. They included the drafting error in the boundary survey, major structural dimension conflicts, foundation and sidewalk conflicts, the relocation of columns due to grid misalignment, one hurricane and one tropical depression, issues with overhead power as result of hurricane damages, the addition of shearheads in a late plan revision, and limited plenum space in the ceilings of most units. While BIM could not have prevented the delay that resulted from extreme weather conditions and the resulting limited supply of permanent power, a number of these discrepancies between the structural and architectural drawings may have been uncovered during the modeling process, prior to the project's notice to proceed. Revised drawings may have been distributed before construction began and many of these issues could have been eradicated.

In a delay claim analysis conducted by Company X, it was found that a total of 249 of the 426 days in total delay were attributed to BIM-discoverable issues. Of those 249 days, 221 days can be considered indirect delay costs to the owner that may have been prevented by BIM.

The boundary survey drafting error resulted in a 32 day delay to the critical path, of which the contractor was awarded an additional 28 days in COR 0003. This has already been calculated as part of the direct cost of COR 0003 and was excluded from the preventable delay total. A major discrepancy between the civil and structural drawings was uncovered in the first delay period of the project. The majority of the building's exterior foundation was designed to be installed at an elevation which conflicted with the final elevation specified for the brick pavers. The excavation and foundation scopes of work were as a result delayed a total of 23 calendar days. It was required that all footings be lowered 16 inches, so as not to conflict with the sidewalk and pavers. As this issue was directly preventable by BIM, the delay it resulted in can be considered a preventable indirect cost of using BIM.

In addition, it was discovered through dimensional discrepancies and grid-alignment conflicts that the column layout had changed an excess of fifty column locations. Of these columns, approximately 26 were already cast-in-place prior to that discovery. As a result, all column work was ceased until an as-built was created and a new set of structural drawings were received. This caused a 25 day delay in the construction schedule and halted other major tasks on the critical path.

According to a delay analysis conducted by a third party during Project C's settlement agreements, a total of 95 calendar days of delay resulted from major dimensional discrepancies between architectural, structural and civil drawing sets over the course of the project. These were in excess of the specific delay already discussed. The ceiling clashes noted in several of the direct BIM-preventable change orders resulted in a large amount of rework that caused a 78 day delay to the critical path. Numerous plan revisions were submitted throughout the project schedule to correct these errors. However, it is anticipated that these errors would have been caught by a BIM model earlier in construction and the resulting delay would have been prevented. Table 4-20 breaks down the BIM-preventable delay by the issues addressed.

Table 4-20. BIM-Preventable Delay Days on Project C

BIM-Preventable Issue	Number of Calendar Days of Delay
Revised boundary survey conflict:	28
Exterior pile cap design conflict with pavers:	23
Grid discrepancies resulting in movement of columns:	25
Structural discrepancies:	95
Ceiling/Soffit changes because of direct piping conflicts:	78
Total Delay preventable by BIM:	249
Actual delay calculated as indirect cost to owner: *(Note: 249 total days - 28 days delay which was included in revised boundary survey change order)*	221

Calculated return on investment (ROI) on Project C

A summary of all of these costs in addition to the estimated final ROI for Project C can be understood in Table 4-21. The total cost of savings was calculated by adding the total direct costs in preventable change orders described earlier to the indirect cost of 221 days of preventable delay to the owner. The net BIM savings were calculated by subtracting the cost of BIM (roughly 0.5% of the original contract price). Then that total was divided by the cost of BIM to estimate BIM's ROI on Project C.

To calculate the indirect costs of time overruns to the owner/ developer, the same four major cost categories described in Case Study One were used. The daily cost of the contractor's General Conditions was estimated based on the past records of Company X and the scale of the job. Then the daily cost for developer administration for the project and the architect's construction administration time was also estimated based on the contract size. Lastly, the daily cost of interest on the owner's construction loan was considered. For the purpose of this study, a 5% interest rate was assumed. It is likely an underestimate as the true interest rate varied on each job based on the scale and the current prime rate that was available when it was constructed. These daily costs were than multiplied by the 221 days of BIM-preventable delay that Project C experienced.

The data revealed that Project C might have experienced great savings had BIM been implemented. The final estimated return on investment of using BIM on Project C was 1,654%. Thus, investment in BIM would have paid for itself up to 16 times on Project C. Though the initial cost of BIM would have been a pricey investment in this contract, just the savings in direct change orders alone would have paid for initial cost of BIM. From these calculations it was also discovered that 9.3% of the total cost of change orders may have been prevented by BIM. This is a substantial proportion of the revised contract price.

Table 4-21. Project C: BIM ROI

Cost Category	Amount
Direct costs in preventable change orders:	
(COR 00004) Revised Boundary Survey:	$24,862.35
(COR 00013) Added Beam in shear wall:	$786.84
(COR 00014) Shear Wall # 1 Revision:	$3,396.34
(COR 00015) Movement of (2) columns due to grid mis-alignment:	$418.60
(COR 00025) Addition of (16) 3" deck drains:	$19,158.08
(COR 00095) Readjustment of fire sprinkler heads for ceiling height changes:	$1,776.81
(COR 00092) Window reorder/install due to conflict with exterior columns:	$2,631.69
(COR 00104) sliding glass doors mis-labled as window type:	$2,207.97
(COR 00146) Revised ceiling heights to conceal drop panels:	$13,061.73
(COR 00151) Additional framing of roof drains:	$19,081.46

Table 4-21 Continued

Cost Category	Amount
(COR 00178) Re-routing of mechanical ductwork around electrical panels:	$2,721.99
(COR 00213) Additional soffits to accommodate return air ductwork:	$14,115.46
(COR 00231) Additional fire sprinkler heads adjustment for dropped ceiling:	$1,284.85
(COR 00175) Demolition and repair of elevator door beams:	$66,812.20
(CO 17) Materials escalation of initial 212 day delay due to boundary survey and structural plan discrepancies:	$300,000.00
Total:	$472,316.37
Indirect costs in time overruns:	
Estimated daily cost of Contractor time overrun (General Conditions): ($5425/day x 221 days of BIM-preventable delay)	$1,198,925.00
Estimated daily cost of 5% interest on construction loan for time overrun: ($5720/day x 221 days of BIM-preventable delay)	$1,264,168.98
Estimated daily cost of Developer Administration for time overrun: ($2466/day x 221 days of BIM preventable delay)	$544,986.00
Estimated daily cost to Architect's Contract Administration for time overrun: ($822/day x 221 days BIM preventable delay):	$181,662.00
Total:	$3,189,741.98
Total Estimated Savings:	$3,662,058.35
Net BIM Savings:	$3,453,270.26
Cost of BIM (0.5% of contract value)	$208,788.09
ROI:	1654%

Calculated return on investment (ROI) on Project D

Just as in Case Study One, the calculated ROI of Project C was used as a model rubric for the measurement of BIM-assisted Project D. The comparative analysis that was conducted demonstrated that Projects C and D were quite similar in terms of the type of issues discovered by the technology and the size, scope, and type of construction. It is also understood that the basic designs were very similar, as they utilized the same designer. Unfortunately, there was little recorded information available on the direct costs avoided on Project D because it was the first BIM-assisted project ever attempted by Company X. Thus, its ROI was also estimated based solely on indirect costs. This analysis is also likely an underestimate of savings, but validates BIM's return on a project of this scale.

Project D is unique in that it actually reached substantial completion roughly two months ahead of schedule. Thus, the same daily cost of time overruns outlined on project C were applied but instead multiplied by its 60 days of early completion. It is assumed that BIM's improved coordination was directly responsible for the lack of schedule delay on this project, though multiple other factors may have contributed to its success. Table 4-22 summarizes these findings.

Table 4-22. Project D: BIM ROI of Indirect Time Savings

Cost Category	Amount
Indirect Costs Saved by Early Completion:	
Estimated daily cost of Contractor (General Conditions): ($5425/day x 60 days early completion)	$325,500.00
Estimated daily cost saved in interest (5%) on construction loan : ($6082/day x 60 days early completion)	$364,931.51
Estimated daily cost of Developer Administration: ($2466/day x 60 days early completion)	$147,960.00
Estimated daily cost to Architect's Contract Administration for time overrun: ($822/day x 60 days early completion):	$49,320.00
Total:	$887,711.51
Total Estimated Savings:	$887,711.51
Net BIM Savings:	$665,711.51
Cost of BIM (0.5% of contract value)	$222,000.00
ROI:	299.9%

This analysis revealed roughly a 300 % return for an owner investing in BIM on Project D, based solely on costs avoided as a result of early completion. In this case, the owner's choice to invest in BIM more than paid for itself.

CHAPTER 5
ANALYSIS

Based on the available project data, this research confirmed the overall high return on investment of BIM to an owner. Overall the use of building information modeling proved to be a worthy investment for all parties involved in the two case studies conducted. BIM's ability to aid in coordination, communication, and visualization alone were valuable assets to Company X. The measurable qualitative benefits of reduced RFIs, reduced change orders, and reduced project delay were apparent in both case studies. This suggests that regardless of the size and scope of the project, the implementation of BIM was a vital tool. The quantitative cost benefits were less simple to prove however. Although measurable savings did exist, it was difficult to quantify them in a scientific and unbiased fashion. Thus, the calculated return on investment of BIM to the owner varied greatly based on the type of project and the data that was available.

The two case studies described in this research illustrate BIM‘s ability to be utilized at different project scales. The first case study illustrated BIMs use on a small scale, while the second case study demonstrated BIM's considerable value on a large project.

Case Study One

Case study one exemplifies BIM on a minute scale for its most basic features. The assistance of BIM technology aided a smoother more organized construction process. In fact, BIM-assisted Project B experienced 34% fewer field RFIs and 29% fewer cumulative change orders than Project A. In addition, seven days of schedule delay were conceivably prevented by the improved coordination that resulted from using this technology. But perhaps more critical to this research was the reduction in change order costs to the owner. More than 5% of Project A's initial contract price was the result of construction changes as opposed to Project B's 3%. In addition, it was projected that Project A may have eliminated up to 4% of its total cost of change orders if BIM was used.

From the ROI analysis, it is apparent that the implementation of BIM was perhaps a greater benefit to Company X than the Owner in the first case study. The qualitative benefits of reduced delay and lower change order costs were measurable direct benefits to the owner, however the savings seen on a project of this size were relatively minor. The 37.6% return is by no means insignificant, as BIM may have saved the owner approximately $13,000 on Project A. The results of Project B's ROI were somewhat inconclusive given the lack of direct cost data that was available. But it was estimated that BIM saved the owner roughly $19,769 in delay costs alone. It is not unexpected that a project of this scale and complexity had a much lower return than the projects indicated in Case Study Two. The mere nature of this type of construction lends itself to fewer major conflicts and the level of detail required on a warehouse job is less significant.

Also, noteworthy were some of the results of Case Study One's RFI analysis. More than one third of the RFI issues cataloged on both projects were the result of document discrepancies between disciplines and 2D errors and omissions. These statistics suggest that a large proportion of the RFIs may have been completed eliminated had the architect used some sort of BIM platform instead of a 2D program to create the construction drawings. It is anticipated that if a design-build approach had been used, these statistics would vary drastically.

Case Study Two

In contrast, Case Study Two exemplifies the use of BIM at a much greater scale. As stated in the earlier analysis, BIM-assisted Project D experienced approximately 52 % reduction in field RFIs and a 76% reduction in change order requests. In addition, it is anticipated to finish two months ahead of schedule. Thus, it is evident that this BIM-assisted Project D benefited greatly from the improved coordination that the technology supported.

Like Case Study One, many of the same RFI issues occurred in the same proportion on both Projects C and D. From the VDC RFI analysis on Project D, it was found that major discrepancies existed in the placement of grid-lines as a result of dimensional rounding in CAD. Had these issues not been resolved before construction, major rework may have ensued. An accurate representation of the building grid was essential for the placement of all columns. In addition, dimensional strings varied greatly in different areas of the building. In one instance, it was found that the difference between a stated distance referenced in the drawings and the actual summation of its dimension string was a full nine inches. Thus, the reduction in direct clashes and grid/column alignment issues found in Project D's Field RFI log was a testament to the technology as well.

Both projects seemed to experience RFIs in high numbers regarding documentation discrepancies between disciplines and 2D errors and omissions. This also suggests that multiple issues would have been eradicated had BIM been used to create the construction drawings in the design phase. If a design-build scenario had been implemented, it is projected that even fewer RFIs and change orders may have occurred.

The results of the return on investment analysis in Case Study Two proved that BIM's return was significantly higher on a larger more complicated project. On project C, BIM paid for itself more than two times solely in direct preventable change orders. In addition, the extensive delay that was attributed to major gridline and structural discrepancies also contributed heavily to the anticipated indirect savings that may have been achieved. It was projected that BIM might have prevented approximately 10% of the total cost of change orders on Project C.

BIM is a worthy investment to the owner just based on Project D's early completion savings. It is estimated that Project D's direct cost savings attributable to BIM likely totaled at least $300-400,000 based on the 75% reduction in change orders and the fact that the same issues arose on Project C. Therefore, it is anticipated that actual return on the cost of using BIM far exceeds 300% on Project D.

CHAPTER 6
CONCLUSIONS

Research Barriers

There were multiple limitations to this study that arose during the collection and analysis of available project data. Perhaps most significant was the lack of direct cost data on the BIM-assisted projects. It was much too difficult to determine the cost of conflicts that did *not* occur as a result of BIM, as there was little information given about how the issues were resolved. It seems in the construction industry there is a large proportion of recorded data for project failures, but little information about the successes. The lack of accurate records is also a direct result of Company X's inexperience with the VDC process. As they grow and gain more experience their VDC processes and records are becoming more refined.

In addition, the estimated indirect cost of time delays used in this research was a rough estimate in both case studies. It is likely that multiple variables contributed to each project's delay and early completion aside from BIM. Project C in particular experienced extreme delays due to unforeseen weather constraints. Much of its delay was outside the control of BIM technology. Thus, inferences were made regarding Project B and D's indirect cost estimates.

Furthermore, as each BIM-assisted project was constructed after their earlier Pre-BIM counterpart, many of their successes may be attributed to the learning curve as well. By producing roughly the same product a second time, it is not surprising that fewer conflicts arose and productivity was improved because of familiarity to the process. Lastly, it should be noted that no two projects are exactly the same. Though the projects that were studied possess strong similarities, they were completed in different time periods in which different economic conditions existed with different staff in some cases.

Conclusion

While quantifiable evidence of Building Information Modeling's benefits to Company X was uncovered in this research, measurement of BIM's actual savings to the owner was a much more challenging task. As hypothesized, BIM-assisted Projects B and D experienced fewer RFIs, fewer change orders, and improved coordination. Both were completed on time or ahead of schedule with relatively lower proportionate costs in change orders. It was confirmed that a greater return on investment was achieved on the larger more complex construction projects. The smaller tilt-up wall warehouse projects still benefited greatly from BIM's implementation but consequently had lower direct savings. It is therefore suggested that when deciding to invest in BIM, the owner should consider the size and scope of his project. Savings will still be realized regardless of the size of the project. However, the magnitude of those savings are directly associated to the scale of the contract. In the future, BIM will not be an additional service offered to clients, but an industry standard. However, at present these results support the argument that BIM is worth its pricey initial investment.

CHAPTER 7
RECOMMENDATIONS

BIM provides numerous benefits to all stakeholders, from conception of design all the way down to the owner's final acquisition of a building. This research justifies many of the qualitative benefits that were outlined in Chapter 2. In addition, the quantitative cost benefits and resulting ROI analysis confirmed BIM's potential value to an owner. However, this study was not without flaws. The two case studies demonstrated were informative, but represent only a small sample of the industry. This research attests that a BIM conversion of 2D construction drawings after the design phase is somewhat limited. If BIM was implemented from a design/build platform and embraced by all parties, the savings would be much greater.

If this study was conducted again, the methodology would be slightly revised. Instead of comparing one BIM- assisted project to one similar project constructed prior to BIM, this researcher would compare the results of a BIM-assisted Project to a sample of projects similar in size and complexity constructed without BIM. This would allow for the use of average statistics for comparison and perhaps minimize the error caused by outliers. There was great variability between the BIM-assisted projects and their pre-BIM counterparts due to extreme outside variables. For example, Project C can by no means be considered an industry norm. It experienced more problems than an average project of this size constructed by Company X.

Given more time, a third case study of a medium sized BIM-assisted project completed by Company X would have been conducted. The two project types selected represented two extreme ends of the spectrum. The tilt wall projects were perhaps too small to really see BIM's return to an owner and the condominium may have been too immense to attempt an accurate study in the allotted time frame. However, if a medium sized project ranging from $15 million to $20 million was analyzed as well, a more comprehensive view of BIM's ROI could be realized. A project of this size would have lent itself better to a study of this scale.

In addition, instead of analyzing Project B and D's ROI based on projections found on their pre-BIM counterparts, the direct costs avoided would have been estimated by conducting quantity takeoffs of the issues addressed in the VDC RFI logs. As a result, a more accurate depiction of BIM's ROI could be illustrated.

Recommendations for Future Research

Suggestions for Company X

As Company X builds its BIM portfolio, it is perfecting its VDC procedures and recordkeeping. It is suggested in addition to the VDC RFI logs between the modeling subcontractor and VDC staff that more information be tracked about the cost of conflicts. Just as a regular field RFI has supporting information and documentation behind it, so must a VDC RFI. As each major issue arises, an estimated projection of the potential cost associated with its fix must be attached. This cost should include: the estimated additional material that may be required, the cost of labor associated with its fix, and the estimated result it might have on the project schedule in order to determine its effect on the project's critical path. This is no simple feat as it requires a much greater commitment from project management staff. The tracking of direct clashes may be better assisted by the implementation of a program like NavisWorks that tracks clashes based on their severity as well. This too may be a future goal of Company X in its VDC efforts.

In addition, a running record of *how* the clashes revealed in the model were resolved should be organized. It is suggested that in addition to the VDC RFI log, there also be a "Resolution Log" that addresses how each conflict was fixed. In many cases, the solution may be simple. Most clashes discovered virtually have little cost implications because design changes and re-engineering is still plausible. However, documentation of these actions is essential for tracking. It was difficult to analyze the project data as an outside party without being a participant of the projects studied. A successful ROI analysis is only really accomplished internally by the company itself. This should be a goal of every company choosing to implement BIM, as it examines VDC progress and assists marketing efforts.

Suggestions for Future Study

Given unlimited resources and time, this research could be broadened to address a comprehensive view of BIM's ROI from the contractor's perspective. It is hypothesized that the greatest savings were actually achieved by Company X in this study, but there was a general lack of data to support the assumption. To a company fully equipped with in house modeling and an experienced VDC staff, the cost of BIM would be much lower than the cost of BIM services to an owner and the amount of savings would likely be much greater.

Therefore, instead of using just one company's data, a sample of multiple projects of different scales from multiple companies could be analyzed. This kind of research endeavor would require a major commitment from all participants so that there was some sort of standardization regarding how direct savings be monitored and tracked. The companies studied would have to be instructed in a standard format of cost record keeping so that there would be no variability in how ROI is calculated.

In addition, the only true way to conduct an accurate comparison like the one featured in this research would be to construct a project without BIM and then construct the *same* exact project again with the use of BIM.

Benefits to the Industry

Few research studies have been conducted to estimate BIM's return on investment. There have been multiple statistics and surveys published in recent years on the general cost savings of using Building Information Modeling, but very few evaluate the measurement of ROI in an exact science. This research illustrates the actual results of BIM's implementation on two projects of varying scales. It offers an example of BIM's success to future contractor's moving toward using BIM and demonstrates to owners that they too can benefit from the technology at large. It is anticipated that BIM's implementation will someday be an industry standard, embraced by all. But at the present, the greatest tool for the construction industry is exposure and communication.

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BIOGRAPHICAL SKETCH

As a native of Gainesville, Florida, Brittany Giel received a Bachelor of Design Degree in Interior Design in the spring of 2007 from the University of Florida. In the fall of 2007, she began work on her masters from UF's M.E. Rinker, Sr. School of Building Construction. It was during that time that she became very interested in construction documentation and computer aided design. While beginning her studies in construction, she worked as an AutoCAD technician for a small custom home builder and served as a graduate teaching assistant for UF's Department of Interior Design. Both occupations provided her with a more expansive knowledge of construction documentation and computer aided design, fueling a new interest in virtual design and construction (VDC).

In the summer of 2008, she took an internship in south Florida assisting in a commercial construction firm's virtual design and construction department. There she was able to utilize building information modeling (BIM) software and observe construction processes. The opportunity exposed her to BIM's implementation in a real world construction context.

Brittany's past career experience and design background have fueled her research interest in improved technology in the construction industry and BIM. She hopes to someday manage a virtual design and construction department within a construction or design firm and practice many of the skills she has learned at the University of Florida.