

BUILDING INFORMATION MODELING:  
HOW IT CAN BENEFIT A MODERN  
CONSTRUCTION PROJECT IN  
A UNIVERSITY SETTING

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## ABSTRACT

The benefits offered by Building Information Modeling, when implemented during a modern construction project, were analyzed. Common inefficiencies of current construction industry practices were observed through evaluation of historical data, and used to demonstrate the need for an improved project approach. Several surveys were presented to reveal the most popular uses of BIM while also displaying the value participating construction companies placed on each use. A case study of the North Engineering Research Complex located on the University of Alabama campus was presented, and observed benefits were evaluated up through the current progress. Potential benefits were explained for the remaining project phases.

The research revealed that a wide variety of benefits can be enjoyed by all project parties when utilizing Building Information Modeling. The most valuable benefit is that of overall increased collaboration during the project. The ability of the entire project team to share the BIM models helped in identifying problems prior to construction, reducing the project cost by avoiding these problems, improving the project schedule and increasing the overall quality of the end product. Viewing the three-dimensional BIM model also helped project members attain a better understanding of the project as a whole. Because Building Information Modeling is a relatively new concept, the owner, architect and general contractor also learned valuable lessons for future projects.

## DEDICATION

This thesis is dedicated to everyone who encouraged me and pushed me through the trials and tribulations of creating this document. My parents, James and Rosanna Duke, offered constant love and support throughout this process and were always there to lend a helping hand. My sister, Emily Duke, never stopped believing in me and always found a way to raise my spirits when I became overwhelmed during this daunting task. My girlfriend, Brittany Stancombe, pushed me to create the best thesis I could while offering unwavering love and endless encouragement. Last but not least, Brad and Jill Stancombe provided many fun weekends to ease the suffering, and offered much needed moral support and positive reinforcement.

## LIST OF ABBREVIATIONS AND SYMBOLS

<i>2D</i>	Two-dimensional
<i>3D</i>	Three-dimensional
<i>5D</i>	Five-dimensional
<i>AEC</i>	Architecture, Engineering and Construction: Refers to the fields of architecture, engineering and construction, as they are commonly interrelated
<i>AIA</i>	American Institute of Architects
<i>BIM</i>	Building Information Modeling or Building Information Model: The process of creating the Building Information Model and the actual model itself, respectively
<i>BOT</i>	Board of Trustees
<i>CAD</i>	Computer Aided Design
<i>CFD</i>	Computational Fluid Dynamics
<i>FTP</i>	File Transfer Protocol
<i>GC</i>	General Contractor
<i>gsf</i>	Gross square feet
<i>HVAC</i>	Heating, Ventilation and Air Conditioning
<i>LOD</i>	Level of Detail: A reference to the amount of detail used while modeling
<i>MEP</i>	Mechanical Electrical and Plumbing: Refers to the mechanical, electrical and plumbing disciplines of engineering
<i>NIBS</i>	National Institute of Building Sciences
<i>NIST</i>	National Institute of Standards and Technology

*O&M* Operations and Management: Refers to the Operations and Management phase of a construction project

*RFI* Request for Information

*RFP* Request for Proposal

*RISA* Rapid Interactive Structural Analysis

*SEC* Science and Engineering Complex

*sf* Square feet

*UA* University of Alabama

*WBA* Williams Blackstock Architects

*VDC* Virtual Design and Construction

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# CHAPTER 1

## INTRODUCTION

There are many deficiencies within the constantly evolving construction industry. Building Information Modeling (BIM) is a new technology that offers many benefits to this industry. These benefits often result in improved project quality, reduced schedules and reduced costs. This research examines the benefits BIM can offer a modern construction project from conceptualization to demolition. Through this and related research, construction firms can learn how to incorporate BIM into their work and experience an increase in overall project quality.

### 1.1 Motivation

Building Information Modeling is a new technology created to improve the execution, delivery, and maintenance of construction projects. Although many past construction endeavors have been successful, the methods and procedures used could have been greatly improved from an efficiency standpoint. With improved procedures often comes improved quality, decreased time, and most importantly – decreased costs. Time is money when dealing with construction, and with BIM being able to further improve on current practices, this technology will indeed become an essential asset within the industry.

The primary motivation of this research is to examine the numerous benefits BIM provides within a modern construction project. The constantly evolving construction industry needs improved, efficient, user-friendly technology. From conceptualization to demolition, BIM

is playing an increasingly vital role in the successful execution of many construction projects. Throughout this “cradle to grave” process, the use of BIM enhances overall collaborative efforts while offering a simplified, real-time approach to any project.

## 1.2 Objectives

The ultimate objective of this research is to provide a better understanding of the vast benefits BIM has to offer the construction industry while explaining how they can aid in increasing project quality. Through this and related research, construction firms can learn how to incorporate BIM technology into their work and, in turn, increase overall efficiency. The specific objectives of the following research are to identify the current deficiencies within the construction process and to explain how BIM technology can improve the entire life cycle of a modern construction project.

## CHAPTER 2

### LITERATURE SURVEY

This chapter focuses on the current literature dealing with multiple aspects of the construction industry. More specifically, the literature review centers on the evolution of the construction industry, the interpretation of trends compiled from historical construction data, and the inefficiencies of current industry practices. The evaluated literature reveals many problematic areas within the current construction industry and explains the need for a more collaborated project delivery process.

#### 2.1 Evolution of the Construction Process

Construction has always played a vital role in the advancement of human civilization. While the first structures were very simple shelters to protect humans from the elements, they likely required minimal collaboration. The earliest large-scale structure that would “require organization and capacities beyond the handicraft and physical strength of a few men” is that of a massive round Neolithic tower discovered in Jericho (Wright, 2009). The 10’x10’ stone tower would have required a preliminary building plan, organized labor force, and skills in transporting such massive boulders (Wright, 2009). This tower is the earliest evidence of an evolved construction process.

As history progressed, the Mesopotamian civilization advanced construction by evolving innovative mud-brick techniques and experimenting with various brick sizes, brick fabrications,

and structural arrangements for their buildings (Bertman, 2005). This allowed for easier construction of large-scale structures and led to a faster, more efficient process. Refining the large-scale construction process even more were the Egyptians, who devised ways to shape and move colossal stones in order to build pyramids. As construction innovation increased with time, the middle ages would spawn a turning point within the industry.

A very profound change came about with the introduction of the master builder. Until this time, the aspects of planning, design, and construction had all been handled and executed by multiple parties. “During the middle ages in western Europe, all three of these tasks were managed by the *master builder* – a single person who planned, managed, and executed the project for an owner” (Kymmell, 2008). The master builder was trained in all phases of design and construction, and his responsibility extended far beyond pure architectural design (Bruno, 2010). This is a good idea “as long as the master builder with the responsibility also had the authority to run the project as the representative of the owner” (Kymmell, 2008). With so much responsibility delegated to one person, this limits project aspects such as size and scope to whatever the master builder can personally handle. Despite these limitations, this process was advantageous as “there was *one* person to solve problems and address the issues right there on the job, *one* person who had all the information” (Kymmell, 2008).

Eventually, however, projects became too large and complex for one person to handle and the process required modification. The master builder was forced to begin using two-dimensional drawings in order to communicate his intentions to the builders on-site. Kymmell explains it best as he writes the following:

*“The most significant change was the removal of the master builder from the construction site, and the resulting need for an on-site ‘superintendent’ to run the job from day to day. This split of the master builder’s role into two new roles increased the*

*necessity for reliable communication. This change in project management has had a very large impact on the evolution of the construction industry. The person who conceived and developed the plans for the construction project now had to communicate his or her understanding to another individual (the building contractor) whose task it was to ensure that these plans correctly materialized into a project. The traditional single owner – master builder relationship became a more complex threefold relationship among the owner, the architect, and the building contractor.”* (Kymmell, 2008)

This process transformation resulted in the use of construction documents (Kymmell, 2008). As the size and scope of projects increased, the sophistication of the documents increased as well. Inherently, the gap between knowledge needed for design and knowledge needed for construction only widened. This inevitably led to the emergence of specialty disciplines such as structural, geotechnical, civil, and mechanical engineering.

Since the solidification of these specialty disciplines, the general nature of construction management has not changed much. This stability has led to numerous improvements and, consequently, various methods of project delivery. Each method has both its advantages and disadvantages, but no method is absolutely perfect. Regardless of the method, the complexity and scale of today’s projects can turn small underlying deficiencies into huge disasters.

## 2.2 Common Inefficiencies of Current Industry Practices

The scope and sheer magnitude of today’s construction projects when compared to the past are astounding. Looking back at these projects, one would think efficiency within the construction industry has also steadily progressed. Unfortunately, the opposite is true. Due to the increasing complexity of modern construction projects, what were small deficiencies in the past have now compounded into even larger problems. These problems have not gone unnoticed, and

numerous studies have been performed with proposals to address the declining performance of the construction industry. The following paragraphs will present some of these studies.

One such analysis was performed by the U.S Department of Commerce, Bureau of Labor Statistics and compares the efficiency of the construction industry to the efficiency of all other nonfarm manufacturing U.S. industries from 1964-2003. This study reveals an obvious flaw in the construction industry. While all non-farming manufacturing industries more than doubled their productivity during the duration of this study, construction actually declined to around 80% of its productivity in 1964. While various factors can be blamed for this occurrence, the concern and need for improved efficiency within the construction industry still remains.

Various reasons have been presented as the cause of this unfortunate decline in productivity. On one hand, Kymmell argues “The largest problem in the planning and construction of building projects is the incorrect visualization of the project information (‘the devil is in the details’)” (Kymmell, 2008). If the project information is not completely comprehended on all levels by the involved parties, complications will arise during construction. In the end, Kymmell simply sums up the weaknesses of the construction industry as communication difficulties, competition among team members, risk shifting, and litigation.

Regarding the aforementioned weaknesses, one of the most common occurrences indicating inefficiency between parties is the issuing of a Request for Information (RFI). An RFI is submitted by the contractor or subcontractor to the appropriate party when there is any doubt regarding the project plans. Although there exists a multitude of reasons why RFI’s are submitted, three reasons remain the most common: construction modification; information clarification; and construction deficiency. Construction modification occurs when a contractor is unable to procure a certain item or material and would like to substitute another item in its place.

Information clarification is simply the act of asking questions prior to and during construction to ensure all details are understood. Construction deficiency is basically any departure from the project plans or project specifications (Stewart, 2013). Regardless of the reason, an RFI indicates a problem that will require additional time and effort that could otherwise be used to further the construction project.

Another area believed to contribute to the steady decline in construction efficiency is the link between lower hourly worker wages and the discouraging of automation in the field (Eastman et al., 2008). In Eastman's referenced book, this study displays the declining base wages for the total manufacturing industry from 1974 to 1996. In addition, the base wages for general contractors and specialty trades are shown to display the decline in these distinct areas. Due to this trend, hiring hourly workers gradually becomes cheaper and cheaper. Although this may seem beneficial at first, it presents an unfortunate downside to construction – discouraged automated solutions. Despite being more expensive than hourly labor, automated offsite solutions can greatly increase productivity of a project, saving both time and money over the long run. If the wages of hourly workers continue to decline, the sustained use of comparatively cheap field labor will only increase the inefficiency of the construction industry over time.

Like the two previously mentioned, there have been many studies which focus on varying aspects of the construction industry. In order for one to attain a better understanding of the overall inefficiency within the industry, a broader and more comprehensive study is desired. The National Institute of Standards and Technology (NIST) has performed a study of the additional costs incurred by building owners as a result of inadequate interoperability (Gallaher et al., 2004). This study focused on a wide range of construction during 2002 while taking into account the exchange and management of information within the projects. The cost of inadequate

interoperability was calculated by comparing current business activities and costs with hypothetical scenarios in which there was a seamless information flow and no redundant data entry (Eastman et al., 2008). It was observed that individual systems were unable to access and use information imported from other systems (Eastman et al., 2008). This single type of incompatibility greatly hinders the accurate and timely exchange of information during a project and only adds to industry inefficiency.

Upon examination of the data, NIST determined that the three costs resulting from inadequate interoperability were avoidance, mitigation, and delay (Eastman et al., 2008). While the majority of costs were incurred by building owners and operators, a wide range of people were impacted from this increasing inefficiency within the construction industry. The final results of the study are shown in Table 1.

Table 1. 2002 NIST Inadequate Interoperability Study (in \$millions)  
*Source: Table 6-1 NIST study*

<b>Stakeholder Group</b>	<b>Planning, Engineering, Design Phase</b>	<b>Construction Phase</b>	<b>O &amp; M Phase</b>	<b>Total Added Cost</b>
Architects and Engineers	\$1,007.20	\$147.00	\$15.70	\$1,169.80
General Contractors	\$485.90	\$1,265.30	\$50.40	\$1,801.60
Special Contractors and Suppliers	\$442.40	\$1,762.20		\$2,204.60
Owners and Operators	\$722.80	\$898.00	\$9,027.20	\$10,648.00
<b>Total</b>	<b>\$2,658.30</b>	<b>\$4,072.40</b>	<b>\$9,093.30</b>	<b>\$15,824.00</b>
Applicable sf in 2002	1.1 billion	1.1 billion	39 billion	n/a
Added cost/sf	\$2.42/sf	\$3.70/sf	\$0.23/sf	n/a

The information presented in this section is strong evidence of an industry in need of help. Due to inadequate interoperability alone, the construction industry annually wastes millions (if not billions) of dollars. As the complexity and scope of projects continues to increase, a

failure to address any current problems, issues, or underlying inefficiencies will only compound their effects in the future. The current approach within the industry is beginning to show its weaknesses, thus, a more collaborative and advanced approach is warranted.

## CHAPTER 3

### INTRODUCTION TO BUILDING INFORMATION MODELING

This chapter introduces Building Information Modeling by offering a comprehensive definition of the technology while explaining the various styles which firms can choose to utilize BIM. An explanation of various BIM programs is offered, including the program name, manufacturer and primary project use. The popular uses of BIM are revealed along with an evaluation of who uses the technology. The costs and returns of BIM are analyzed and display many benefits BIM can offer. Finally, three case studies are evaluated to reveal how BIM can assist the execution of construction projects across multiple industry sectors.

#### 3.1 What is BIM?

Building Information Modeling is an evolving tool in the construction industry. Although people use the term BIM, its exact meaning sometimes varies from person to person. The National Institute of Building Sciences consulted a collection of standards and formed an accepted national definition of BIM to help the confusion. Eventually, the NIBS created the National Building Information Modeling Standard.

*“The Building Information Model is primarily a three dimensional digital representation of a building and its intrinsic characteristics. It is made of intelligent building components which includes data attributes and parametric rules for each object. For instance, a door of certain material and dimension is parametrically related and hosted by a wall. Furthermore, BIM provides consistent and coordinated views and representations of the digital model including reliable data for each view. This saves*

*a lot of designer's time since each view is coordinated through the built-in intelligence of the model. According to the National BIM Standard, Building Information Model is "a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition."* ("About the National BIM Standard-United States", 2010)

Although an official standard definition exists, the acronym BIM can represent two different things depending on context. BIM (Building Information Modeling) refers to the technology and processes used to create the model. A BIM (Building Information Model) refers to the actual model containing all the information for the structure and is generated during a process known as virtual design and construction (VDC). The BIM is capable of being updated in real-time throughout the lifecycle of the project.

There are multiple styles which firms can choose to utilize BIM. Factors such as who are involved in the BIM process, reasons for using BIM, and who chooses to share any risks involved all contribute to which approach is used. For example, three-dimensional renderings of a project can be generated from a Building Information Model. The contractor may decide to use the BIM model for the sole purpose of better communicating the visual aspects of the building. If this occurs and the contractor does not take advantage of the additional information embedded within the model, this style is known as "Hollywood" BIM. This approach is used to specifically exploit the visual capabilities of Building Information Modeling and is often used to win jobs. Although this method displays the high quality visuals available within BIM, much of the potential value of the technology is lost (Hergunsel, 2011).

When Building Information Modeling is exploited internally within a single organization and is not shared with any other project parties, this is referred to as "lonely" BIM. This style is sometimes utilized by the architectural firm during the design phase of a project. For example,

the architect might decide to design a BIM model to use solely for visualization and detailing purposes. During this process, the architectural firm would most likely have some level of internal collaboration. When the time comes to provide the drawings; however, the architect may decide to only provide two-dimensional drawings while restricting access to the model. This impedes the participation and collaboration of the remaining organizations within the project. If any other involved parties needed a Building Information Model during the remainder of the project, a new model would need to be created. (Vardaro et al., 2009).

Ideally, the Building Information Model would be shared between all parties involved on a project. This collaborative approach is known as “social” BIM and allows all project teams to effectively communicate with one another. This approach takes advantage of BIM meetings, in which the architect, engineer, construction manager, and subcontractors can all provide their expert knowledge on various topics. The construction manager can also use these models for planning as well as to generate a wide variety of deliverables such as schedules, cost estimates, and constructability reports. After collaboration efforts between these parties are completed, specialty contractors can use the models for prefabrication (Hergunsel, 2011).

The final approach is known as “intimate” BIM and occurs when the main parties within a project all contractually share risk and reward. This situation is likely to arise when a gain sharing approach is used as the procurement method for appointing a main contractor and other project organizations (Abbasnejad and Moud 2013, 292). This approach is made possible through BIM-enabled integrated project delivery. Both “social” BIM and “intimate” BIM encourage collaboration between project teams while leading to the production of better drawings, decreased time, and decreased cost (Hergunsel, 2011).

### 3.2 BIM Programs

Numerous programs are used during Building Information Modeling. This section will reveal many of these tools while identifying the primary function of each. The first list of programs are known as BIM authoring tools and includes architectural, structural, MEP, and 3D site work modeling software. Table 2 displays the BIM authoring tools and their accompanying details as explained by Reinhardt.

The Revit products provided by Autodesk Inc. are among the more well-known authoring tools. Revit Architecture offers built-in sequencing options in which each object can be assigned a particular phase of the project. After each object is assigned, Revit then creates snapshots of the model for each phase. This creates a chronological phase sequencing timeline displaying the advancement of the project. Phase sequencing is a very helpful process and has made Revit Architecture popular among today's architects.

Revit Structure allows engineers to create a single digital model rather than creating two-dimensional plans, sections, and elevations separately. This combines the physical model with the analytical model and allows engineers to perform varying structural analyses. When selecting an object in Revit Structure, the dimensions of the object are displayed as well as the distances from neighboring objects. This allows the engineer to more accurately construct the model. Additionally, Structure improves on traditional CAD software by eliminating the use of layers. Instead of layers, building elements are organized based on their type or category. This enables the engineer to select what elements are visible or only inspect objects of a certain type. These improvements, along with numerous enhanced viewing options, have made Revit Structure a widely used program (Khemlani, 2005).

Table 2. BIM Authoring Tools

Product Name	Manufacturer	Primary Function
Cadpipe HVAC	AEC Design Group	3D HVAC Modeling
Revit Architecture	Autodesk	3D Architectural Modeling and parametric design
AutoCAD Architecture	Autodesk	3D Architectural Modeling and parametric design
Revit Structure	Autodesk	3D Structural Modeling and parametric design
Revit MEP	Autodesk	3D Detailed MEP Modeling
AutoCAD MEP	Autodesk	3D MEP Modeling
AutoCAD Civil 3D	Autodesk	Site Development
Cadpipe Commercial Pipe	AEC Design Group	3D Pipe Modeling
DProfiler	Beck Technology	3D conceptual modeling with real-
Bentley BIM Suite (Microstation Bentley Architecture, Structural, Mechanical,	Bentley Systems	3D Architectural, Structural, Mechanical, Electrical, and Generative Components Modeling
Fastrak	CSC (UK)	3D Structural Modeling
SDS/2	Design Data	3D Detailed Structural
Fabrication for AutoCAD MEP	East Coast CAD/CAM	3D Detailed MEP Modeling
Digital Project	Gehry Technologies	CATIA based BIM System for Architectural, Design, Engineering, and Construction Modeling
Digital Project MEP Systems Routing	Gehry Technologies	MEP Design
ArchiCAD	Graphisoft	3D Architectural Modeling
MEP Modeler	Graphisoft	3D MEP Modeling
HydraCAD	Hydratec	3D Fire Sprinkler Design and Modeling

Another popular program among engineers is Revit MEP. Designed specifically for mechanical, electrical, and plumbing aspects of design, this tool facilitates better coordination between MEP engineers, structural engineers, and architects. Within this program, engineers can design duct/pipe systems, perform pressure and lighting calculations, monitor electric loads and voltage drops, and also check for interferences between building elements. Rendering (generating an image from a model using computer programs) is also available and allows better visual communication among project members. Lastly, worksharing with Revit MEP provides multiple collaboration modes. This offers design teams more opportunities to interact and collaborate based on project needs (www.autodesk.com, 2008).

Reinhardt also explains that shop BIM tools for drawing and fabrication exist. These are mainly used by structural and MEP contractors and are displayed in Table 3:

Table 3. BIM Tools for Shop Drawing and Fabrication

Product Name	Manufacturer	Primary Function
Cadpipe Commercial Pipe	AEC Design Group	3D Pipe Modeling
Revit MEP	Autodesk	3D Detailed MEP Modeling
SDS/2	Design Data	3D Detailed Structural Modeling
Fabrication for AutoCAD MEP	East Coast CAD/CAM	3D Detailed MEP Modeling
CAD-Duct	Micro Application Packages	3D Detailed MEP Modeling
Duct Designer 3D, Pipe Designer 3D	QuickPen International	3D Detailed MEP Modeling
Tekla Structures	Tekla	3D Detailed Structural Modeling

A variety of BIM construction management and scheduling tools are shown in Table 4. As explained by Reinhardt, these programs support coordination and schedule integration with such features as clash detection, construction schedule simulation, estimating, and 5D presenting.

Table 4. BIM Construction Management and Scheduling Tools

Product Name	Manufacturer	BIM Use
Navisworks Manage Navisworks Scheduling	Autodesk	Clash Detection Scheduling
ProjectWise	Bentley	Clash Detection Scheduling
Digital Project Designer	Gehry Technologies	Model Coordination
Visual Simulation	Innovaya	Scheduling
Solibri Model Checker	Solibri	Spatial Coordination
Synchro	Synchro Ltd.	Planning & Scheduling
Tekla Structures	Tekla	Structure-centric Model Schedule driven link
Vico Office	Vico Software	Coordinate Scheduling Estimating

There are a wide variety of BIM programs on the market today. Unfortunately, some of the programs are not compatible with one another. In this case, middleware software must be used to import/export information between the incompatible programs. Two of the most common middleware softwares are Synchro and Innovaya. Both of these are capable of integrating information between common scheduling softwares and select BIM softwares (Hergunsel, 2011). Due to the complexity of today's projects and the large number of BIM programs available to the industry, compatibility between programs is becoming increasingly important.

### 3.3 BIM Users and Uses

The complexity and scale of a construction project heavily influence how BIM is utilized. A large influential factor on how BIM is used is the level of detail (LOD) required for the model. The LOD is an agreed upon standard published by the American Institute of Architects (AIA) and contains levels 100, 200, 300, 400 and 500. LOD 100 is an object modeled in the conceptual stage. LOD 200 is the approximate geometry stage. LOD 300 is precise geometry stage. LOD 400 is fabrication stage. LOD 500 is the as-built stage (Bedrick, 2008). An increasing level signifies enhanced graphics and a greater amount of usable information linked to the object.

To accurately understand BIM costs, one must first analyze exactly who uses it and for which project aspects it is used. A 2010 study performed by Ralph Kreider, John Messner, and Craig Dubler determined the frequency and impact of BIM application for different purposes on projects. To begin the study, a BIM use survey was developed and distributed to around 1000 potential participants. These participants had previously entered contact information before downloading the BIM Project Execution Planning Guide between October and December of 2009. While the survey contained demographic inquiries, the focus pertained to two major

questions. The first question asked “How frequently does your organization use each BIM Use defined in the BIM Project Execution Planning Guide?” The second question was “What is your organization’s perceived level of benefit to the project for each use?” (Kreider et al., 2010). As analyzed by Kreider, the demographics of the respondents are shown in Figures 1 and 2.

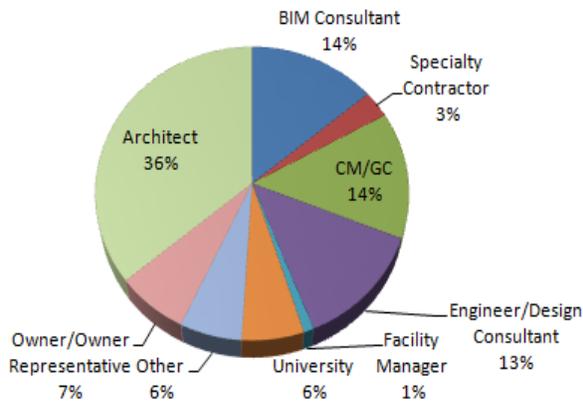


Figure 1. Discipline in Organization

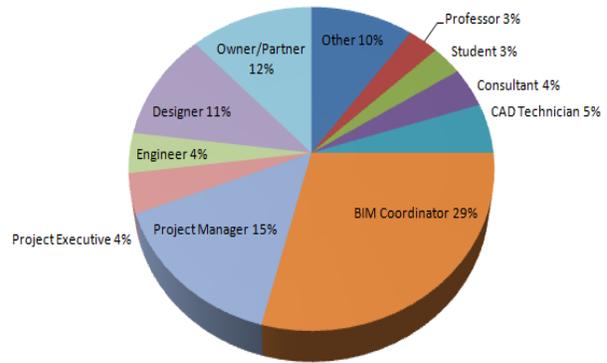


Figure 2. Organizational Role

This portion of the survey not only shows which engineering disciplines most often use BIM, but also focuses on the individual roles of BIM users within the organization. More than one-third of the respondents claimed to be an architect (36%) which asserts that the architectural discipline has a high BIM usage. Along with the architects, BIM/CAD consultants (14%), CM/General contractors (14%) and Engineer/Design consultants (13%) comprised the vast majority of organizational disciplines (77%). As for the respondent’s individual role, most would claim to be BIM/VDC coordinators (29%), project managers (15%) or an owner/partner (12%).

The two major survey questions were summarized using the median response as well as the average frequency. As collected by Kreider, the detailed results of the first question are displayed in Table 5.

Table 5: Organizational BIM Use Frequency

BIM Uses	0%	5%	25%	50%	75%	95%	100%	Response Count	Average Frequency	Median Response
3D Coordination	14	16	17	24	30	22	35	158	60.4%	75%
Design Reviews	22	17	25	23	22	19	33	161	53.5%	50%
Design Authoring	48	14	16	18	21	6	29	152	42.2%	25%
Construction System Design	47	25	17	18	12	5	28	152	37.0%	25%
Existing Conditions Modeling	32	34	26	23	17	6	16	154	35.2%	25%
3D Control and Planning	54	21	14	17	20	9	15	150	34.4%	25%
Programming	56	20	27	15	12	6	17	153	30.7%	25%
Phase Planning (4D Modeling)	55	25	18	15	20	3	13	149	29.6%	5%
Record Modeling	58	27	15	15	20	5	10	150	28.2%	5%
Site Utilization Planning	52	30	21	13	19	5	10	150	28.2%	5%
Site Analysis	51	24	28	18	15	3	10	149	27.7%	5%
Structural Analysis	74	19	10	13	11	6	16	149	26.8%	5%
Energy Analysis	58	32	19	17	17	6	6	155	25.4%	5%
Cost Estimation	53	33	28	15	11	6	8	154	24.7%	5%
Sustainability LEED Evaluation	64	29	21	11	16	5	6	152	23.0%	5%
Building System Analysis	64	33	17	14	14	6	5	153	22.3%	5%
Space Management / Tracking	77	25	15	13	9	5	10	154	21.4%	0%
Mechanical Analysis	88	15	10	7	14	7	7	148	20.9%	0%
Code Validation	77	26	16	8	8	8	5	148	18.9%	0%
Lighting Analysis	74	32	16	12	8	4	4	150	16.9%	0%
Other Eng Analysis	90	21	10	9	10	3	3	146	14.7%	0%
Digital Fabrication	87	26	13	8	8	3	4	149	14.4%	0%
Asset Management	104	17	13	8	3	1	3	149	9.6%	0%
Building Maintenance Scheduling	118	26	8	2	4	0	0	158	4.6%	0%
Disaster Planning	124	17	0	3	4	0	0	148	3.6%	0%

For easier observation and understanding, Figure 3 displays a bar chart of the previous data. This question reveals 3D Coordination and Design Reviews to be the most commonly used BIM uses according to the respondents, with both being utilized over 50% of the time. For 18 of the 25 BIM uses, the Median response is either 0% or 5%. The mode of responses was 0% for 22 of the 25 possible BIM uses, showing that the majority of respondents' organizations never use BIM for the given purpose. Overall, the average frequency of these BIM uses falls between 20% and 30%.

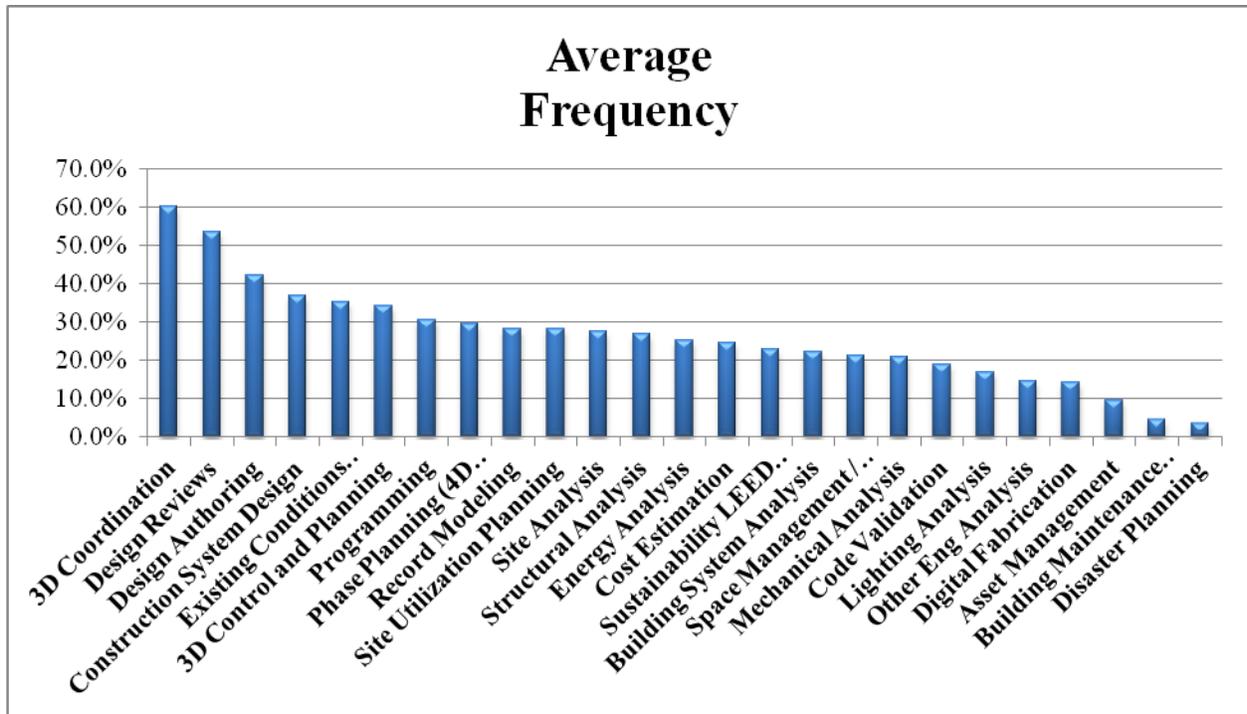


Figure 3: BIM Use Frequency by Organizations

The second question relates to the perceived value of each BIM use for making a positive impact on a project. 3D Coordination and Design Reviews were once again the top two BIM uses, both receiving the highest median response of Very Positive. The remaining BIM uses received median responses of either Positive or Neutral, with all but three receiving the former. It is interesting to note that no BIM uses received median responses of Negative or Very Negative. In addition, there were only three Very Negative responses throughout the entire survey. This survey question seemingly dictates that no harm is perceived to come from incorporating BIM technology into an organization. In fact, the respondents perceive BIM to give an added benefit for 22 of the 25 defined uses. Table 6 displays the detailed results of this question as collected by Kreider:

Table 6: Perceived Benefit to the Project by Organization

BIM Uses	Very Negative (-2)	Negative (-1)	Neutral (0)	Positive (+1)	Very Positive (+2)	Response Count	Perceived Benefit	Median Response
3D Coordination	0	1	6	40	92	139	1.60	Very Positive
Design Reviews	0	3	15	47	72	137	1.37	Very Positive
Existing Conditions Modeling	0	3	22	56	49	130	1.16	Positive
Phase Planning (4D Modeling)	0	3	20	52	44	119	1.15	Positive
3D Control and Planning	0	1	29	44	42	116	1.09	Positive
Construction System Design	0	4	25	49	44	122	1.09	Positive
Design Authoring	1	2	36	33	46	118	1.03	Positive
Site Utilization Planning	0	2	30	49	33	114	0.99	Positive
Programming	0	1	35	48	33	117	0.97	Positive
Sustainability LEED	0	2	26	59	22	109	0.93	Positive
Energy Analysis	0	4	35	46	34	119	0.92	Positive
Cost Estimation	1	7	30	50	37	125	0.92	Positive
Structural Analysis	0	3	35	42	32	112	0.92	Positive
Record Modeling	0	4	31	53	26	114	0.89	Positive
Digital Fabrication	0	2	37	37	29	105	0.89	Positive
Building System Analysis	0	1	36	50	23	110	0.86	Positive
Site Analysis	0	3	37	52	25	117	0.85	Positive
Space Management Tracking	0	1	39	52	17	109	0.78	Positive
Code Validation	0	1	39	51	16	107	0.77	Positive
Lighting Analysis	0	4	37	51	16	108	0.73	Positive
Mechanical Analysis	0	4	42	42	16	104	0.67	Positive
Other Eng. Analysis	0	2	47	40	10	99	0.59	Positive
Asset Management	0	1	61	28	10	100	0.47	Neutral
Building Maintenance Scheduling	0	2	65	28	9	104	0.42	Neutral
Disaster Planning	1	2	71	15	7	96	0.26	Neutral

For easier comprehension and better visualization of the results, Figure 4 displays a bar chart of the previous information. This survey shows 3D Coordination to have the highest perceived benefit with Design Reviews coming in a close second. 3D Coordination and Design Reviews are also the most and second most frequently utilized BIM uses, respectively. Although Existing Conditions Modeling, Phase Planning and Digital Fabrication had the next highest perceived levels of benefit, the level of use attributed with them did not coincide. The majority of BIM uses rank between 1.2 and 0.8, thus demonstrating the majority of respondents believe these uses positively benefit a project. Figure 5 combines the frequency and perceived benefit of each BIM use. In most cases, the frequency of use corresponds with the perceived benefit of that use.

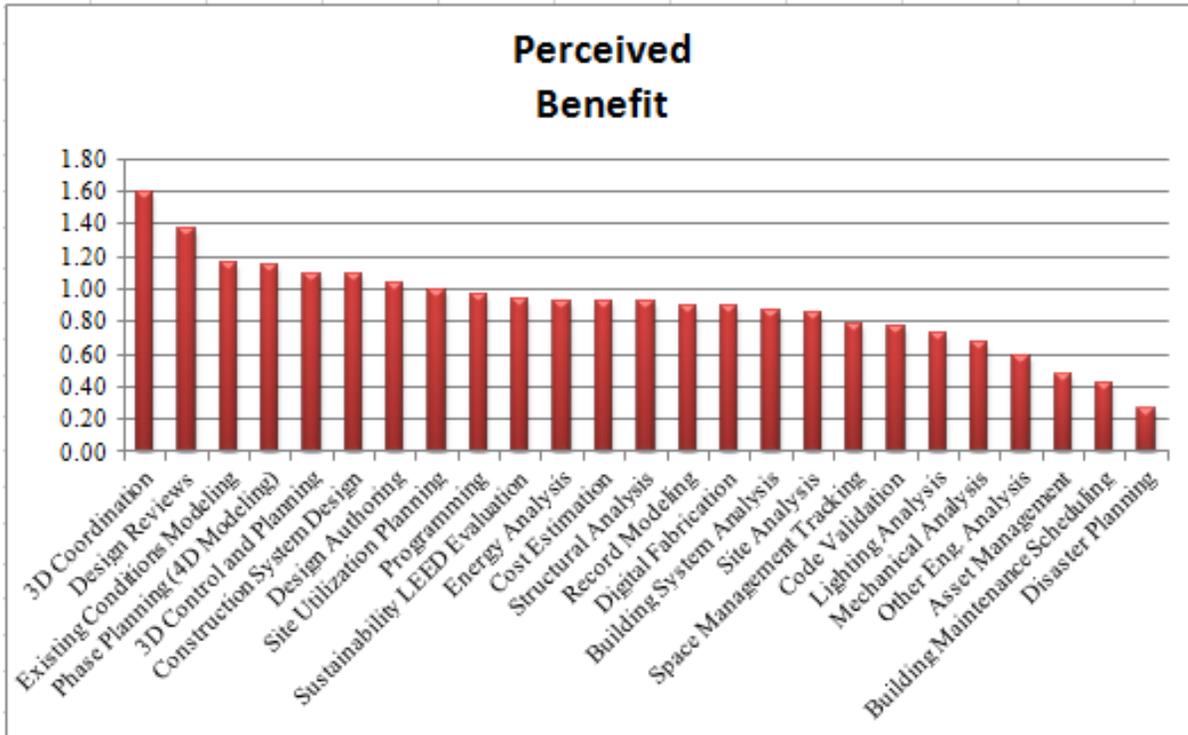


Figure 4: Perceived Level of Benefit for BIM Uses by Organizations

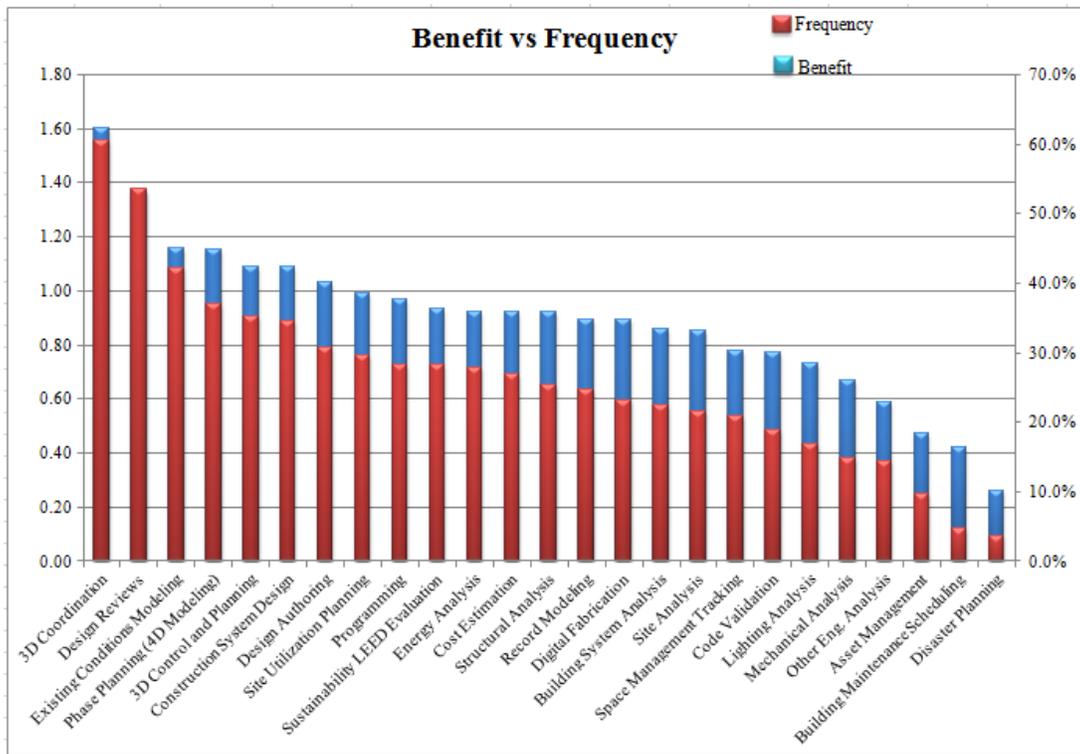


Figure 5: Bar Chart Comparing Frequency of Use and Perceived Benefit

The previous data in this section determined who uses BIM and for which project aspects it is used. Since these questions have now been answered, the costs and benefits of BIM associated with the construction industry can now accurately be examined.

### 3.4 Costs and Returns of BIM

One of the most common questions asked when a company is considering implementing BIM is “How much will this cost?” Building Information Modeling does not have a set cost or a guaranteed amount of savings. Costs vary based upon the size of the implementing organization, complexity of the project, level of detail (LOD) required for the model, and the capabilities of the model design team (Hergunsel, 2011). Also, how and when a company chooses to implement BIM has the greatest effect on the experienced cost and savings.

In the 2009 BIM SmartMarket Report, McGraw-Hill Construction conducted a Building Information Modeling Study in an effort to gauge industry-wide BIM adoption while also revealing the observed value firms received by implementing BIM. The 2,228 received responses were comprised of 598 architects, 326 engineers, 817 contractors, 118 owners, 73 building product manufacturers and 296 other industry respondents. While the report contains much useful information regarding Building Information Modeling, the portion regarding return on investment with BIM will be the focus of this section. Factors such as costs, benefits, and returns were evaluated.

As previously mentioned, cost may be the largest determining factor relating to BIM implementation. The majority of firms in the construction industry handle BIM processes in-house. It is more common for contractors and construction managers to outsource BIM work when compared to designers. This is because design firms must pay for their hardware, hardware

maintenance, software, upgrades and employee training. Design firms are unable to pass the costs of BIM services on through fees; however, they make up for these costs in terms of overhead. In addition, man-hours needed for drawing production are reduced.

The 2009 BIM SmartMarket Report reveals many interesting facts relating to BIM costs within the construction industry. Due to the rapidly growing popularity and steep learning curve associated with Building Information Modeling, consultants are sometimes needed to assist in the performance and training of BIM processes. According to the survey, 59% of firms did not even hire outside BIM consultants. Of the firms that did hire consultants, nineteen percent said this added less than 1% to total job cost and ten percent said it equaled between 1% and 3% of total job cost.

Staff and office space requirements are often another issue associated with BIM adoption. Again, the results of the survey are in favor of BIM. Fifty-nine percent said their office space needs were unchanged after using BIM, with 11% saying they used less space and 9% using more. With regards to the impact on company staff, 41% reported an unchanged need in staffing and 21% actually required less staff. Thirteen percent of respondents claimed to need more staff when using BIM.

Overall, the costs of BIM seem to display more pros than cons. The majority of firms did not even require outside BIM consulting. Those who did require some form of outside consulting commonly spent no more than 3% of total job cost. Office space needs were unchanged for the majority of firms, with some firms actually needing less space to work. With regards to staffing, the majority either had an unchanged need or required less staff. Although cost interpretation is a relative concept, the amount spent on BIM technology seems to be minimal. A 2009 study performed by Burcin Becerik-Gerber and Samara Rice analyzed BIM costs associated with

software, software upgrades, hardware, hardware maintenance and training. The study concluded that overall costs associated with BIM technology are usually less than 2% of overall net revenue.

While Building Information Modeling does require investments of both time and money, there are many benefits. According to the SmartMarket Report, 55% of respondents claimed BIM cut project costs, with 39% saying costs were reduced by up to 25%. More apparent was the impact on schedule improvement. Sixty-three percent claimed BIM helped reduce the project schedule with 45% saying it reduced schedule by up to 25%. Although most firms saw reduced schedules, the savings were realized during varying phases. There was a reported increase in work at the beginning of the project while work towards the end tended to decrease. Most claimed BIM added time to the schematic and conceptual design phases while reducing the duration of detailed design and construction.

Overall, the majority of respondents reported an increase in project profitability. The 2009 Becerik-Gerber study produced statistics for this aspect which are used in the BIM SmartMarket Report. Forty-eight percent of survey respondents claimed BIM use increased project profitability while 28% were unsure if BIM aids project profitability. This may be because they do not believe the advantages of BIM extend beyond the enhanced visual aspects (Young et al., 2009). While 12% felt BIM negatively impacted profitability, this may be attributed to beginning users. Users may initially dislike BIM due to the technological investment and steep learning curve. Overall, persistent users of BIM technology are the most likely to reap the benefits and notice profit increases. The initial investment in BIM may be expensive, but the many capabilities of this technology have been proven to increase profits, reduce project schedules and lower overall project costs.

### 3.5 Case Studies of BIM Application

It is one thing to discuss the potential benefits of Building Information Modeling, but it is another to display how BIM improves real-world projects. Many construction projects have chosen to utilize BIM and the benefits of doing so were documented. Although BIM is not always used throughout the entire life cycle, many projects have seen benefits from applying it to a particular project phase or activity. This section will present three case studies which display how BIM technology significantly improved the project.

The first study is that of Sutter Medical Center in Castro Valley, California. Known as the SMCCV, the Sutter Medical Center Castro Valley is a seven story, 130-bed capacity hospital which will operate in replacement of Eden Medical Center in Castro Valley ([www.edenmedicalcenter.org](http://www.edenmedicalcenter.org)). At a budgeted cost of \$320 million, the 230,000sf hospital consists of cast-in-place friction piers as well as a three-story reinforced concrete shear-wall podium supporting a four-story steel-braced frame ([www.aceBIM.ca](http://www.aceBIM.ca)). This was a complex large-scale project and presented many challenges from the beginning (Christian et al., 2011):

- The hospital was constructed on a sloped grade with limited space for construction activities. Also, the current Eden Medical Center was to remain operational with minimal disturbances.
- Strict schedule deadlines for design, permitting, and construction were set by the legislation governing the seismic safety standards for hospitals in California. To meet these deadlines, the project team had to design the building at least 30% faster.
- The hospital was budgeted for \$320 million and could not exceed this value under any circumstances.

- The Office of Statewide Health Planning and Development (OSHPD) mandates extensive regulatory oversight on hospital projects in California. OSHPD normally take 24 months for review upon design completion. To accelerate the permitting process, this project had to be one of the first to use OSHPD's Phased Review Process.

To best address many of the challenges presented by this project while also providing a high-value end product for the owner, BIM was utilized on several aspects for the SMCCV project. A Level 400 model was achieved throughout most systems and components, while additional details were added if deemed advantageous (compared to effort required to make the changes) by the project team ([www.aceBIM.ca](http://www.aceBIM.ca)). Figure 6 shows the included aspects of design as described by aceBIM:

- Building interior
- Building exterior, curtain wall and pre-cast
- Stairs and elevators
- Structural steel and concrete
- Slabs and slab openings
- All mechanical and plumbing systems
- All electrical systems including conduit
- Fire protection
- IT and low voltage systems
- Nurse call systems
- Furniture
- Fixed medical equipment
- Rebar detailing
- Foundations
- All underground utilities
- Civil site
- All seismic restraints
- Drywall framing

Figure 6: Design Aspects

Navisworks was used to combine all separate disciplinary models into a single model while also being used for clash detection ([www.aceBIM.ca](http://www.aceBIM.ca)). This allowed the project team to identify design conflicts and potentially avoid system interferences in the field. BIM also allowed for enhanced constructability reviews between the GC and subcontractors. During these

reviews, members of the GC and subcontractors were able to identify and resolve hundreds of constructability issues without affecting site productivity. In return, design certainty was increased and resulted in lower construction risk at site. This lowered field changes, RFIs, and rework on the SMCCV compared to similar projects (Christian et al., 2011).

This project also took advantage of an advanced BIM technology – laser scanning. Laser scanning was incorporated to compare model design against the as-built status of the building in the field. When the laser scanner is activated, the machine scans three hundred and sixty degrees and eventually creates a 3D representation of the surrounding building area. The model is then superimposed onto the scan to validate the as-built condition. By utilizing this technology, the project team was able to make the necessary adjustments to components before installation occurred. Additional aspects assisted by BIM use were production of reliable paper documents, automated code-checking, automated quantity takeoffs, and model-based cost estimating ([www.aceBIM.ca](http://www.aceBIM.ca)). .

A variety of benefits were recognized by incorporating BIM into this project. Aspects such as schedule, cost, and construction productivity were all positively impacted in response to BIM use. A few of the schedule benefits were as follows:

- Design was completed in 15.5 months and allowed construction to commence on schedule. (Lamb et al., 2009)
- It only took 11.5 months between the start of the OSHPD structural review and construction commencement. In response, all deadlines of the project review plan were achieved. (Alarcon et al., 2011)

- The structural systems design period was reduced from an expected 15 months to 8 months. Additionally, a better quality design was delivered because significantly more information from other disciplines was used. (Khemlani, 2009)
- In response to Sutter finalizing the Clinical Space Program and LEED Goals in April 2008, the First Patient Day milestone was improved by six weeks from January 1, 2013 to November 15, 2012. (Christian et al., 2011)

The following displays a selection of cost benefits observed for the SMCCV project:

- As design progressed, the estimated cost of the project was reduced by more than \$20 million to achieve the target value of \$320 million. (Lamb et al., 2009)
- The project team was able to generate an updated project cost every two weeks. This process was approximately 80% more efficient than traditional estimating. (Tiwari et al., 2009)
- The shortened design process saved \$1.2 million in design labor. (Post, 2011)
- The steel package was completed \$1.5 million under budget due to the fabricator's involvement in the BIM process that resulted in better connection details and conflict resolution. (Post, 2011)

In addition to the aforementioned schedule and cost benefits, construction productivity also increased anywhere between 6% to 28% and rework decreased between 50% to 95%. For example, the mechanical discipline had a construction productivity of 116% while performing rework only 0.5% of the time. Framing received the most benefit from increased construction productivity with a recorded 125%. In regards to the as-built conditions, 99% of installed mechanical and plumbing products closely matched the model, with 79% of framing and 71% of electrical closely matching (Christian et al., 2011). Lastly, RFIs and owner initiated change

orders were reduced by approximately 90%. During one point in construction, there were 333 RFIs and 26 change orders when the normal is 3,000 and 400 respectively for a similar project (Post, 2011).

The second case study is that of the U.S. Department of Energy's National Nuclear Security Administration complex in Amarillo, Texas. Although this study is not as in depth as the previous SMCCV study, the benefits of BIM use were still observed and positively impacted the project. CH2M-Hill performed full design services for the \$100 million, 45,000 sqft high-explosives pressing facility. This project included some unique features such as multi-layered blast-resistant concrete architecture, sophisticated operating equipment, extensive process piping, and eight separate electrical and control systems (Young et al., 2009).

The CAD construction documents were 95% complete when the project went on hold for funding and scope review. It was at this time that Pantex project engineer Stephen Forman decided BIM was a good idea for this project. To accommodate BIM, Forman modified CH2M-Hill's contract and gave them four months to convert the CAD design into BIM models. CH2M-Hill then modeled everything down to  $\frac{3}{4}$  inch conduits to optimize spatial coordination in the systems-sensitive facility. They also modeled every piece of equipment to be used in the structure (Young et al., 2009).

By utilizing clash detection software on the BIM models, thousands of collisions were identified and addressed prior to construction. A virtual walkthrough of the facility was also created and shown to the operations staff. This walkthrough uncovered over 500 serious design problems. One such problem involved the cranes within the facility, as they would be in the way and impede the user's ability to function. As a result, the cranes were redesigned to work correctly and a potentially costly design error was avoided (Young et al., 2009).

Upon completion, independent cost estimators calculated a savings of \$10 million as a result of the modeling. Forman expressed how BIM helped with better constructability for this project in terms of the conduit. Since all the wiring was in conduit, Forman explains that it would be easy to just field route it. Instead of risking the uncertainty that comes with field routing, BIM was used to place the conduit. In addition, new pipe supports were developed for the conduit to hold it securely in place. Quantities from the models are “almost exactly” what the independent estimators found doing traditional quantity takeoff. As an added bonus, Forman is planning to use the model to train employees at the facility virtually before occupancy, which would take months out of the traditional startup phase (Young et al., 2009).

The final case study on BIM use is Capitol Theatre in Alberta, Canada. The 2-story, 14,000sf recreational facility consists of 243 seats, a 4D theater, and includes state-of-the-art sound, lighting and F/X. The schedule for this project was tight, as opening night was scheduled only 12 months from the start of design. The building was budgeted at \$7 million and construction began in the summer of 2010, being completed by late summer 2011. In regards to the LOD, a Level 300 or 400 model was most often achieved ([www.aceBIM.ca](http://www.aceBIM.ca)).

The project architect chose to utilize Revit as the main software to create the building model. The structural engineer modeled the primary structural system, including pile foundations, concrete pads and footings, and the primary steelwork such as columns, beams, bracing, roofing deck systems and flooring systems. The MEP design was also created in Revit, but was imported to Tekla for constructability analysis. This was to ensure aspects such as adequate air duct clearance and clash-free routes. While the structural and MEP models were designed in Revit, the steel fabricator used Tekla and had to create importable IFC (Industry Foundation Classes) files to upload to the Revit control file ([www.aceBIM.ca](http://www.aceBIM.ca)).

A very important use of BIM on this project was structural design and steel detailing. By modeling these details, conflicts with the architectural and MEP models were identified early on in design and often resulted in resizing a structural member. Construction coordination was also enhanced by the use of BIM technology. During the construction phase, the steel Tekla model was exported to Trimble GPS equipment to ensure correct positioning of piles and foundations. This process revealed errors that would have delayed steel erection by at least a week when discovered on-site ([www.aceBIM.ca](http://www.aceBIM.ca)).

Another major benefit of BIM use was the ability to incorporate clash detection during the project life cycle. Clash detection was performed with both Revit Architecture and Revit MEP models, as well as the Tekla IFC file. This process was routinely performed and allowed for immediate design or construction change when any an error was discovered ([www.aceBIM.ca](http://www.aceBIM.ca)). The Revit control file with the imported IFC Tekla model used for clash detection can be seen on the aceBIM website.

An interesting aspect about this project was that one single file was used by all disciplines. Usually, each discipline works on their specific model alone and then coordinates with other disciplines periodically. This project allowed all disciplines to view the Revit control file and coordinate with other disciplines as needed. While all the discipline-specific models could be seen by all involved parties, each team could only modify components of the model related to their own design. The rest of the model was displayed as a “read only” file and could not be altered by that team. This not only reduced the number of field conflicts, but also reduced the number of virtual conflicts, as they were identified immediately rather than waiting for the next coordination meeting ([www.aceBIM.ca](http://www.aceBIM.ca)).

RFIs were handled with a different approach on this project when compared to standard paper-based methods. Rather than produce RFIs on paper that had to be hand-delivered, virtual RFIs were used that incorporated model snapshots instead of traditional long descriptive paragraphs. This allowed the RFIs to be more multi-directional rather than the usual linear contractor to consultant flow. In addition, virtual RFIs are more economical due to the eliminated need for paper.

Additional aspects enhanced by BIM were quantity takeoff, 4D construction simulation and integrated deliverables. Quantity Takeoff 2011 was used to extract and export material quantities from the model. By using the BIM with its own worksets, the Construction Manager was able to use a 4D construction approach by linking some model elements into the construction schedule. From these links, a 4D simulation of the building construction sequence was created. Integrating deliverables allowed the fabrication model to coordinate deflection locations which proved invaluable for building envelope coordination ([www.aceBIM.ca](http://www.aceBIM.ca)).

BIM offered many benefits during the execution of the Capitol Theatre project. The following is a list of some key benefits documented for this project as a result of BIM use ([www.aceBIM.ca](http://www.aceBIM.ca)):

- RFIs and change orders were significantly decreased. The project finished with 0 RFIs and only 4 change orders.
- On budget (only 0.5% over budget) and on schedule project delivery.
- 85% cost reduction compared to traditional practices for construction of metal connections, metal frames, and other elements.
- Higher level of pre-fabrication that resulted in higher quality and better productivity.

- Budget and schedule risk mitigation on 75% of the budget – structure, MEP and envelope.
- Structure Steel finished at 8% additional cost – 2% lower than the anticipated risk.
- Structural steel erection began 4 months earlier when compared to traditional practice.
- All drawing deliverables were digital (i.e. no paper shop drawings).
- Increased safety on-site due to increased accuracy of design.

These case studies display how BIM can offer a wide variety of benefits to multiple types of construction projects. During the course of research for this paper, many case studies on BIM application were found. The popular internet search engine Google was utilized as well as a selection of literature. Throughout all of the discovered BIM case studies, the vast majority dealt with commercial, government, and healthcare buildings. Very few case studies focused on academic buildings or buildings in a university setting.

In Kymmell's book *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations*, an entire section is dedicated to case studies of BIM use on various projects. The six case studies included:

- DPR Construction's use of BIM on a large healthcare project
- RQ Construction's use of BIM on Sutter Surgical Hospital North Valley
- Turner Construction's (Seattle, WA) use of BIM on various office buildings, medical office buildings, and residences
- Gregory P. Luth & Associates' BIM use utilizing Tekla
- Webcor Builders' implementation of model-based estimating practices
- Turner Construction's (Sacramento, CA) use of BIM laser scanning for medical work

The main focus of these studies was on healthcare and commercial buildings or only a specific aspect of BIM. The use of BIM on a university building was not presented in this literature.

In Eastman's *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, Chapter 9 is solely dedicated to case studies of BIM application. Again, not one project is on the topic of a building in a university environment. The ten case studies focused on the following topics:

- A V6 engine plant expansion
- U.S. Coast Guard BIM implementation
- A medical office building complex
- A foreign aquatics center
- A San Francisco federal building
- A residential condominium in New York
- A commercial office building located in Hong Kong
- A parking structure
- A commercial project in Dallas, TX
- A courthouse in Mississippi

This chapter focused on BIM use in the commercial, government and healthcare industries. Again, BIM use in a university environment was not mentioned and the benefits of BIM in such a setting were not analyzed. Upon searching in the previous two books, as well as a selection of others, no case studies on BIM application in a university setting were found. It was at this point that Google was utilized to conduct a more in-depth search from a wider variety of sources.

Google offered a much larger variety of information when searching for BIM case studies in a university setting. However, not many in-depth studies were found, as the vast majority

covered only a particular aspect of BIM use or broadly analyzed BIM use on an academic project. The website [www.aceBIM.ca](http://www.aceBIM.ca) contained two case studies of university BIM use. The first was the University of Colorado-Denver Health Science Center Research 2, an eleven-story biomedical research facility located on the UCDHSC Anschutz Medical Campus. The study analyzes BIM use throughout multiple phases of the project, but only gives a broad overview of each use. Additionally, the building is a medical facility, once again reiterating the point of most case studies being focused on healthcare, government or commercial projects. The second case study was that of the Universite de Montreal (UdeM) located in Quebec, Canada. This study focused solely on BIM use for Operations and Management activities for various buildings on the UdeM campus. Again, no in-depth analysis of an entire project was given and, for this study, only a certain aspect of BIM was analyzed.

Another academic BIM case study was discovered on [www.rics.org](http://www.rics.org) and analyzed the expansion of the city centre campus of Birmingham City University in the UK. The case study was only about five pages long; however, and very broadly discussed the uses and potential uses of BIM for this project. Additionally, a selection of experienced benefits and potential benefits was presented, but was not comprehensive of an entire project. *National Guidelines for Digital Modeling: Case Studies*, published by the Cooperative Research Centre for Construction Innovation, also presented a variety of BIM case studies. National and international projects were discussed and various BIM uses on them were analyzed. While this publishing offered case studies from many different geographical areas, the focus was completely on government and commercial projects. No academic projects were presented, thus, further proving the lack of study and research on the topic. If desired, the paper can be found at [www.construction-innovation.info](http://www.construction-innovation.info).

Although case studies have been performed on academic buildings and construction in university settings, not much detailed information was found on this topic during research. The benefits of BIM when implemented in a university setting warrant further analysis. University construction projects are very unique and the question of how BIM impacts these projects needs to be answered. A university construction project is unique in many ways. First, the project will usually have to fit a pre-conceived campus master plan, thus dictating many project procedures. In many cases, new construction is required or desired to blend with old construction. Additionally, the area must still be able to accommodate campus events when necessary and foot traffic around the site during school is increased. The building life of campus buildings may be hundreds of years and require high quality maintenance throughout the entire life cycle. University construction projects are usually funded by bonds or grants, which will dictate certain project aspects. Lastly, campus projects are in an urban setting and are completely schedule driven, as the building must be available when school opens. The next section presents an in-depth case study of BIM implementation on a university project while explaining the experienced benefits of BIM use throughout the project life cycle.

## CHAPTER 4

### SEC IV CASE STUDY

This section presents a case study of the Science and Engineering Research Complex Phase IV building located on the University of Alabama campus. The project was initiated in 2010 and completed in August of 2013. SEC IV is currently in the final closeout stages and will soon be fully owned by The University of Alabama College of Engineering for operations and management of the facility. The role of BIM throughout the project life cycle of SEC IV is analyzed. Building Information Modeling aspects such as project procedures, utilization of BIM technology, benefits and lessons learned are evaluated. The information in this section was gathered through numerous interviews and communication with Williams Blackstock Architects, Doster Construction and The University of Alabama Construction Administration. A chronological approach was used during research in order to best understand and explain how BIM was used during the project process. This chapter demonstrates how BIM can improve the life cycle of a modern construction project in a university setting when compared to standard paper-based industry practices.

#### 4.1 Planning & Design Phase

The approximate 208,000 gsf of new construction required for SEC IV was conceptualized by the UA College of Engineering with the goal of completing the science and engineering quad. The four-story \$70 million building is categorized as an interdisciplinary

research facility and includes 59 research laboratories, five instructional labs and a 7,000sf clean room. The research conducted within SEC IV focuses on materials characterization and technology, specifically in structural characterization, composite and nanocomposites, coating and corrosion, materials processing, welding and joining, as well as electronic, magnetic and photonic devices ([www.eng.ua.edu](http://www.eng.ua.edu)). A key aspect of the building design was that the appearance had to be in balance with the current SEC Commons. This was considered necessary in order to preserve the geometry of the surrounding buildings as well as for aesthetic purposes. Construction of SEC IV also required the partial demolition of neighboring engineering building H.M. Comer.

To officially initiate the project, UA publicly advertised a Request for Proposal (RFP). After receiving all sealed bids from potential architectural firms, a short-list of 3-5 firms was created. These firms were then invited to deliver an oral presentation in front of a pre-selected committee. Upon completion of each presentation, the committee individually assigned a score to the firm and a composite score was created. After selecting the candidate with the best score, the committee sent their recommendation to the Board of Trustees for approval. Following BOT approval, Williams Blackstock Architects was selected as the architectural firm for SEC IV (Skinner, 2013).

Williams Blackstock began the planning of SEC IV by modeling the existing conditions of the project site. Civil engineering firm McGiffert & Associates provided AutoCAD 2008 site detail drawings to WBA, which were then imported into Revit (Austin, 2013). WBA chose to use Revit software throughout the planning and design phases of SEC IV due to the many advantages it offers architectural firms. The site drawings contained details such as site topography, existing utilities, surrounding structures, roads, ditches, and other necessary

planning information. By importing the CAD files into Revit, WBA immediately began exploiting the benefits of early BIM implementation. First, Revit allows for more collaboration than current AutoCAD programs and can also be updated in real-time. Next, Revit is capable of providing three-dimensional views which allow for better visual understanding of the site layout. Finally, Revit grants the future opportunity for more advanced and detailed design when compared to current CAD programs.

After modeling the existing conditions, WBA produced preliminary models of SEC IV. To show a variety of possible design options, several models were created and presented to UA. Aspects such as window placement and door placement, along with other aesthetic elements, were altered to produce the models (Austin, 2013). By utilizing BIM for the preliminary models, WBA was able to show UA the completed appearance for each possibility early on in the planning phase. UA chose their desired model, and this became the control model for Williams Blackstock Architects.

After choosing the control model, programming for SEC IV was required. Revit was used for this task as well, for both pre-schematic and schematic plans (Austin, 2013). By choosing to utilize BIM for programming, WBA were able to efficiently and accurately assess design performance regarding spatial requirements by the owner. Color-coding rooms based on intended use is a popular aspect of programming. By incorporating BIM into this process, WBA was able to color-code faster, produce more aesthetically pleasing plans, and greatly aid in visual understanding of spatial needs. Along with speeding up the programming process, BIM also provided excellent graphics. These are not only beneficial to the architect while working, but also improve the quality of the product shown to the owner. The programming of the first floor of SEC IV is displayed in Figure 7:

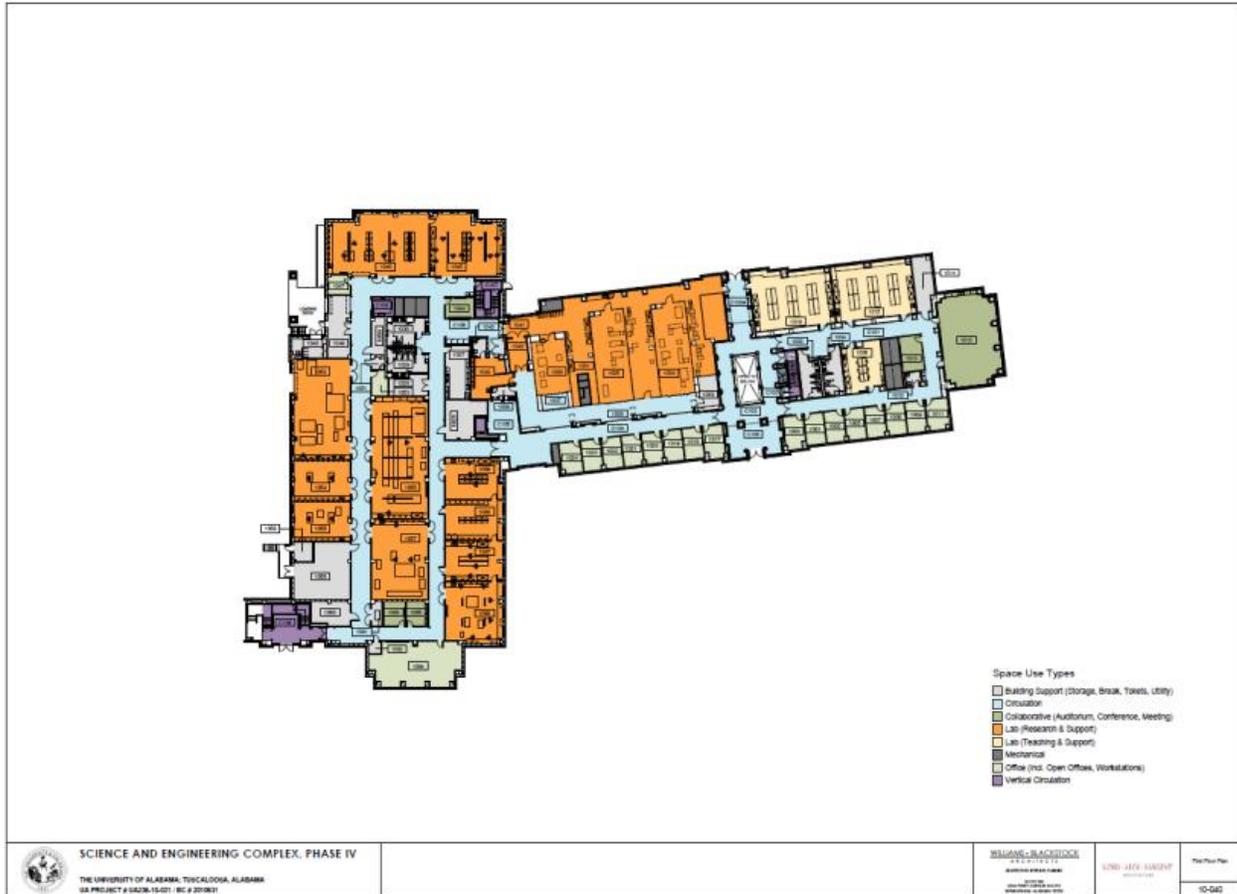


Figure 7: SEC IV 1<sup>st</sup> Floor Programming  
 Source: Williams Blackstock Architects

Another important task during this phase is cost estimating and the production of a preliminary budget plan. HOAR Construction performed these tasks since many HOAR employees work for UA Construction Administration on the University of Alabama campus. BIM software was not utilized for this task because HOAR had not yet adopted BIM estimation at the time of this project (Tomlin, 2013). Alternatively, On-Screen Takeoff by On Center Software was used for quantity survey while an in-house Excel program was used to assemble the estimate (Goree, 2013). Figure 8 displays an On-Screen Takeoff beam estimate for Level 1 Wing B of SEC IV while a pre-con base bid budget summary created using the in-house Excel program is shown in Figure 9.

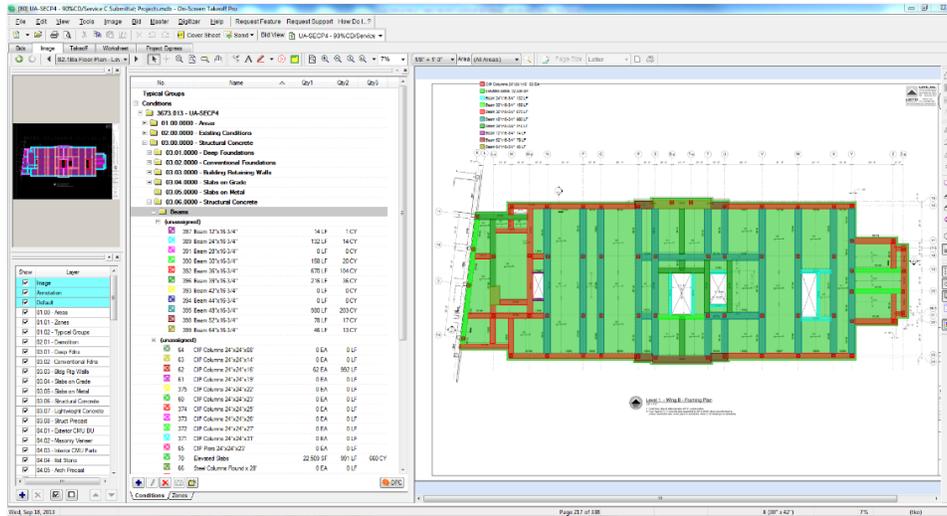


Figure 8: On-Screen Takeoff Beam Estimate of SEC IV Level 1 Wing B  
 Source: HOAR Construction

**Science & Engineering - Phase IV  
 SECP4 - Building & Site Completion Package**  
 - Estimate # 11-0102B for 3713.013B  
 The University of Alabama  
 AL - Tuscaloosa - Tuscaloosa County  
 January 26, 2011

*Construction Documents Review Estimate*  
 This Sheet ✓  
 Unit Cost Factor =  
 Gross Building Area  
 194,314 SF

**BASE BID BUDGET SUMMARY**

Division	Description	Estimate Value	Unit Cost	Percent of Taxed Total	Last Estimate Value	Increase / (Decrease)
01 00	General Requirements	\$ 1,539,879	\$ 7.92	2.7%	\$ 1,788,608	\$ (248,729)
02 00	Existing Conditions (Coner Hall)	\$ 1,688,217	\$ 5.44	1.9%	\$ 1,946,395	\$ (258,178)
03 00	Structural Concrete	\$ 6,340,625	\$ 32.63	11.2%	\$ 6,029,114	\$ 311,511
04 00	Masonry & Architectural Concrete	\$ 3,480,936	\$ 17.91	6.1%	\$ 3,510,172	\$ (29,236)
05 00	Metals	\$ 1,870,540	\$ 9.64	2.9%	\$ 1,810,014	\$ 60,526
06 00	Woods & Plastics	\$ 207,045	\$ 1.07	0.4%	\$ 221,055	\$ (14,010)
07 00	Thermal & Moisture Protection	\$ 1,019,382	\$ 5.25	1.8%	\$ 1,231,019	\$ (211,637)
08 00	Openings	\$ 1,602,721	\$ 8.25	2.8%	\$ 1,584,091	\$ 18,630
09 00	Finishes	\$ 3,232,698	\$ 16.64	5.7%	\$ 3,021,452	\$ 211,246
10 00	Specialties	\$ 240,892	\$ 1.24	0.4%	\$ 255,508	\$ (14,616)
11 00	Equipment	\$ 227,638	\$ 1.17	0.4%	\$ 225,979	\$ 1,659
12 00	Furnishings	\$ 6,419,690	\$ 33.04	11.9%	\$ 6,233,228	\$ 186,462
13 00	Special Construction	\$ 5,364,245	\$ 27.61	9.5%	\$ 5,245,859	\$ 118,386
14 00	Conveying Systems	\$ 509,916	\$ 2.62	0.9%	\$ 478,448	\$ 31,468
21 00	Fire Suppression	\$ 388,463	\$ 2.00	0.7%	\$ 412,076	\$ (23,613)
22 00	Plumbing	\$ 4,067,750	\$ 20.93	7.2%	\$ 3,975,330	\$ 92,420
23 00	HVAC	\$ 11,172,243	\$ 57.20	19.7%	\$ 11,136,888	\$ 35,355
26 00	Electrical	\$ 4,172,515	\$ 21.47	7.4%	\$ 4,210,976	\$ (38,461)
27 00	Communication Systems	\$ -	\$ -	0.0%	\$ -	\$ N/A
28 00	Safety & Security Systems	\$ 265,791	\$ 1.37	0.5%	\$ 268,241	\$ (2,450)
29 00	Allowances	\$ 120,000	\$ 0.62	0.2%	\$ 120,000	\$ -
31 00	Earthwork	\$ 244,129	\$ 1.26	0.4%	\$ 243,601	\$ 528
32 00	Exterior Improvements	\$ 592,956	\$ 3.05	1.0%	\$ 1,077,738	\$ (484,782)
33 00	Utilities	\$ 569,460	\$ 2.93	1.0%	\$ 517,697	\$ 51,763
50 00	State License, Payment and Performance Bond, General Liability & Umbrella, Warranty, Design Contingency	\$ 709,887	\$ 3.65	1.3%	\$ 869,876	\$ (160,020)
	General Contractor's Fee	\$ 249,930	\$ 1.29	0.4%	\$ 750,362	\$ (500,432)
		\$ 1,112,987	\$ 5.75	2.0%	\$ 1,144,942	\$ (31,955)
<b>PROJECTED BASE BID WITHOUT SALES TAX:</b>		<b>\$ 56,760,797</b>	<b>\$ 292.11</b>	<b>100.00%</b>	<b>\$ 58,392,066</b>	<b>\$ (1,631,269)</b>
<b>Project Information:</b>						
	Gross Building Area	194,314	SF			
	Heated Area	176,776	SF			
	Site Area	6.35	AC			
	Payment & Performance Bond Rate	0.71	%			
	Approximate Sales Tax Value	-	USD			

Figure 9: HOAR Excel Base Bid Budget Summary  
 Source: HOAR Construction

Phase planning is also a very important task performed during project planning and focuses more on the physical aspect of site layout and construction sequencing. WBA was able to create a phase plan for SEC IV while utilizing Revit. The general phasing of the project had been master planned by UA before the project began; however, it was steadily revised by WBA at the beginning of the early design phase and finalized throughout the entire design process (Austin, 2013). The construction of SEC IV as well as the demolition of neighboring building H.M. Comer was phased. The phased demolition of Comer Hall included the scope of work, general demolition notes, life safety notes, and visual depictions of the designated demolition areas. The phasing of Comer Hall is displayed in Figure 10:

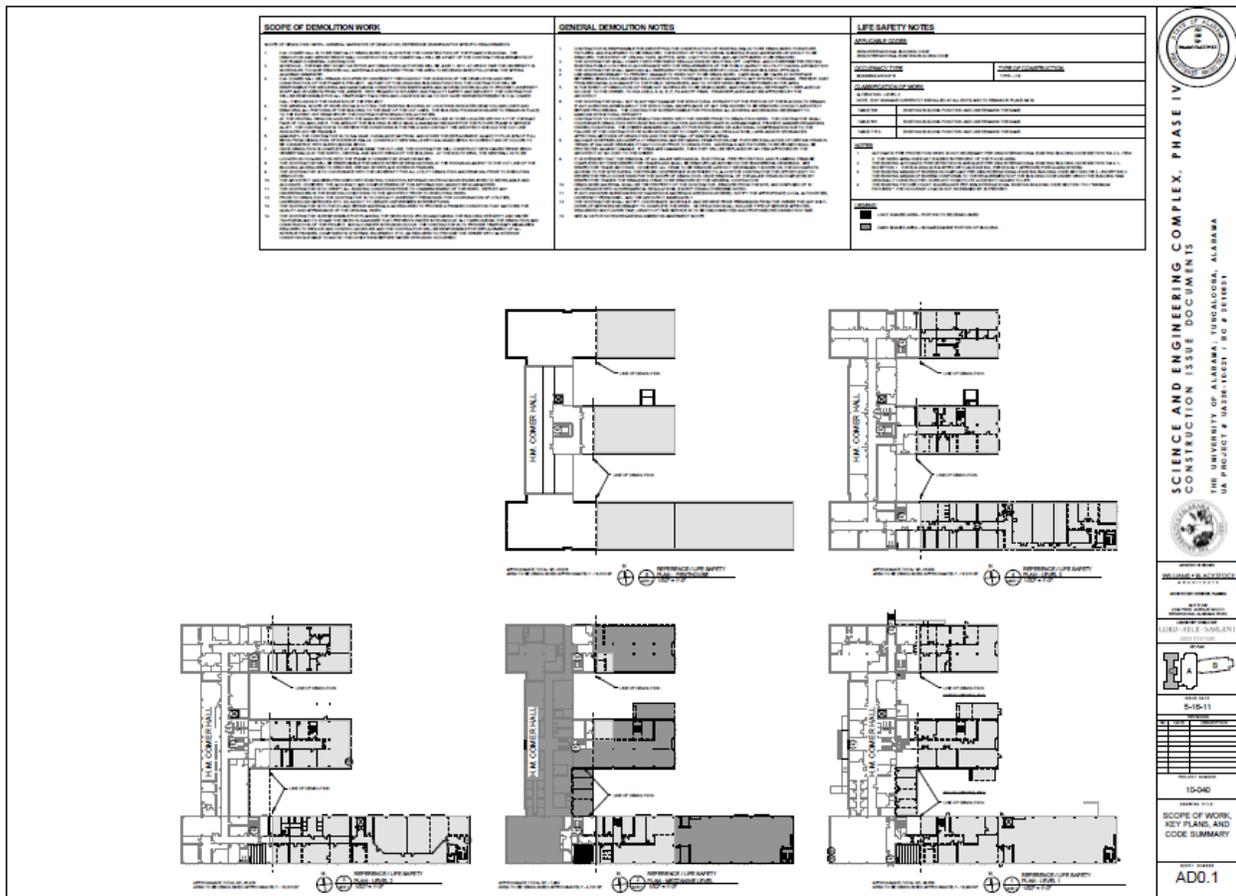


Figure 10: Contract Document of H.M. Comer Phased Demolition  
*Source: Williams Blackstock Architects*

The phasing of SEC IV differed from Comer Hall in that there was no required demolition and the project site was much larger. SEC IV phasing included aspects such as project site limits, required fencing areas, designated construction access and alternate routes for workers and students. Figure 11 shows a phasing example of SEC IV:

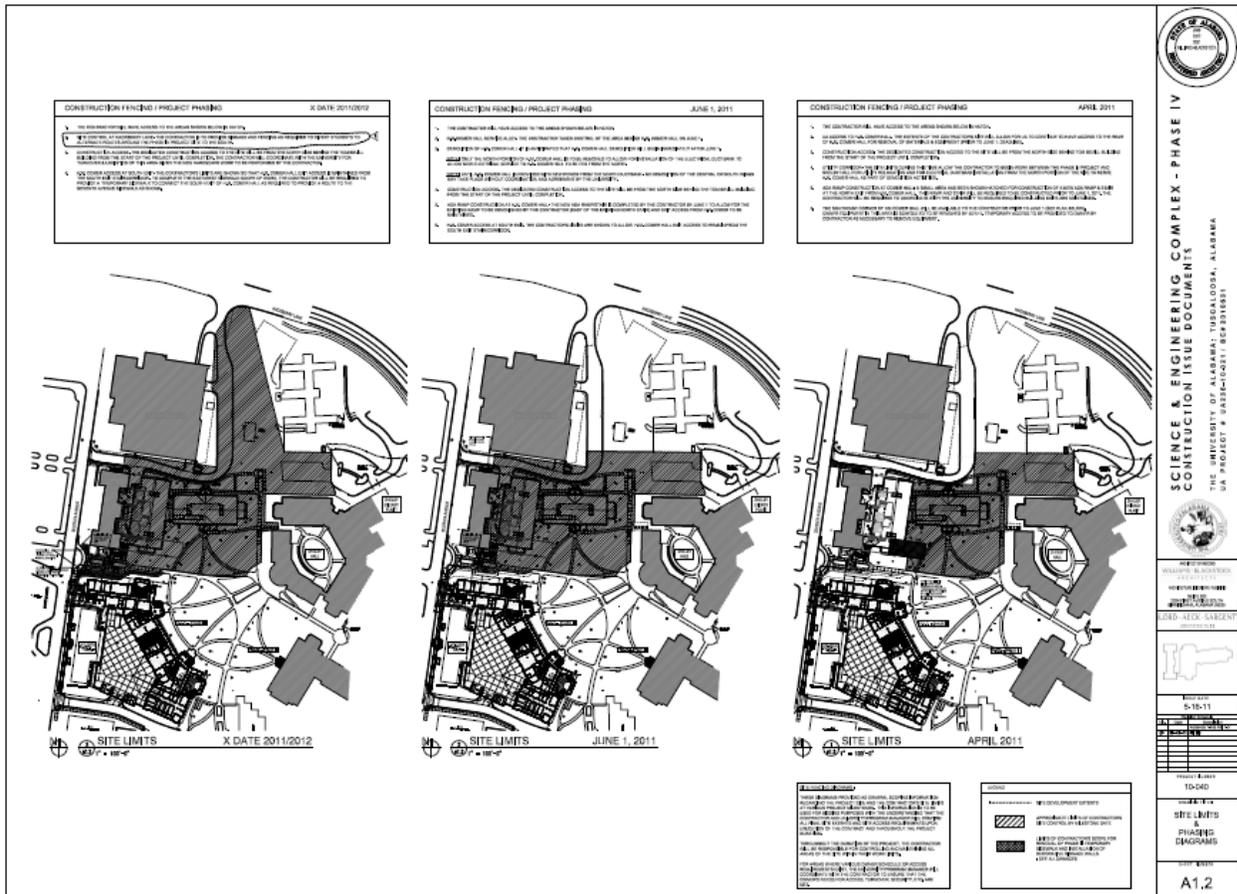


Figure 11: SEC IV Example Phasing Plan  
 Source: Williams Blackstock Architects

By using Revit to assist in phase planning, much potential value was added to the project. The owner gains a better understanding of the phasing schedule and can collaborate with the design team to identify any scheduling or sequencing issues. Space and workspace conflicts are also able to be identified and resolved before construction commences. This planning also helps to increase productivity and decrease waste on the job site.

Upon the completion of project planning and early design, the project moved into the detailed design stage. WBA now hired several specialized engineering firms to produce detailed design models. The list of hired firms (provided by WBA) and their associated specialties are displayed in Table 7:

Table 7: Engineering Firms Hired by Williams Blackstock Architects

Engineering Firm	Specialty
Whittaker & Rawson	Mechanical and Plumbing
Jackson Renfro	Electrical
LBYD	Structural
LAS	Lab Architect
McGiffert & Associates	Civil

To enhance coordination efforts, WBA ran a FTP site in which they could freely exchange BIM design models with the newly hired engineering firms. To begin, WBA uploaded the control design model to the website so it could be viewed by the firms during the design process. At this point, the 3D Revit control model was purely aesthetic (meaning it contained no internal systems) and each firm used this model as the basis for their initial system design. After each firm completed the initial design of their system, they sent a copy of it to WBA. Upon receiving all initial system designs, WBA compiled them into the first coordinated control file (Austin, 2013).

While the engineering firms each used the same initial control model, they did not perfectly coordinate their system designs with one another. This inevitably led to “clashes” or interferences between systems. To solve these problems, Applied Software was assigned the task of performing clash detection for each control file (Austin, 2013). A clash report from the 3<sup>rd</sup> floor in Wing A of SEC IV is displayed in Figure 12, with each red box indicating a clash within

the model. Autodesk Navisworks was used to find these clashes and the results were then distributed amongst the design team. After fixing the clashes, the engineers re-submitted their designs to WBA, who then updated the control file. The control file was exchanged with the engineers each week and clash detection meetings were held every month. This process continued throughout the design phase until all clashes were resolved and a final control model was established (Austin, 2013).

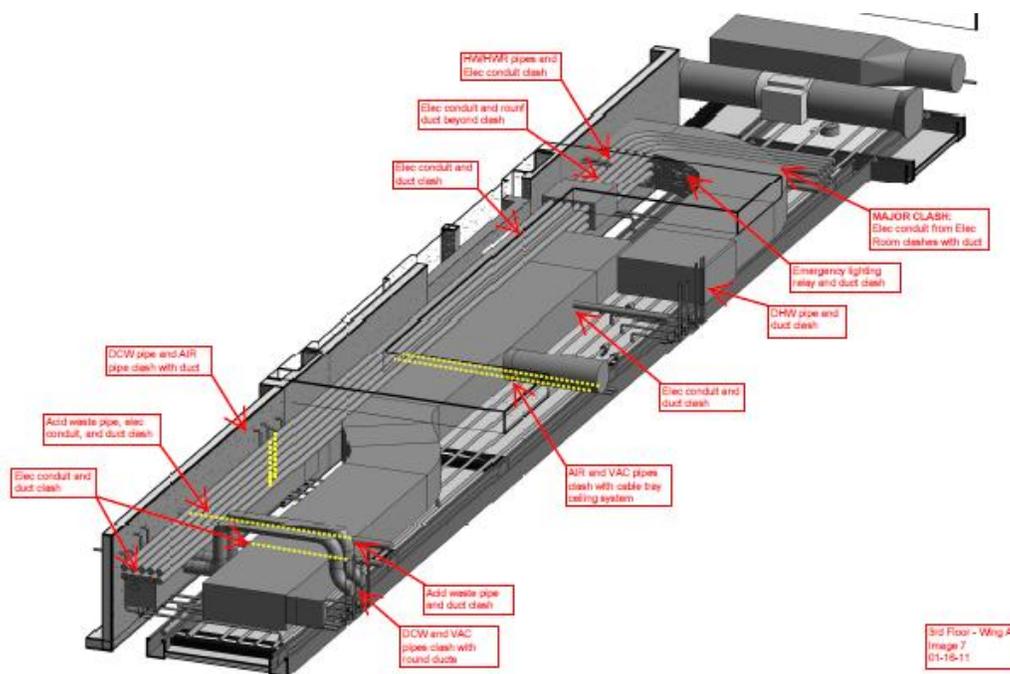


Figure 12: 3<sup>rd</sup> Floor Wing A Clash Detection  
Source: Williams Blackstock Architects

Having the ability to upload a 3D BIM model and distribute it to the entire design team adds incredible benefit to the detailed design process. Rather than having to design based off of a 2D paper document, each firm can use the same exact 3D model to design their system. This saves valuable time by eliminating the task of distributing 2D paper models back and forth among multiple firms. It also ensures each firm has the same information and model to work

with at all times. Clash detection allows the design team and the owner to discover clashes before construction begins, thus reducing construction issues in the field. Identifying and eliminating clashes during the design phase helps to improve the project schedule and decrease costly change orders during construction.

Using BIM not only increases collaboration between the architect and engineers during design, it enhances collaboration between the architect and the owner during design reviews. Reviewing the 3D BIM model with UA, rather than using 2D models, allowed for much easier communication regarding design issues. The owner was able to give immediate feedback and address any concerns or additional needs they had. These changes can then be modeled in real-time during design review and are available to all project stakeholders. Costly and time consuming traditional construction mock-ups are eliminated, saving valuable time and money. Overall, BIM allows the design team and owner to better evaluate the effectiveness of design in meeting building program criteria and owner needs. In doing so, members are able to generate better decisions for design and a shorter, more efficient design review process is created.

Many benefits come from using BIM during project planning and design, especially when compared to traditional 2D drawings. However, producing these drawings is still a necessary part of the design process. Two-dimensional Schematic, Design Development, and Construction and Shop Drawings can all be easily produced from a 3D BIM model. A major benefit of BIM is the ability to generate multiple views (plan, section, elevation, etc.) from a single model. Figure 13 shows a perspective view of SEC IV generated with the BIM model while Figure 14 displays an exterior elevation view:



Figure 13: Northeast and Southeast Building Perspectives  
*Source: Williams Blackstock Architects*

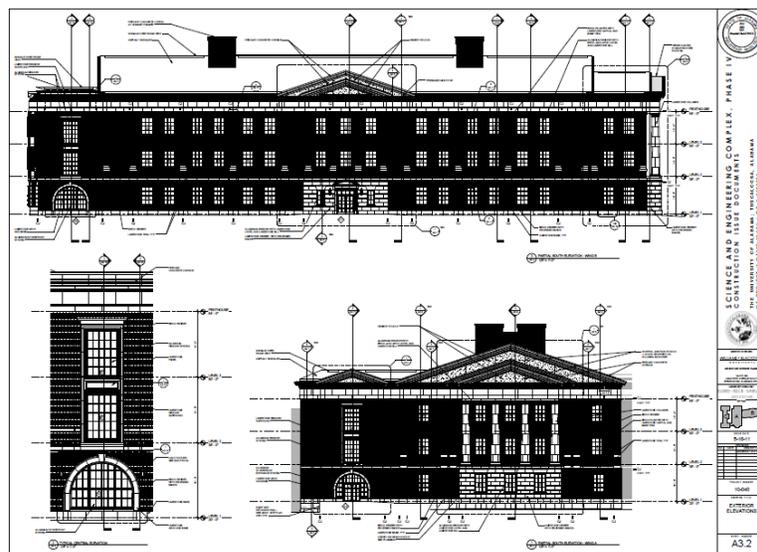


Figure 14: Exterior Elevation View  
*Source: Williams Blackstock Architects*

Figure 15 shows a section view of SEC IV in addition to Figure 16 displaying a document showing chimney details:

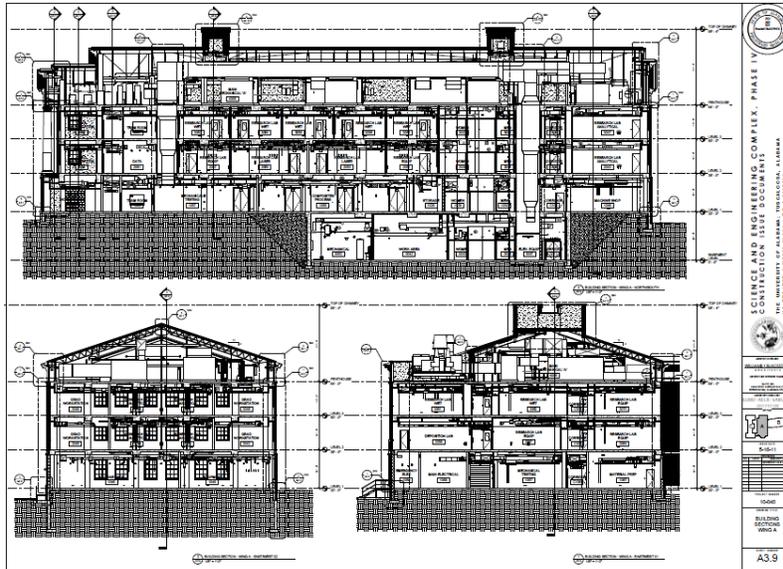


Figure 15: Wing A Building Sections  
 Source: Williams Blackstock Architects

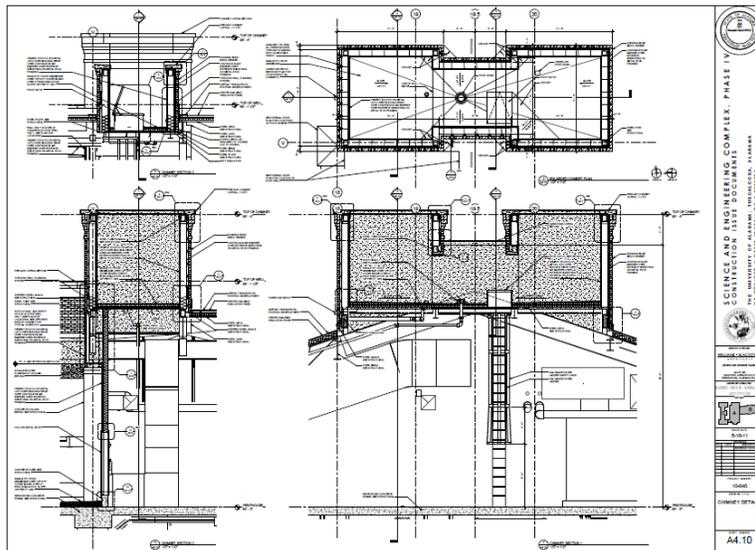


Figure 16: Chimney Details  
 Source: Williams Blackstock Architects

The same building model can be used to create these drawings and eliminates the need to manually update each drawing after every design change. Since all drawing data is extracted from the same model, there is increased consistency between different views.

Early implementation of BIM during planning and design offered numerous benefits to both the architect and owner.

- Existing site conditions had the benefit of being modeled and viewed in three dimensions, offering a better visual understanding of the project site.
- Preliminary models were created by the architect to provide a variety of building options to the owner.
- Once a design was selected, BIM decreased programming time while providing a simplified approach and enhanced graphics.
- The architect was also able to share the control model with all project engineers. This allowed for better collaboration during detailed design and provided many opportunities for clash detection to solve potential problems before construction.
- Phase planning provided the owner with a better understanding of the construction sequence while allowing for the identification and elimination of any schedule or site workspace issues before construction began.
- Lastly, BIM helped the team to perform high-quality design reviews and allowed many design documents to be generated from a single building model.

#### 4.2 Bid Phase

BIM is capable of offering several advantages depending on the bidding style of a construction project. However, SEC IV was what is known as a “hard bid” project and greatly reduced the BIM opportunities for general contractors (Hand, 2013). A hard bid project is similar to the design-bid-build process and can simply be defined by the following five steps:

1. The owner hires an architect

2. The architect prepares drawings and specifications defining the scope of project work
3. The design documents are advertised to solicit potential bidders
4. Multiple general contractors submit project bids
5. A general contractor is selected typically based on lowest bid

This process allows the architect to withhold previously created BIM design models until a GC is selected. Accordingly, the bidding general contractors only have 2D contract documents to use for creating a bid and no accompanying BIM models are available. Since the owner always sets a bidding deadline and no bids are considered after time has expired, this discourages GC's from spending time creating BIM models based on the provided drawings and specifications. Eventually, Doster Construction was awarded the project and assumed the role of general contractor. However, no BIM models were used to create the estimate for the bid (Hand, 2013).

#### 4.3 Construction Phase

After winning the bid for SEC IV, Doster Construction received the BIM models previously created by Williams Blackstock. Upon receiving the models, Doster distributed them to their subcontractors to be used for various construction and coordination purposes. Realizing the design models were created using 2011 versions of various Revit software, Doster upgraded to 2012 versions prior to coordination (Hand, 2013). Revit files are not backwards compatible, so it is very important to coordinate the upgrade with all involved parties. After all distribution and upgrading was completed, the construction phase was underway.

Creating a project schedule and a refined estimate are two of the most important tasks in construction. This is another area where BIM can add many benefits and save valuable time. Doster had already created a basic project schedule during preconstruction to assist in the bid

estimate, but no BIM was used in the process. Shortly after being awarded the project and gaining access to the BIM design models, they created a complete detailed project schedule. They chose not to utilize BIM for this process and instead used Primavera P3 (Davis, 2013). A portion of the created schedule is displayed in Figure 17:

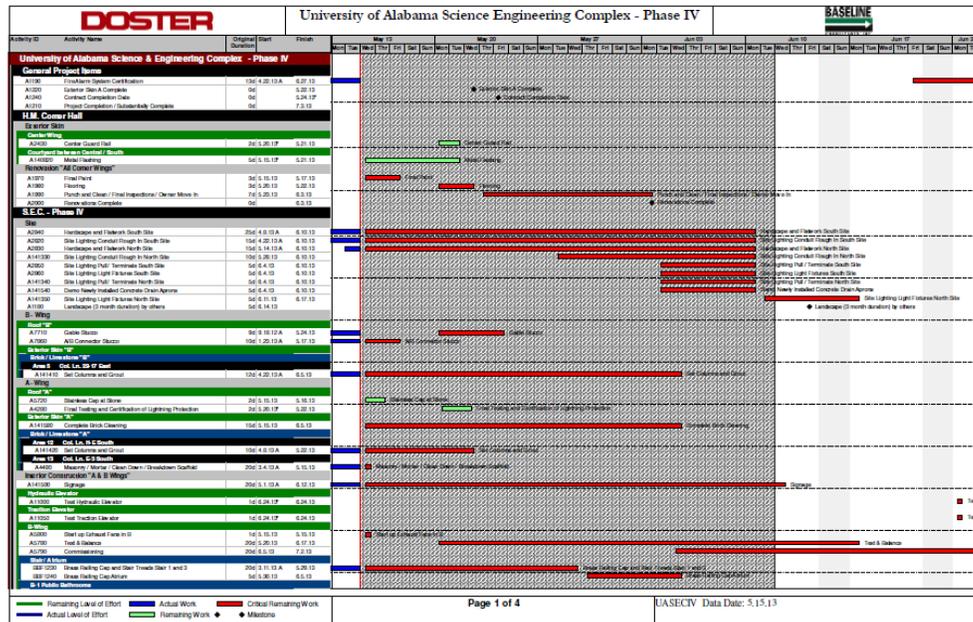


Figure 17: SEC IV Project Schedule  
 Source: Doster Construction

Despite not utilizing BIM to create the detailed project schedule, Doster did use BIM to create a better post-bid estimate. Revit was used to estimate based on the design models and coordinated models with subcontractors. When compared to estimating with 2D drawings, BIM estimating saves valuable time while increasing estimation accuracy by using the digital model. One important area of estimation was concrete pouring. Rather than performing laborious calculations and wasting time doing manual takeoff, the design model was broken into parts and assemblies to create estimates based on pours (Hand, 2013). Figure 18 shows an example of a

concrete estimate produced using Revit software. Using Revit not only saved Doster valuable time but also increased estimation accuracy by utilizing exact model geometry.

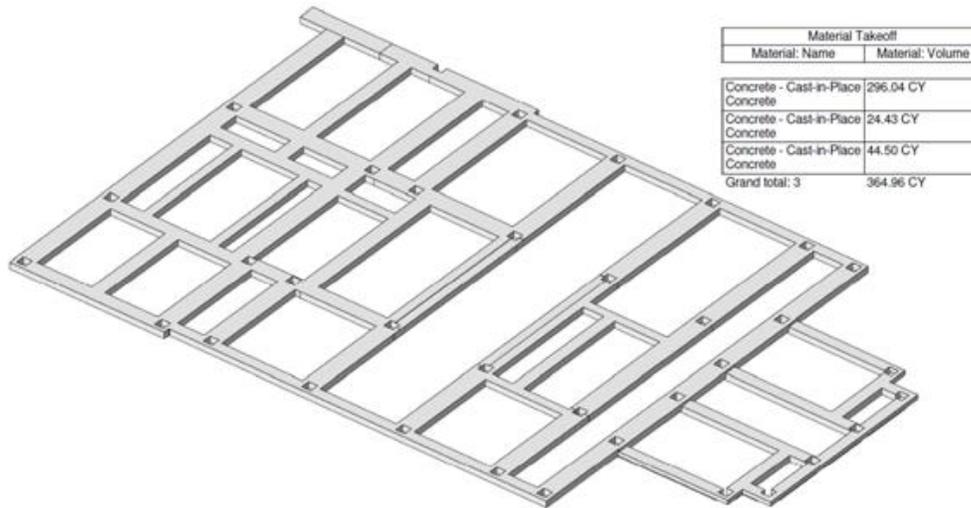


Figure 18: Concrete Estimation Using Revit  
*Source: Doster Construction*

Following the completion of the detailed project schedule, Doster began site utilization planning. BIM (mainly Google Sketchup) was used to accomplish this by graphically representing both permanent and temporary facilities on the project site during each phase of the construction process. Aspects such as crane location, laydown area, how much soil to bench back, and utility guidance into the building were all planned and represented (Hand, 2013). A graphical representation of site utilization for SEC IV is displayed in Figure 19. Although BIM is capable of linking the site utilization plan with the project schedule, this benefit was not exploited because BIM was not used during schedule creation.

Much value is added to the construction process by choosing to use BIM for this task. Doster was able to efficiently generate site usage layouts for multiple project tasks during each phase of construction. In doing so, potential space and time conflicts were identified before construction began. The site was also able to be evaluated for any safety concerns. All involved

parties were easily able to view and understand the construction sequence while all space usage and site utilization was updated in real time. BIM granted Doster the ability to have valuable collaboration with involved parties while minimizing time spent on site utilization planning.

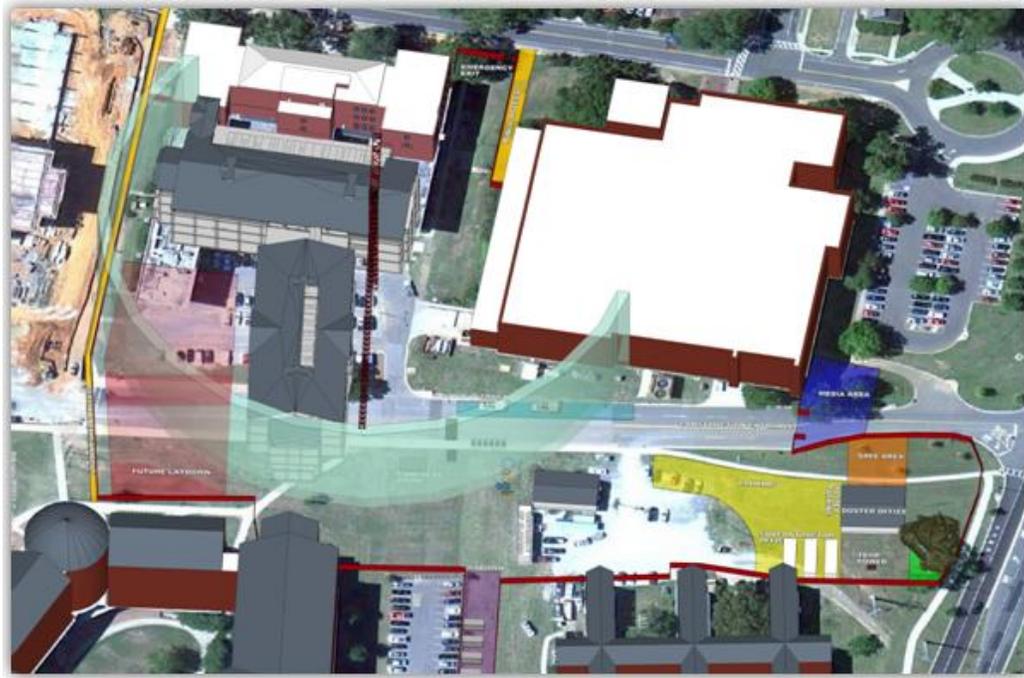


Figure 19: SEC IV Site Utilization Plan  
*Source: Doster Construction*

Subcontractors primarily utilized BIM for what is known as pre-construction detailing, which involves the preparation of shop drawings as well as submittals. The process began with Doster distributing the design control model to each subcontractor. Subs began to model their specialized designs with the software of their choice (Hand, 2013). Many different BIM softwares were used by the subs and can be seen in Table 8:

Table 8: Subcontractor BIM Software  
*Note: Table created by author*

Subcontractor Software	Use
Tekla	Rebar Modeling
CADMech	HVAC Piping Plumbing Specialty Gases
AutoCAD MEP	Electrical
Revit Architecture	Lab Equipment Lab Casework
HydraCAD	Fire Protection
Navisworks 2012	Coordination

After modeling was completed, the subs put their designs into the control model to run clash detection. A clash discovered between two intersecting system designs is shown in Figure 20:

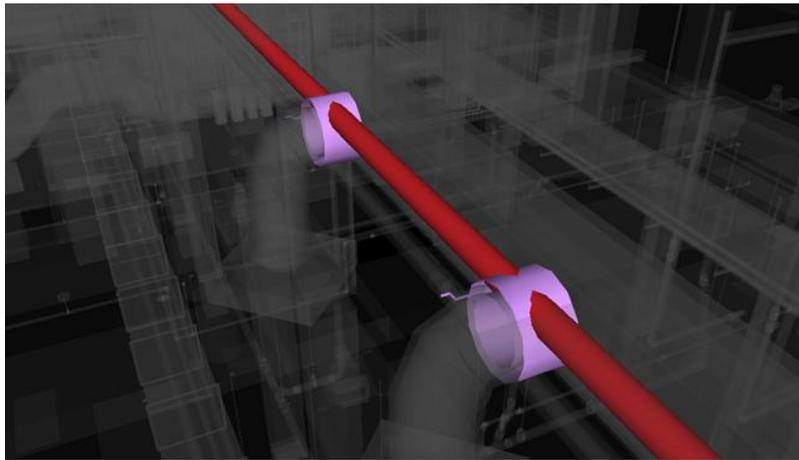


Figure 20: Pre-construction Clash Detection  
*Source: Doster Construction*

After holding multiple design meetings to fix all identified clashes, Doster sent the control model and shop drawings to the design team for review. Doster made the changes requested by the design team and eventually received their final approval. The final result after clash detection and coordination had completed can be seen in Figure 21.

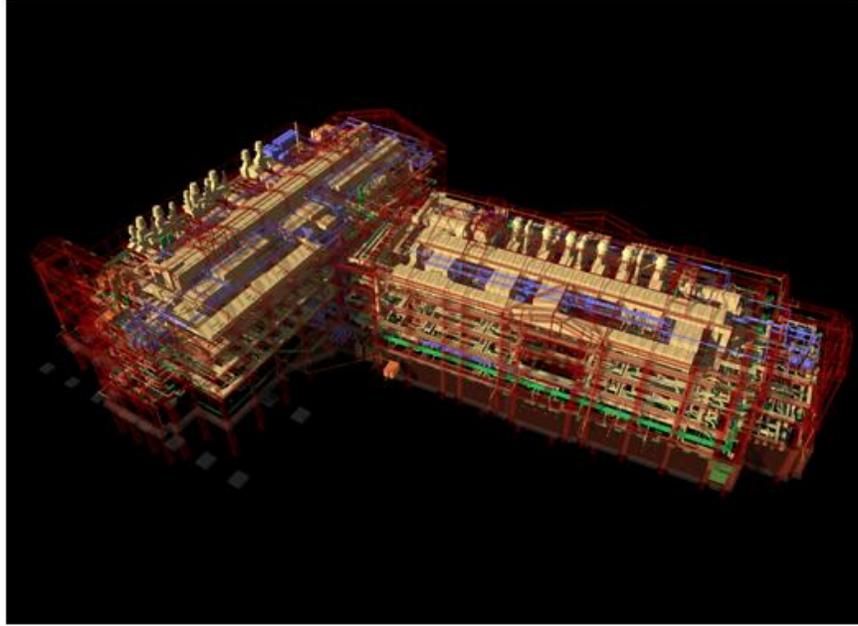


Figure 21: Clash Detection and Coordination Results  
*Source: Doster Construction*

Doster then notified the subs of final approval and digital fabrication was initiated. The main benefits BIM offered for this process are increased collaboration and reduced time for pre-construction detailing.

Digital fabrication while using BIM offers numerous benefits to both subcontractors and the general contractor. By using BIM, the subs input digital information into the computerized system to facilitate the fabrication of construction materials (Hand, 2013). This ensures a high quality of information and also allows for minimized tolerances due to machine fabrication. Since machines are used, productivity and safety are simultaneously increased. The GC gets the benefit of reduced lead time while the subs reduce dependency on 2D paper drawings. This reduced time allows for more of a safety cushion and makes it easier to adapt to late design changes. After enough fabrication is completed, the materials can be installed based on the shop

drawings. Before construction began; however, Doster participated in a virtual walkthrough of the model with all project managers to show the final product.

During construction and material installation, Doster also used BIM for in-field clash detection. The overall goal of “field BIM” is to ensure conformance to contract documents and owner performance requirements while assisting in field safety compliance. A major benefit in using field BIM is the real-time updating of building models in the field. This allows all parties to see the current construction progress and adjust anything if necessary before running into a problem. This helps to optimize the initial work and greatly reduces the amount of costly, time consuming change orders during construction. This also accelerates the project schedule and time to operations. Doster also had the additional capability of creating a history log of field management activity for future auditing. Contractor callbacks are able to be avoided and warranty claims are eliminated due to construction defects. Finally, field BIM allowed Doster to document all as-installed information for use in the record model and handover process while granting the ability to develop a digital handover asset of structured data and documents.

#### 4.4 Operations and Management Phase

Using BIM during the operations and management phase provides invaluable insight into the entire useful lifecycle of the building. Unfortunately, SEC IV is still in the final stages of the closeout process and handover has not yet been completed. Accordingly, UA has had no time to utilize BIM for O&M purposes. For the intentions of this paper, the benefits of BIM use during O&M will still be explained; however, they will not reflect current benefits experienced by the University of Alabama College of Engineering.

Once the closeout process is completed, Doster will provide the current record model to UA. The immediate benefit of this will be that UA possesses a real-time as-built model of the completed new facility and can analyze numerous building aspects at any time. Any future data they wish to embed into the model for renovation or equipment replacement can easily be added. UA will also be able to assess room areas and environmental performance to ensure the building is meeting the expected requirements (Messner 2011). The record model is an extremely valuable asset and can also be used for other advantageous processes.

One such process is known as preventative maintenance scheduling. This will allow UA to track and maintain the functionality of the building structure as well as any operating equipment during the entire useful life of the facility. This will allow for the proactive planning of maintenance activities and also allow tracking of maintenance history. Corrective maintenance and emergency repairs will be reduced. The productivity of all maintenance staff will likely increase due to a better understanding of equipment location. If maintenance is required, different approaches can be evaluated and minimal cost can be achieved (Messner 2011).

Building systems analysis will also be possible if BIM is utilized throughout O&M. The performance of the building can be compared to the previously specified design and corrective actions can be taken to improve performance if necessary. This will aid in ensuring the mechanical system functions correctly as well as monitoring the amount of energy the building uses. Additional uses include lighting analysis, internal and external CFD airflow, and solar analysis. If desired, UA will also be able to create “what-if” scenarios and change building materials to see if facility performance would improve or deteriorate (Messner 2011).

Another great benefit of BIM use during O&M is asset management. This process would require UA to link an organized management system to the record model to aid in maintenance

and operation of SEC IV. First, this would allow UA to store maintenance owner user manuals and equipment specifications for immediate access when needed. Facility and equipment data, such as maintenance schedules, warranties, upgrades, and replacements would be very easy to maintain. Scheduled work orders would have the capability of being automatically generated for maintenance staff. Accurate quantity takeoff of current company assets would be possible and would aid in financial reporting and future estimating of cost implications of upgrades or replacements. Lastly, asset management will allow future updates of the record model to show all current building asset information (Messner 2011).

BIM use would also allow for effective space management and tracking of SEC IV. This would be highly beneficial during building renovations when certain facility segments must remain occupied. Space management will ensure the appropriate allocation of spatial resources throughout the life of the facility while also proficiently tracking the use of current space and resources. Future space needs can easily be assessed and the efficiency of transition planning and management will be increased (Messner 2011).

The last benefit offered by BIM during O&M is disaster planning. If UA utilizes this benefit, emergency responders would have invaluable access to critical building information. The model would potentially improve the efficiency of the response as well as minimize safety risks. Once the system is properly configured for disaster planning, emergency responders will be able to clearly identify where the emergency is located within the facility. Once the emergency location is established, the responders will be able to plan out the best routes to the area (Messner 2011).

#### 4.5 Demolition Phase

Eventual demolition is inevitable when it comes to the majority of construction, and SEC IV is no different. Upon reaching the end of its useable life, it will require a carefully planned destruction. Although BIM does not have to be used to achieve a successful demolition, it would potentially offer some benefits. Site boundaries could be planned and graphically depicted on the demolition site. In addition, the record model would allow for easy identification of possible safety hazards and aid in their preventative planning. The model could also allow for an easier building analysis when determining the most effective spots to place demolition charges. As in the construction phase, the model could potentially be used for site utilization planning and show the location of all temporary facilities and equipment on the site. Lastly, BIM could be used to create the most efficient demolition process possible and aid in reducing waste on the project site.

## CHAPTER 5

### CONCLUSIONS

BIM benefits usually result in decreased cost, decreased time, increased quality, or a combination of the three. The main benefit BIM offers any project is increased collaboration. By using BIM, project teams can more effectively communicate with one another and create innovative and optimized solutions. While creativity is encouraged in construction, BIM also offers increased safety on the project site. Site conditions can be monitored and future safety hazards identified to ensure the safety of workers and future occupants alike. Upon project completion, BIM can then be used for managing the building during its useful life cycle. BIM is not an immediate cure-all; however, and many lessons were learned during the execution of SEC IV which will be addressed during future projects.

#### 5.1 Overall Benefits of BIM

All benefits experienced by BIM users can potentially be summarized by one or more of these three aspects: decreased cost; decreased time; increased quality. The greatest benefit of Building Information Modeling is, without a doubt, increased collaboration. By this alone, project teams become more involved with one another and the time taken to complete project tasks is reduced. Increased collaboration also leads to a better understanding of the project as a whole and helps facilitate a more efficient use of project time and resources. When time and resources are used efficiently, waste is reduced and the whole project team receives more value

during the project. If the project team gains a better overall understanding of the project, a more efficient, cost effective, and sustainable solution is possible.

Building Information Modeling also increases the ability to produce innovative and optimized solutions. By utilizing the many capabilities of BIM, the user can achieve almost anything they desire. Projects can be visualized at a very early stage and this helps owners identify the desired outcomes of their end product. Although some desired outcomes always conflict with one another (such as minimum cost and minimum schedule), the owner is able to get a high quality end product in return for his investment. In addition, the owner is able to receive the end product faster by incorporating BIM into the project lifecycle. By implementing BIM early in the design stage, potential future problems can be addressed and overall project duration is decreased.

Safety is the most important factor on the jobsite as well as for future occupants of the facility. BIM can be used to monitor all site conditions and assists the project team in identifying many possible safety concerns. Additionally, the impact of future tasks can be evaluated and allow the project team to take preventative measures against any observed or possible safety hazards. Future residents can rest assured their safety is in good hands with the use of BIM for disaster planning. This will provide critical building details to emergency responders, who can then identify the exact physical location of the emergency and plan the safest, most efficient route to the area.

Last but not least, BIM adds great benefit to the lifetime management of the facility. By possessing the record model created during construction, the owner has a real-time as-built representation of the facility at their fingertips. Maintenance needs of building systems and equipment can be evaluated and automatic maintenance schedules can be generated. Building

performance, such as energy use or mechanical system efficiency, can be monitored to ensure the facility is maintaining the desired level of performance previously expressed by the owner during design. The owner can also evaluate the potential financial impact of aspects such as equipment replacement and building renovation before any action is ever taken. By doing so, the owner can identify the most efficient, cost-effective solution and rest assured they are maintaining a high quality facility while receiving the best performance for the money.

## 5.2 Lessons Learned

With any new procedure or process, some level of trial and error is expected. While using BIM during the SEC IV project, the owner, architect, and general contractor learned valuable lessons. The University of Alabama realized that, in wanting 2D paper documents for closeout, the 3D BIM drawings had to be flattened. Although this does not heavily impact the overall project timeline, it was realized that time was unnecessarily wasted to perform this process (Davis, 2013)

. Williams Blackstock Architects learned the value of sharing the design model with the general contractor (Austin, 2013). It is a well-known fact in the construction industry that architects are very protective of their intellectual property rights when it comes to design. This causes many architects to withhold the design models from the general contractor and leave the GC to create their own models based off the design documents (or to not create models at all if the owner does not require them). In choosing to share their models, Williams Blackstock developed a more intimate and trusting relationship with Doster Construction. Sharing the design models also allowed for much more collaboration between the project parties and ensured

everyone had the exact same information. As previously mentioned, increased collaboration leads to more efficient project execution and brings added quality to the project.

Doster Construction learned four very important lessons during the construction procedures of SEC IV. The first lesson was to coordinate all concrete slab penetrations first. For this project, Doster participated in 3D MEP coordination and generated penetration drawings after much review and revision. This led to a tight schedule and penetrations were missed due to stress. Doster now models the sleeve, reviews penetrations, creates overhead partitioning and clash detects the sleeve, pipe, and slab (Hand, 2013).

The second lesson learned was confusion regarding typical details in a model. Typical details are sometimes confusing in a model and it is hard to know whether a detail overrides the model in a given location. After dealing with this subcontractor detail confusion, Doster will now clarify these details before construction begins (Hand, 2013).

Lesson number three is to always leave tolerances when prefabricating. When fabricating the building supports, little to no installation and layout tolerance was factored into the process. When installing the supports, Doster discovered that they would need slots instead of precision drilled holes to make up for this oversight. In the future, Doster will confirm all tolerances before prefabrication begins (Hand, 2013).

The final lesson learned was patience and attention to detail when using Navisworks for clash detection. When large portions of the model (and the entire model) were clashed all at once, thousands of clashes sometimes appeared. The default view of clashes in Navisworks can sometimes be confusing and, when dealing with such a large model, can lead to mounting frustration. Doster learned to step back and look at clash detections one aspect at a time. Instead of trying to deal with all clashes at once, Doster chose a particular type of clash and focused on

those until they were complete. By breaking clash detection down according to their desired categories, Doster felt less overwhelmed and was able to evaluate each clash with more clarity and understanding (Hand, 2013).

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