THE IMPACT OF BUILDING INFORMATION MODELING (BIM) ON CHANGE ORDERS FOR UNIVERSITY CONSTRUCTION PROJECTS

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A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil Engineering
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2014

ABSTRACT

Recent growth in construction volume is leading The University of Alabama to identify areas for improvement in the construction process. Change orders have a significant impact on project cost and schedule; therefore they are in need of improvement. Researchers have worked on improving the change order management and prevention plan and implementing it into their construction management. With the implementation of Building Information Modeling (BIM) for the design and construction of new facilities new research is necessary in order to determine the impact of BIM on the change order management and prevention strategy. The University of Alabama recently completed the construction of two similar engineering facilities, The South and North Engineering Research Centers (SERC and NERC), designed for labs and classrooms. The first building is designed and built using 2-Dimension modeling while the second building is designed and built using BIM for 3-Dimension modeling and coordination. Change orders due to design errors/omissions are noted as preventable, and the main focus of the research. Pertinent information was extracted and analyzed when reviewing change orders from both SERC and NERC. Change orders due to design errors/omissions diminish from 45 on SERC to 9 on NERC. The change in the project cost due to change orders from design errors/omissions decreased from 0.54% on SERC to 0.18% on NERC. Researchers found that BIM is not the only contributing factor in change order reduction. A thorough design review process coupled with the implementation of BIM, allows a level of reduction not yet achieved on other projects.

ACKNOWLEDGEMENTS

To begin with, I cannot thank my advisor, Dr. Johnson, enough for the guidance and wisdom he has provided me throughout this process. I must also thank Tim Leopard for his assistance and The University of Alabama Construction Administration office for allowing me this opportunity. I am grateful for the input and feedback provided by my committee members Dr. Edward Back and Dr. Gary Moynihan. I am also very thankful to have the love and support of an amazing wife, Allison Bruhn, who has supported me during the course of this entire project. Finally, I would not have made it this far in my academic career without the love and support of my family Ricky, Carolyn and Buddy Bruhn.

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CHAPTER 1

INTRODUCTION

The University of Alabama has grown at an unparalleled rate over the past seven years. In 2006 the student population was 23,878 and in 2013 it increased to 34,852 (Lane and Andreen 2006), an increase of nearly 46% in seven years. Not only has the University grown in student population, but also they have grown in size, with 11 new dorms since 2005 that hold approximately 3,300 additional students (Greene 2012). However, the University does not limit its construction efforts to dorms alone; they also have increased the number of research facilities and classrooms in order to accommodate the growing demands. The University just completed the new engineering quad, which added four new buildings totaling approximately $300 million (Doster). The high construction volume leads the University to perform research in order to identify areas of cost and schedule overruns. With this goal in mind, it was determined that the area of change orders could improve (Andres 2007). The goal of the research then began to focus on how to reduce costs and schedule overruns due to change orders by designing an effective change order management and prevention plan (Stone 2009). The University of Alabama Construction Administration has implemented this research into the their change order management process on multiple construction projects in hopes of reducing change orders due to design errors/omissions. Since the completion of the previous research, the University has decided to implement Building Information Modeling (BIM) in their construction process. This in turn should have a significant impact on change orders. The University has postulated that the implementation of BIM will help eliminate change orders, specifically change orders caused by design errors/omissions.

A change order results from either/or a change in the work scope, adjusted contract price, or any change in the amount of time to perform the work that is approved and initiated by the owner. (O'Brien 1998). All parties involved must acknowledge and agree that the change is indeed, a change, in order to initiate the change order (Hanna and Russel 1999). A change order is usually the result of an owner-initiated change in the scope or time frame of a project, unforeseen conditions that require change, or a design error/omission that results in change (Sudaram 2012). An owner-initiated change at its core is a change to the project scope or duration that is requested by the owner (Kovert 2012). This type of change is typically forthright and results in little dispute (Günhan et al. 2007). Change orders involving unforeseen conditions are usually the result of physical conditions differing from what was agreed upon in the original contract (Callahan 2005). Inadequate designs that prevent the contractor from completing their work are due to design errors/omissions and result in a change order (Günhan et al. 2007). There are many ways to prevent change orders, such as; design reviews, checklists, coordination meetings, and now, 3-Dimensional modeling. A change order management and prevention program should include all of these elements in order to achieve the desired result which is little to no change orders.

Building Information Modeling (BIM) was created in order to improve design coordination, execution, delivery, and maintenance for construction projects (Duke et al. 2013). Although the definition of BIM seems to vary depending on who you ask, the National Institute of Building Science has compiled an assortment of standards to help eliminate misperceptions. They have now created what is known as 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 the 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)

When the term "BIM" is used it is typically referring to the modeling software that coordinates the data from the design process and compiles it into a 3-Dimensional model. This software typically contains more capabilities than the traditional 2-Dimensional model as it holds the capacity to update the entire model when making a change. For example if some conduit is added above a ceiling, in a hall way, this is updated on all of the views, quantity take-offs, and schedules. Having this software helps the designers visualize the project and minimize errors/omissions (Chelson et al. 2010).

To see if the BIM software is making a difference in preventing change orders, reducing the frequency of change orders, or eliminating trends, research becomes necessary. The University recently completed the South Engineering Research Center (SERC) and the North Engineering Research Center (NERC), the former was built without BIM, and the later was built with the aid of BIM. Both projects were similar in type, size, cost and delivery method as seen in Table 1.

TABLE 1 PROJECT COMPARISON

	South Engineering Research Center	North Engineering Research Center
Type	Research Building with Classrooms and Labs	Research Building with Classrooms and Labs
Size	3-stories 175,000 square feet	4-stories 206,000 square feet
Original Cost	$ 47,637,000.00	$ 57,713,916.00
Delivery Method	Design-Bid-Build	Design-Bid-Build

(“Buildings” 2013)

Since both projects are similar, they offer a unique opportunity to examine the effects of the BIM software on change orders. This research will focus on the two projects and what advantages the BIM software provides. An investigation of the change order management system is conducted in order to identify deficiencies and suggest areas for improvement. Additional factors are also considered such as the use of new or alternative designers and project management teams, original project budget vs. project estimate, and project type. This research will highlight how BIM impacts change orders caused by design errors/omissions since the use of BIM should greatly reduce or eliminate those types of issues.

Construction Administration at The University of Alabama consistently focuses on reducing cost and schedule overruns caused by change orders. Now that the University is implementing new software that should help reduce change orders it is wise to investigate the impact the new software is producing. The purpose of this study is for researchers to measure the effect of BIM on the change order management and prevention strategy, and recommend improvements so that cost and schedule overruns are reduced or eliminated altogether. Change orders due to design errors/omissions are highlighted in previous studies as an area for improvement since they are classified as preventable (Stone et al. 2011). At the time the original research was conducted, the number of change orders due to design errors/omissions was approximately 43% (Andres et al. 2007). This will be a benchmark in order to determine if any reduction occurs. It is important to revisit what was put in place and lessons learned in order to develop the most effective change order management and prevention program. This study examines the new change order management system to see if adequate time and effort is being put forth into the documentation of change orders so that the effect the change has on the project is properly quantified. By looking at a wide range of factors we will be able to not only determine causes of change orders, but also the effect that BIM is having on change orders. This investigation of the newly implemented BIM software on the NERC project compared to the SERC project will allow four things: (1) A quantification of the impact of BIM on change orders, (2) Identification of trends in change orders, (3) An updated prevention checklist, and (4) Making improvements in the quality of data collected.

CHAPTER 2

LITERATURE REVIEW

Change order management and prevention for Universities is not a new topic. This issue is addressed continually across the country (Mrozowski et al. 2004). As student population increases, the University's size must also increase, in order to accommodate the growing student population. This means that there is a need for construction projects, and a need to control the costs, specifically cost due to change orders. The previous research conducted by Universities on change orders identifies areas where there are common causes of change orders and areas for improvement (Stone et al. 2011). Researchers also focus on how to implement this data into change management and prevention strategies. Since the focus of this research revolves around University construction, literature based upon change order management and prevention is sought out. Research conducted by Michigan State University yielded a new change order management and prevention plan, however there was no data to quantify the effects of the execution of this plan (Mrozowski et al. 2004). Their plan addressed common issues they experience, including scope increases (owner-initiated changes), field changes (unforeseen conditions), and document errors (design errors/omissions). The research conducted at The University of Alabama also addresses these issues (Andres et al. 2007). The results of this implementation reveal a steady improvement in the reduction of change orders due to design errors/omissions (Stone et al. 2011). The downfall of this past research is that it does not incorporate the influence of BIM. This is part of the motivation for this current study. BIM will have a significant impact on the change order management and prevention strategy, but what kind of impact and how it can be maximized is yet to be evaluated.

Research conducted on construction projects helps identify the impacts of implementing BIM in design and construction on cost and schedule (Chelson et al. 2010). Since this research is comparing two sets of data, additional literature is examined in order to determine what has been done in the area of data comparison. This type of research takes a look at a broad range of information in an attempt to summarize the overall impact of BIM. The researchers that conduct studies on the impact of BIM try to compare generalized data from diverse groups of projects (Chelson et al. 2010 and Suermann et al. 2009). For example, the researchers will often select a broad range of projects and take the averages of the established metrics, such as the number of RFIs, Change Orders, Schedule Migration, and Productivity, and compare them directly to the averages of another broad range of projects. While this is not completely erroneous in approach, there are flaws to this system. Many factors affect a project other than the implementation of BIM. Project planning, project management team, design team, and economic environment are a few factors that will have a major influence on a project's outcomes and are often become disregarded when determining the impact of BIM on a project (Pakseresht and Asgari 2012). In order to form a more accurate picture of the impact of BIM on construction projects researchers need to analyze projects that are as similar as possible where one project has implemented BIM software and the other has not. Unfortunately, because every project is unique these opportunities are fairly rare. Also, instead of looking at the big picture when it comes to the impact of BIM on a project, it is beneficial to focus in on a single aspect in which more accurate results and additional information become available.

In order to improve upon existing research, this study will look into how BIM has affected change orders and the change order management and prevention plan. The opportunity to study two projects that are similar in size, costs, scope, and function will help identify other trends that may influence change orders as well. Understanding the impact of BIM on the change order system will allow users to create a change order management and prevention strategy that will accommodate the changing technologies. Documentation throughout time proves that changes are nearly inevitable (Günhan et al. 2007). However, by further investigating the change order management and prevention system paired with innovations in technology, the goal to greatly reduce them on projects becomes realistic.

CHAPTER 3

METHODOLOGY

In order to compare the data from both the South and North Engineering Research Center (SERC and NERC) we need to define some metrics in which to classify and collect data. The metrics researchers establish need to be able to help identify the effectiveness when implementing the Building Information Software (BIM). In the previous study an effective metric was based off of CII's five criteria which include:

1. Measurability,
2. Significance to the organization and project team,
3. Ability to be influenced in some predictable way by management action,
4. Repeatability, and
5. Timeliness (CII 1994)

This study will utilize the same metrics. CII also made some recommendations as to what information is necessary to extract from change orders and analyze. This includes the cost of the change; the type, origin, and impact of the change order; the time at which the change occurs during the project life-cycle; and the engineering function or craft trade involved (CII 1994). Since the conclusion of the previous research on change orders most of this data is made available on the University's Change Order Request Approval Form (CORAF) for easy data collection and use in their Lessons Learned program.

The specific data collected from both SERC and NERC is based on the data available from the CORAF form: Cost, CSI Division Impacted, Description, and Notes. The goal of this research is to identify the impact of BIM on change orders, so it becomes necessary to add an additional category for the SERC building data collection; "Would BIM have prevented this change?" Time delays do not apply in the current study. University projects follow a strict deadline. The University does not allow for contract time extensions, therefore overtime is calculated into each change order. The use of these metrics will allow us to see what kind of impact BIM would have had on the SERC building.

In order to see what kind of change orders BIM has the most effect on, we need to classify each change order. The four categories used in the past for the research at The University of Alabama are owner-initiated changes, design errors/omissions changes, unforeseen conditions, and value engineering. Value engineering changes are separated from owner-initiated changes so the study can focus on changes that cause a negative impact and since value engineering category is a positive impact they are separate. After reviewing the change orders it was determined that an additional category became: contract modification. These changes result from adjustments to allowances that were already in place or an addition that was anticipated if sufficient funding remained. Since those are not considered changes they are separated from the data.

The reason for each change order is determined by a two-step process, first, the cause is determined by the justification entered on the CORAF form and then logged into a spreadsheet. Once all the data is logged it is then reviewed by the project manager, Assistant Vice President of Construction Administration for The University of Alabama, and the Executive Director of Construction Administration for The University of Alabama to ensure its accuracy. The review process involves looking at each change order item and discussing the reason for the corrective action, checking to see if it is logged correctly, and determining if the use of BIM software would have prevented the change. Determining the cause of each change order and if BIM could have made an impact allows for a more accurate picture of the true influence BIM enforces on change orders. This categorization system will also allow for a direct comparison between both the SERC and NERC projects in an objective manner.

It is also determined that it is important to figure out which trades cause most change orders and to see what effect BIM will have on them. For this reason, every change order is categorized by the trade it impacted. Since some change orders affected multiple trades, they are classified by which trade caused the change. The best way to classify which trades are impacted is to classify them based on the Construction Specifications Institute (CSI) Master Format Division. Since the University uses the 1994 version of the Master Format, it was determined to classify them based on that version as opposed to the 2004 edition. After each change order item is classified by type and division we can then begin to pick out trends and determine what trades cause certain types of changes.

The first step in the process is to obtain access to the desired data. Ever since the conclusion of the previous research the data is made readily available and easy to interpret. The data is then taken and organized into Excel spreadsheets (Fig. 1).

CORAF#	Category	Cost	Percentage cost	CSI Division	Description	Notes

FIGURE 1: DATA COLLECTION SPREADSHEET

There is a separate spreadsheet for both the SERC and NERC projects. The CORAF#, Cost, Description, and Notes are all taken directly from the CORAF while Category and CSI division were determined based on the description and notes. The percentage cost is based upon the cost of the change order compared to the original contract amount. Each category is determined as Owner-Initiated, Design Errors/Omissions, Value Engineering, Unforeseen Conditions, or Contract Modification as discussed previously. Once the data is input into Excel it is then analyzed by separating the data into tables that showed the distribution between the reason for change and CSI divisions. This data is useful in identifying problem areas as well as areas for improvement.

A previous study produced a checklist of frequently occurring items that resulted in change orders (Stone et al. 2011). The checklist is then used by design reviewers for the University to inspect the contract documents to identify any common design errors/omissions as well as correct any items that are not in accordance with University standards. This checklist is used by reviewers during the 10, 30, 60, 90, and 100 percent completion design phase in order to aid in-house reviewers. Upon the completion of the current data study, the checklist will be revisited in order to update and improve it, as well as to accommodate the University's migration towards BIM. This checklist will help catch items that BIM may miss such as joint sealant color, additional door closers, or furniture coordination.

CHAPTER 4

FINDINGS

The data collection process proved a fairly simple task due to the improvements made to the change order management system as a consequence of previous research at The University of Alabama (Andres et al. 2007 and Stone et al 2011). Change orders are now recorded in an online data base that includes cost, description, and often a reason for the corrective action. Once access is obtained, the data collection process can begin.

SERC

First, the data was collected from the South Engineering Research Center (SERC). The results from the number of change orders were in line with what is expected. There were 94 change orders on the project and nearly half were caused by design errors/omissions (Table 2). Although incurring 94 change orders on a project of that size is not unreasonable, the number is higher than desired.

TABLE 2: SERC CHANGE ORDERS

Number of change orders. (SERC)	
OIC	41
DE/O	45
UC	3
VE	5

However, discussions with the project team indicated that the bids on the project were under budget, and since the funding was acquired via a grant, it was in the Universities best interest to use the money to add value to the project. Therefore the University expanded the project once it became clear that the project would, in fact, finish under budget so almost half of the total changes are owner-initiated to add value to the project.

The remaining changes then were broken down by CSI Divisions. This determined which trades were responsible for producing the most change orders (Table 3). Mechanical was by far the most expensive source of change, and electrical was not far behind. Division 11, equipment was between the two, an unexpected result because on other University of Alabama projects this category rarely accounts for changes (Stone et al. 2011). On this project it accounts for 20.6% of the total change order costs. However, further investigation indicated that this also was an owner-initiated change. Equipment for some of the research labs was also purchased with excess funds.

TABLE 3: CHANGE ORDERS BY CSI DIVISION (SERC)

Change Orders by CSI Division (SERC)						
Div. #	CSI Division	Number of Change Orders	Percentage of Total Occurance	Cost	Percentage of Total Change Order Cost	Percentage of Project Cost
1	General Requirements	1	1.1%	$ 437.50	0.0%	0.00%
2	Site Construction	7	7.4%	$ 152,482.39	5.2%	0.32%
3	Concrete	2	2.1%	$ 10,381.79	0.4%	0.02%
4	Masonry	0	0.0%	$ -	0.0%	0.00%
5	Metals	3	3.2%	$ 10,872.10	0.4%	0.02%
6	Wood and Plastics	1	1.1%	$ 6,241.36	0.2%	0.01%
7	Thermal and Moisture Protection	4	4.3%	$ 22,698.80	0.8%	0.05%
8	Doors and Windows	7	7.4%	$ 33,712.40	1.2%	0.07%
9	Finishes	8	8.5%	$ 21,696.52	0.7%	0.05%
10	Specialties	4	4.3%	$ 23,590.43	0.8%	0.05%
11	Equipment	2	2.1%	$ 598,608.95	20.6%	1.26%
12	Furnishings	0	0.0%	$ -	0.0%	0.00%
13	Special Construction	0	0.0%	$ -	0.0%	0.00%
14	Conveying Systems	0	0.0%	$ -	0.0%	0.00%
15	Mechanical	18	19.1%	$ 1,566,574.92	53.9%	3.29%
16	Electrical	37	39.4%	$ 460,383.51	15.8%	0.97%
Total		94		$ 2,907,680.67	100%	6.104%

When the information from types of change orders and CSI Division is combined, additional analysis of the data can take place (Table 4). The breakdown shows which divisions produce the most design errors/omissions. This is significant because areas where there are design errors/omissions are areas where there is room for improvement. This data shows that the divisions with the most room for improvement are Division 15 and 16. This is noteworthy because this is an area where BIM can have a major influence on a project. With design errors/omissions in Division 15 and 16 being the cause of nearly a 0.40% increase in the original contract, there is the potential savings of nearly $200,000.

TABLE 4: IMPACT ON TOTAL PROJECT COST BY CSI DIVISION AND CAUSE (SERC)

Change orders by CSI Division and Cause (SERC)					
CSI Division	Owner Initited	Design Error	Unforseen Conditions	Value Engineering	% of Original Contract
1	0.00%	-	-	-	0.00%
2	0.14%	0.02%	0.18%	-0.01%	0.32%
3	0.02%	-	-	-	0.02%
4	-	-	-	-	0.00%
5	-	0.03%	-	0.00%	0.02%
6	-	0.01%	-	-	0.01%
7	-	0.05%	-	0.00%	0.05%
8	0.06%	0.01%	-	-	0.07%
9	0.01%	0.03%	-	-	0.05%
10	0.05%	0.00%	-	-	0.05%
11	1.26%	-	-	-	1.26%
12	-	-	-	-	0.00%
13	-	-	-	-	0.00%
14	-	-	-	-	0.00%
15	3.18%	0.11%	-	-	3.29%
16	0.77%	0.28%	0.01%	-0.09%	0.97%
Totals	5.49%	0.54%	0.18%	-0.11%	6.104%

In an effort to normalize the data the cost of each change order is compared to the cost of each CSI Division (Table 5). For example, there is a change of nearly $600,000 to the original

$2,500,000 scheduled for Division 11 due to owner initiated changes. This affects the total contract price by 1.26% but it affects the individual division by 25.47%. This data shows a more accurate picture of the amount of impact change orders are having per CSI Division. Although Division 15 has the greatest impact on the overall contract price it does not have the greatest impact on its own specific division because the cost for Division 15 is much higher than the other Divisions. Division 11 shows a significant change because the scheduled value is relatively low in comparison to the overall project cost so when the owner initiated a significant change it has a large impact on the cost of the division.

TABLE 5: NORMALIZED IMPACT ON PROJECT COST BY CSI DIVISION AND CAUSE (SERC)

Change orders by CSI Division and Cause (SERC)					
CSI Division	Owner Initited (SERC)	Design Error (SERC)	Unforseen Conditions (SERC)	Value Engineering (SERC)	% Change in Division Contract
1	0.02%	-	-	-	0.02%
2	6.85%	0.86%	9.03%	-0.65%	16.10%
3	0.19%	-	-	-	0.19%
4	-	-	-	-	0.00%
5	-	0.49%	-	-0.05%	0.44%
6	-	1.95%	-	-	1.95%
7	-	2.21%	-	-0.10%	2.11%
8	1.94%	0.17%	-	-	2.12%
9	0.24%	0.67%	-	-	0.91%
10	10.12%	0.79%	-	-	10.91%
11	25.47%	-	-	-	25.47%
12	-	-	-	-	0.00%
13	-	-	-	-	0.00%
14	-	-	-	-	0.00%
15	9.40%	0.32%	-	-	9.72%
16	7.53%	2.74%	0.05%	-0.88%	9.43%

NERC

After the information was collected from SERC, the documents from the North Engineering Research Center (NERC) project were examined and input into a separate spreadsheet. The same method was used in collecting the data; information was taken directly from the CORAF forms and put into the spreadsheet. At first glance the data was shocking, especially for a nearly $60 million project. The number of change orders for the NERC project was about 75% lower than the SERC project despite the NERC project being slightly larger (Table 6).

TABLE 6: NERC CHANGE ORDERS

Number of Change Orders. (NERC)	
OIC	9
DE/O	10
VE	0
UC	4

Even more striking was that the number of change orders due to design errors/omissions was only 10 as compared to 41 on SERC. The number of owner-initiated changes was significantly lower as well. Upon the collection of this data the results were discussed with the Assistant Vice President of Construction Administration. A discovery was made that when the contractors bid on the project, the bids came back higher than what was budgeted for the project. Since the project started over budget, there was not much room for the owner to add changes to the project in order to add value to the facility.

Once all the data was gathered and placed into spreadsheets the same procedure conducted for SERC was then implemented on NERC. The change orders were then broken down by CSI division and cost (Table 7). Again, Divisions 15 and 16 are the source for the majority of the change orders, making up over 50% of the total number of change orders and accounting for nearly 41% of the total costs for change orders. Even though they make up nearly 41% of the total change order costs, they only change the original contract amount by about 0.31%. Another division worthy of mentioning is Division 2, which is site work. This is relatively high, but in order to understand the big picture we need to understand what types of change orders are showing up in each of these divisions.

After merging the data from change order type, CSI Division, and cost a more accurate picture began to take shape (Table 8). Design errors/omissions only accounted for a 0.18% change to the total project costs, while owner-initiated changes made up 0.51%. Also, this table shows that even though divisions 2, 15, and 16 made up over a 0.59% change in the original contract price, only about 0.15% of that was caused by design errors/omissions.

TABLE 7: CHANGE ORDERS BY CSI DIVISION (NERC)

Change Orders by CSI Division (NERC)						
Div. #	CSI Division	Number of Change Orders	Percentage of Total Occurances	Cost	Percentage of Total Change Order Cost	Percentage of Project Cost
1	General Requirements	0	0.00%	$ -	0.00%	0.00%
2	Site Construction	6	26.09%	$161,970.46	37.38%	0.28%
3	Concrete	0	0.00%	$ -	0.00%	0.00%
4	Masonry	1	4.35%	$ 78,129.00	18.03%	0.14%
5	Metals	0	0.00%	$ -	0.00%	0.00%
6	Wood and Plastics	0	0.00%	$ -	0.00%	0.00%
7	Thermal and Moisture Protection	1	4.35%	$ 8,326.88	1.92%	0.01%
8	Doors and Windows	1	4.35%	$ -	0.00%	0.00%
9	Finishes	1	4.35%	$ 7,340.14	1.69%	0.01%
10	Specialties	0	0.00%	$ -	0.00%	0.00%
11	Equipment	0	0.00%	$ -	0.00%	0.00%
12	Furnishings	0	0.00%	$ -	0.00%	0.00%
13	Special Construction	0	0.00%	$ -	0.00%	0.00%
14	Conveying Systems	0	0.00%	$ -	0.00%	0.00%
15	Mechanical	5	21.74%	$ 56,268.00	12.99%	0.10%
16	Electrical	8	34.78%	$121,259.07	27.99%	0.21%
Total		23		$433,293.55	100%	0.75%

TABLE 8: IMPACT ON TOTAL PROJECT COST BY CSI DIVISION AND CAUSE (NERC)

Change Orders by CSI Division and Cause (NERC)					
CSI Division (NERC)	Owner Initited (NERC)	Design Error (NERC)	Unforseen Conditions (NERC)	Value Engineering (NERC)	% of Original Contract
1	-	-	-	-	0.00%
2	0.23%	0.00%	0.04%	-	0.28%
3	-	-	-	-	0.00%
4	0.14%	-	-	-	0.14%
5	-	-	-	-	0.00%
6	-	-	-	-	0.00%
7	-	0.01%	-	-	0.01%
8	-	-	-	-	0.00%
9	0.01%	-	-	-	0.01%
10	-	-	-	-	0.00%
11	-	-	-	-	0.00%
12	-	-	-	-	0.00%
13	-	-	-	-	0.00%
14	-	-	-	-	0.00%
15	0.00%	0.09%	-	-	0.10%
16	0.12%	0.06%	0.02%	-	0.21%
totals	0.51%	0.18%	0.07%	0.00%	0.75%

The data was normalized for the NERC project as well in order to show the true impact on change orders on each individual CSI Division (Table 9). This data shows that the division that is impacted the most by change orders is Division 2. However, no CSI Division was impacted by more than 1% due to Design Errors. This is significant because it shows not only do change orders due to design errors have a small impact on the total contract price but they also have a small impact on the change in the CSI Division cost.

TABLE 9: NORMALIZED IMPACT ON PROJECT COST BY CSI DIVISION AND CAUSE (NERC)

Change Orders by CSI Division and Cause (NERC)					
CSI Division (NERC)	Owner Initited (NERC)	Design Error (NERC)	Unforseen Conditions (NERC)	Value Engineering (NERC)	% Change in Division Contract
1	-	-	-	-	0.00%
2	9.95%	0.21%	1.79%	-	11.95%
3	-	-	-	-	0.00%
4	2.40%	-	-	-	2.40%
5	-	-	-	-	0.00%
6	-	-	-	-	0.00%
7	-	0.59%	-	-	0.59%
8	-	-	-	-	0.00%
9	0.22%	-	-	-	0.22%
10	-	-	-	-	0.00%
11	-	-	-	-	0.00%
12	-	-	-	-	0.00%
13	-	-	-	-	0.00%
14	-	-	-	-	0.00%
15	0.01%	0.26%	-	-	0.27%
16	0.93%	0.48%	0.18%	-	1.59%

NERC vs. SERC

When you compare both projects side by side you can start to see the impact of having used Building Information Modeling (BIM) software (Fig. 2). It is immediately obvious that the overall number of change orders became reduced by about 75% and the reduction in change orders caused by design errors/omissions is at 80%. Even more important is the difference between the changes to the overall cost of the each project (Fig. 3). However, changes due to design errors/omissions were reduced only by 0.36%. Even though that seems like a small number, it amounts to a savings of over $200,000 for a $60 million dollar project.

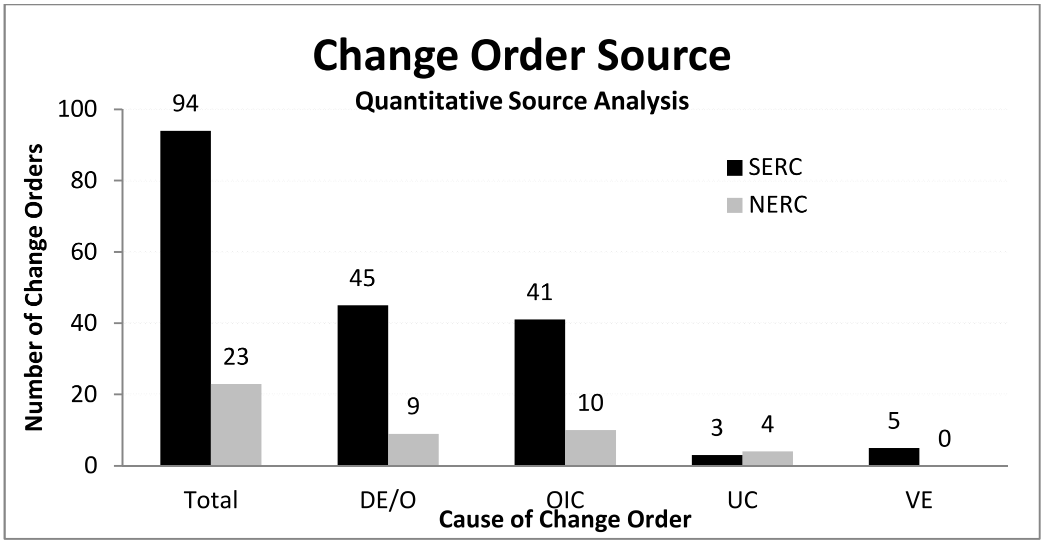

FIGURE 2: CHANGE ORDER SOURCE PER PROJECT

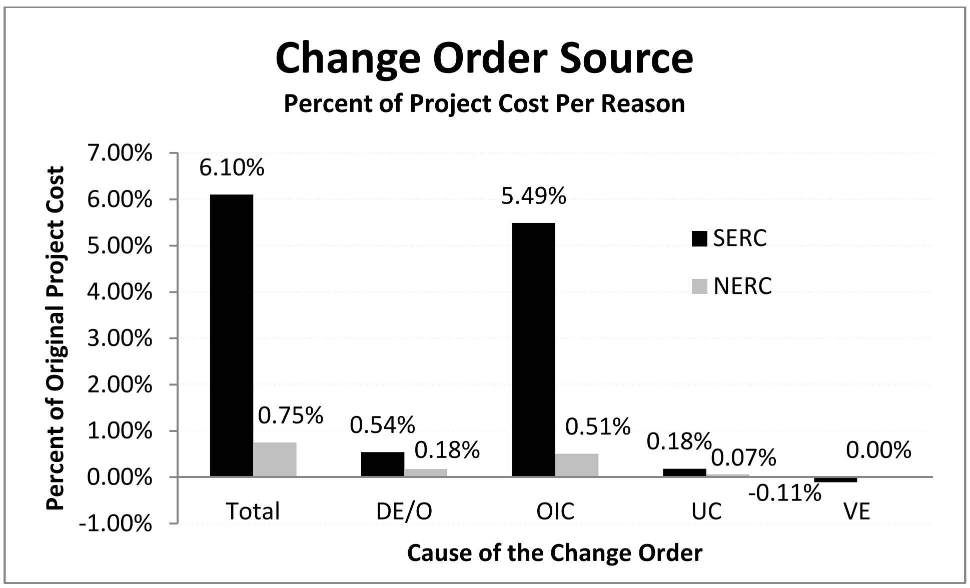

FIGURE 3: PERCENT CHANGE IN PROJECT COST AND SOURCE

When you put the two projects side by side and compare which division the changes come from, it is clear that Division 15 and 16 are not only the cause for the most changes, they are the cause for the most change in the contract price as well (Figs. 4 & 5). Though this is no surprise, it just goes to show the value of BIM, and the ability it has to help out the Mechanical, Electrical, and Plumbing trades through proper coordination. For Division 15 there is a reduction from SERC, $1,566,574.97 (3.29% of the original project cost), to NERC, $56,268.00 (0.10% of the original project cost), that may not seem like a lot percentage wise, but monetarily, it is saving about $1.5 million. Division 16 shows similar results going from $460,383.51 (0.97%) on the SERC project to $121,259.07 (0.21%) on the NERC project. Although the savings are not as drastic as Division 15, it is still over $300,000 in savings. These two divisions alone show a savings of nearly $2 million. Another thing that becomes clear when comparing the projects is a reduction in both the number of occurrences and the percentage change in contract costs in nearly every single division.

It has become apparent that owner-initiated changes are the source for the largest cause for change in both projects, specifically the SERC project. This is somewhat expected due to the fact that the owner mentioned that they are aware of the projected cost of each facility and the actual funds available. Since the SERC project has more funds available they are more willing to make changes on the project that are not necessarily critical. Meanwhile the NERC project is over budget and the University is careful to initiate only changes that are critical for the project's completion. This is seen in the findings, which show the owner-initiated changes increasing the project cost by nearly 5.5% for SERC and only 0.5% for NERC. Another cause for more owner-initiated change in the SERC project is that lab space is more diverse and complex which requires more coordination and planning for specific equipment. In effect, if the equipment changes the whole layout of the room has to change. The NERC project has more general use labs that are simple and require less planning so there are not a lot of changes involving equipment. Division 11, equipment, shows this clearly for SERC where there is a relatively large percentage change in the overall project cost. Conversely, there are no change orders relating to lab equipment in the NERC project.

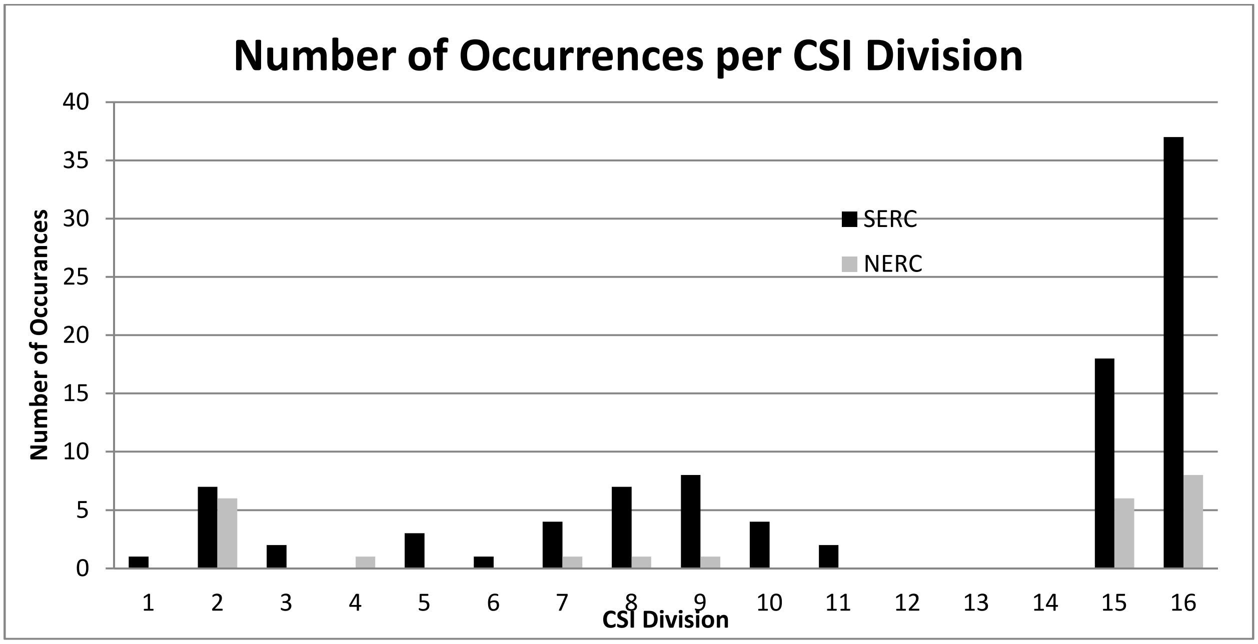

FIGURE 4: NUMBER OF OCCURANCES PER CSI DIVISION

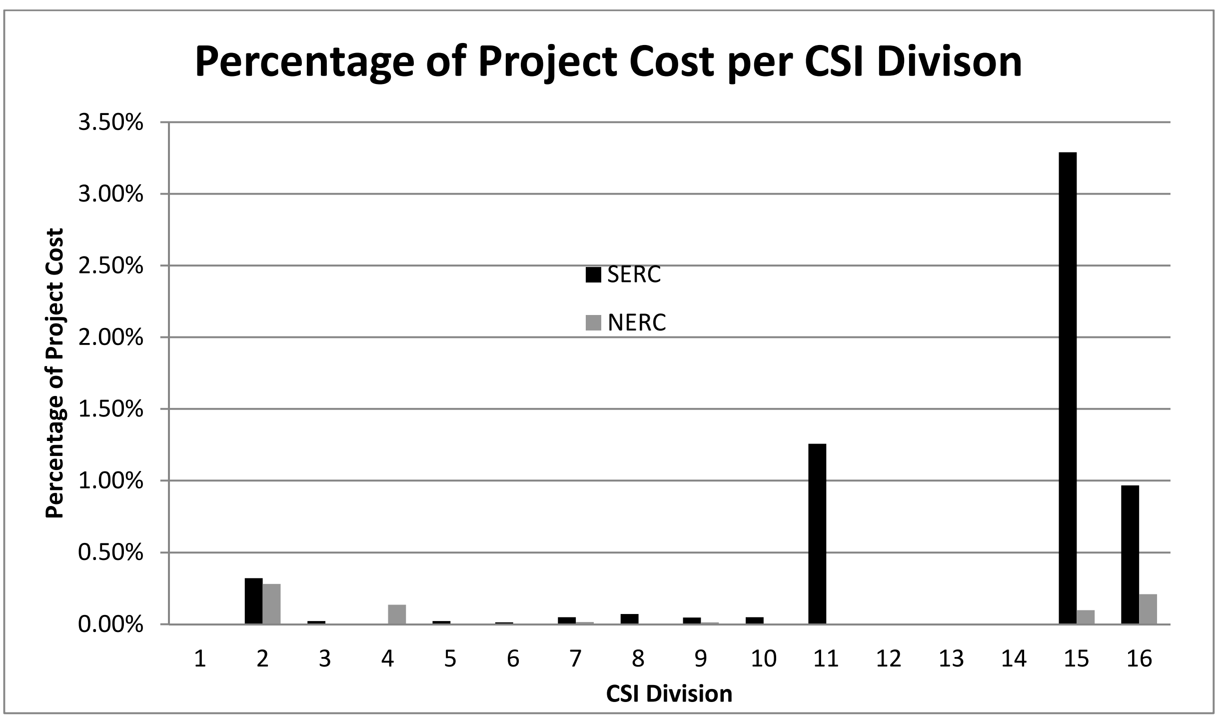

FIGURE 5: PERCENTAGE CHANGE IN PROJECT COST PER CSI DIVISION

A summary of the data can be seen in Figure 6 which compares both projects, the percent change in the contract price, the change order cause, and the CSI Divisions affected. This data again shows that owner initiated change orders were the main cause in the increase of the contract price for both SERC and NERC. It also shows their impact relative to other causes for both projects.

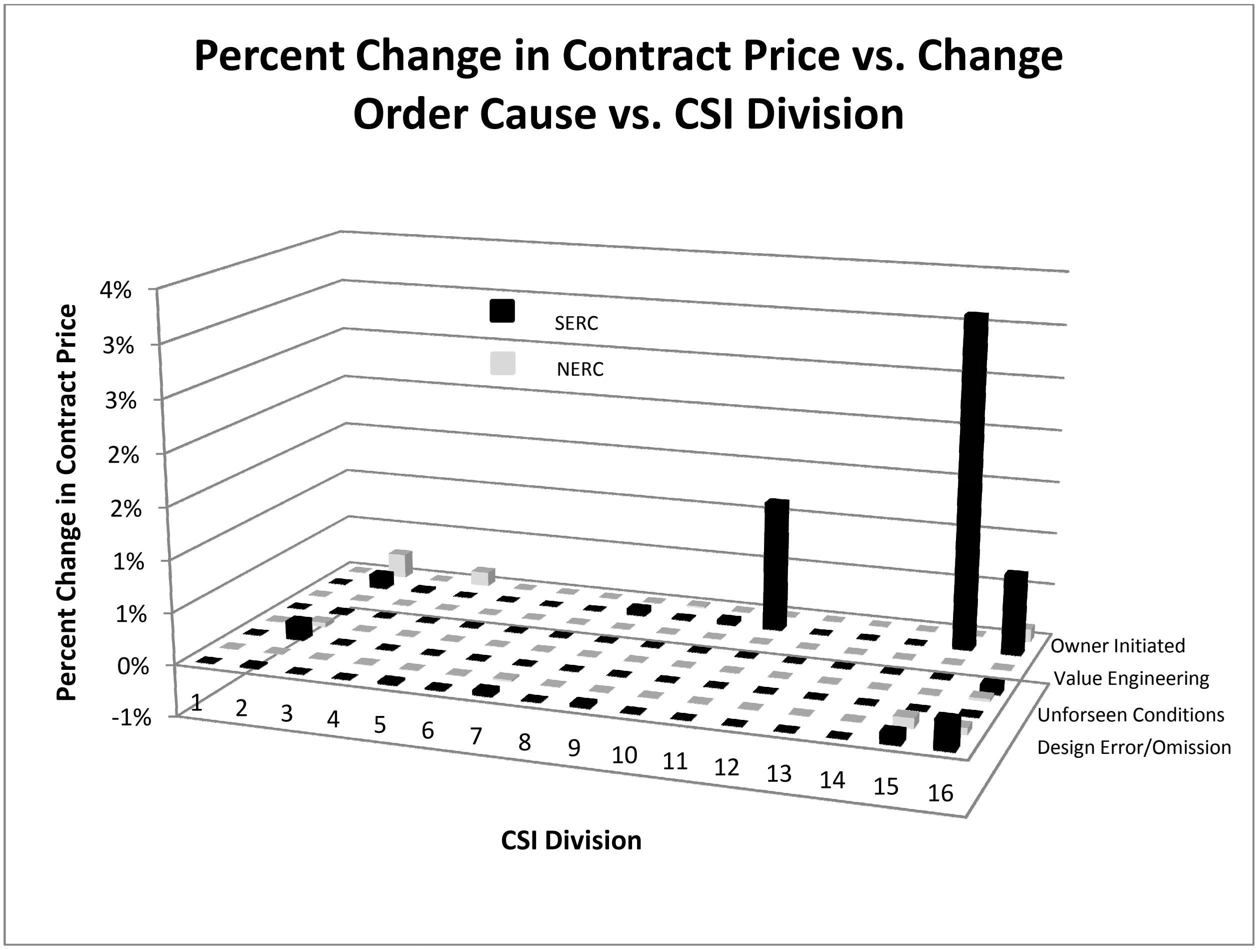

FIGURE 6: PERCENT CHANGE IN CONTRACT PRICE VS. CHANGE ORDER CAUSE VS. CSI DIVISION

A final meeting with the Project Manager, Assistant Vice President of Construction Administration, and Executive Director of Construction Administration took place after all of the data was collected. They were asked to identify which change orders from the SERC project they believe would have been prevented if BIM was implemented on the project. They concluded that approximately 20 change orders could have been prevented. Those 20 change orders accounted for over $150 thousand. Of the 20 change orders that could have been prevented, 80% of them came from Divisions 15 and 16. Also, 75% were due to lack of coordination between trades. They also noted that having the benefit of a 3-D model could have helped to visualize rooms, layouts, and equipment which could possibly prevented even more changes. They also believe that the BIM models could eventually be used to detect when plans and specifications are not in line with University standards which will also reduce change orders in the future.

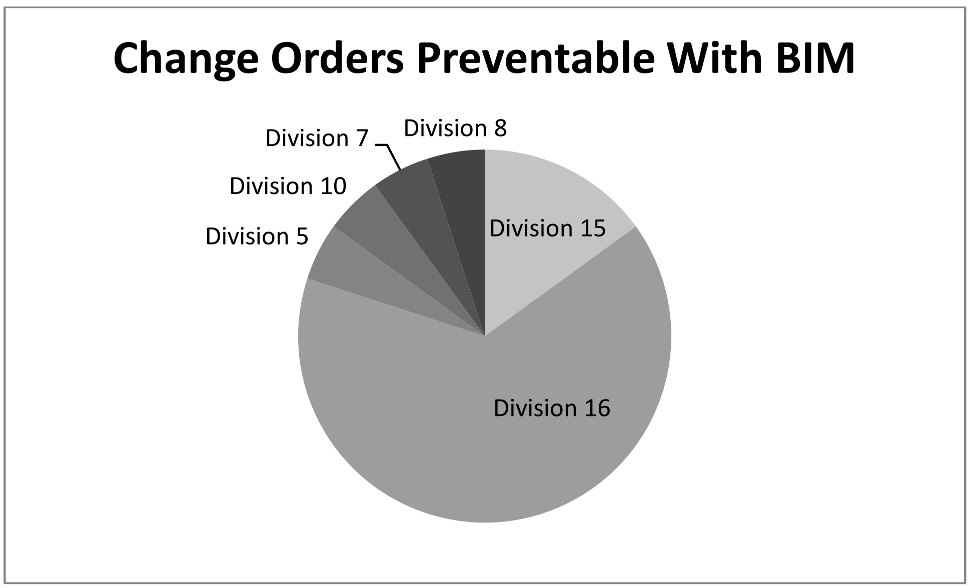

FIGURE 7: PREVENTABLE CHANGE ORDERS DUE TO BIM PER CSI DIVISION

An additional piece of information that was reviewed in order to identify trends is the construction of back to back similar size and scope projects. In 2005 and 2006 The University of Alabama finished construction on Riverside Residential Community and then Lakeside Residential Community. The projects are similar in size. Riverside Residential Community is 377,882 square feet and Lakeside Residential Community is 225,680 square feet. The projects have similar scopes since they are both dormitories. Again in 2007 and 2009 The University of Alabama completed construction on the Ridgecrest North Residential Community and then Ridgecrest South Residential Community. Both of these projects are also dormitories and while Ridgecrest South was slightly larger than Ridgecrest North (345,425 square feet compared to 245,680 square feet) they were similar in size. In 2009 Matt Stone studied the projects for evidence showing improved change order performance. He found that the total number of change orders from Riverside to Lakeside went from 96 to 43, while the total number of change orders from Ridgecrest North to Ridgecrest South went from 61 to 50. Further analysis by Dr. Stone showed that the total number of change orders due to design errors/omissions decreased from 27 on Riverside to 28 on Lakeside and from 16 on Ridgecrest North to 14 on Ridgecrest South (Fig. 8). Even though the numbers stayed relatively the same the change in the percentage cost due to design errors/omissions from Riverside (1.54%), was much higher than Lakeside (0.90%). However, percentage increases in project cost due to design errors/omissions went up from Ridgecrest North, 0.24%, to Ridgecrest South, 0.29% (Fig. 9).

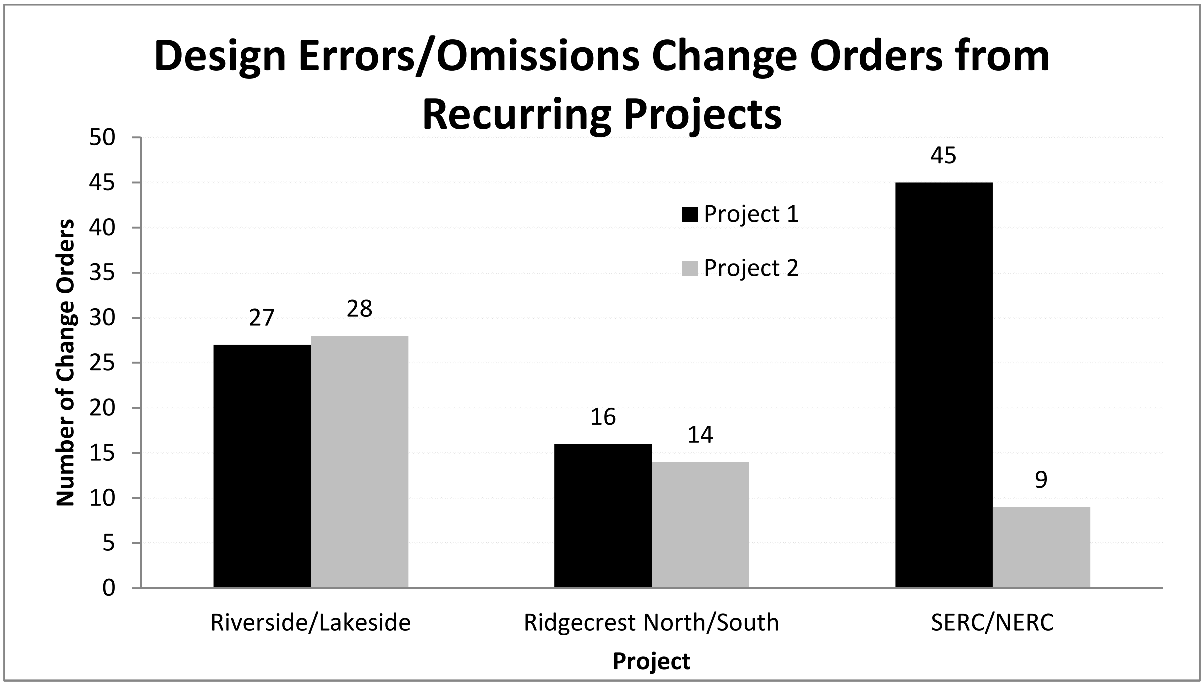

FIGURE 8: DESIGN ERRORS/OMISSIONS CHANGE ORDERS FROM RECURRING PROJECTS

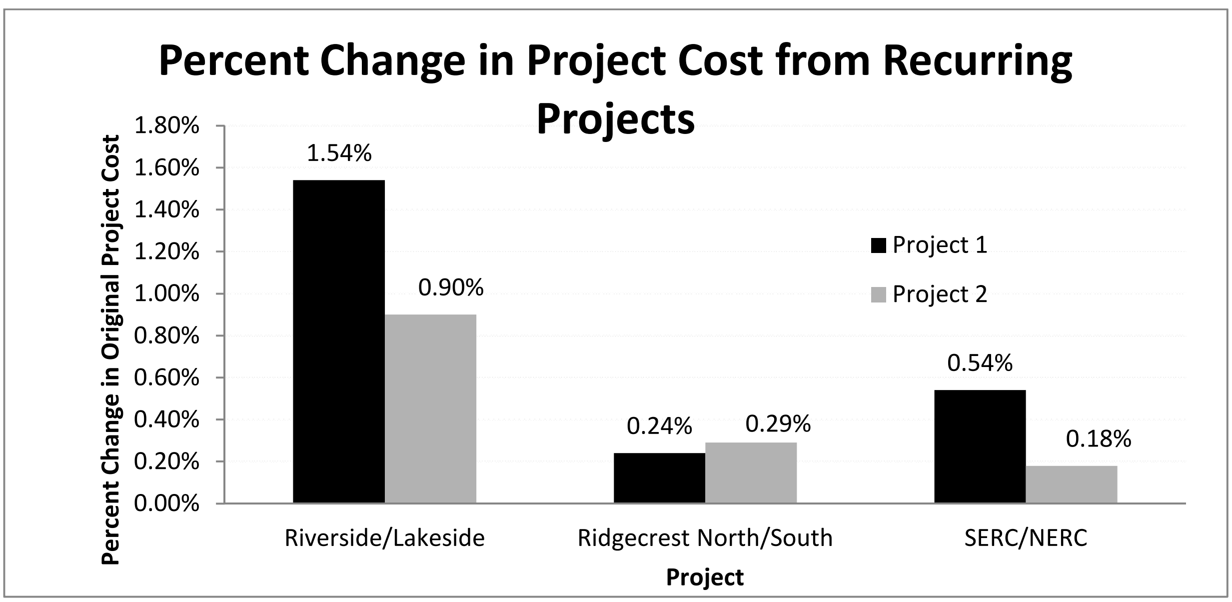

FIGURE 9: PERCENT CHANGE IN PROJECT COST FROM RECURRING PROJECTS

CHAPTER 5

DISCUSSION

With any set of data, false correlations that lead to misconceptions in the data interpretation become a possibility. Although looking at the data and automatically assuming that the change order reductions from the South Engineering Research Center (SERC) to the North Engineering Research Center (NERC) were purely from the implementation of the Building Information Modeling (BIM) software seems accurate, this assumption is false. There are many other factors that have an effect on the number and cause of change orders on any project.

Also, as discussed previously there is a correlation between the fact that SERC came in under budget and NERC came in over budget. The fact that the owner has more funds to use at their disposal means they are more inclined to actually use them on change orders. This shows up in the data where there is nearly a 5.5% increase in the SERC project cost due to owner-initiated changes, but there is only a 0.5% change in the NERC project cost due to owner-initiated changes. Although this has an impact on the total number of change orders, it really has little effect on change orders caused by design errors/omissions, which is what BIM has the most impact on. Even though this will have an effect on the results, it does not affect the correlation between BIM's influence on change orders.

The fact that these are two similar projects built back to back by the same designers and project team was the first factor investigated. According to the finding of Matt Stone in 2009 there is typically a drop off in the total number of change orders when using similar designers and project teams, however, none of the projects Dr. Stone studied showed the degree of improvement that the SERC and NERC projects experienced (Stone et al. 2011). Also, the number of change orders due to design errors/omissions stayed roughly the same from project to project, but the percentage in project costs went down from Riverside (1.54%) to Lakeside (0.90%), while they slightly increased from Ridgecrest North (0.24%) to Ridgecrest South (0.29%). This could ultimately be due to the fact that from Riverside to Lakeside they used the same Architect and Engineers, while from Ridgecrest North to Ridgecrest South there is a change in the structural, electrical, and civil engineer as well as contractor (Stone et al. 2011). The SERC and NERC projects followed the same pattern as Riverside and Lakeside and used the same design team with the only difference being that SERC used a different architect than NERC. So the fact that they used the same design team and saw a decrease in the changes due to design errors/omissions indicates a correlation. The best results are observed when the same design team is maintained along with the implementation of BIM software. Not only does it produce the most dramatic drop in the number of change orders caused by design errors/omissions, but also results in the fewest amount of change orders due to errors/omissions on any project analyzed for this study. Similar results show up in the percent change in project costs due to change orders caused by design errors/omissions. In order to achieve optimal results the researchers found that the project team must: document changes carefully, study them and implement the results, keep the same team, and use BIM.

In order to identify what factors have an impact on change orders, six engineers who were members of the design team of both SERC and NERC were interviewed in order to determine what they believe had the most significant impact on change orders. During each interview the designer is asked to assess the level of impact each factor has on the reduction of change orders going from SERC to NERC on a scale of 0 to 10 with a score of 0 meaning it had no impact and a score of 10 meaning it had an extremely significant impact. Their scores are averaged together in order to obtain a summary of the data and to minimize the impact of outliers from biased opinions. Once they give their score they are asked to provide reasoning for their score. A summary of their responses is seen in Table 10. The data collected from the designers on the perceived impacts of each factor lines up with the data that was collected in that the areas which have the highest impact involve mechanical, electrical, and plumbing complexity, specialty equipment, available project funds vs. actual project cost, and the implementation of BIM.

TABLE 10: INTERVIEW RESULTS

Factor	Impact (0-10)	Reason
Planning/design time frame	0	Both were Similar
Complexity of Mechanical, Electrical and Plumbing	7	SERC had more specialized/unique equipment.
Front End Planning	1	NERC had slightly higher level of front end planning.
Design Review	3.25	NERC had slightly higher level of design review.
Available project funds vs. Actual project cost	8	SERC had more funds to spend.
Project Schedule	0	Both projects were subject to similar schedule restrictions
Coordination between trades	6.25	NERC had a higher level of coordination.
Contract Type	0	Both projects were subject to similar contract types.
Specialty equipment	8.25	SERC had more specialized/unique equipment.
Lessons Learned review process	4.75	NERC had a more extensive lessons learned review.
Effect of BIM	6.75	NERC used BIM in an effective way
Contractor Competency	0	Little to no effect.
Project Location	0	Both projects were located within 100 yards of each other
Climate	0	Both projects were in similar climate conditions

Summary of Discussion

- There are multiple factors that affect the reduction of change orders.
- Available project funds vs. Actual project cost plays a significant role in the amount of change orders, however, it more directly affects the amount of owner initiated change orders.

- Using the same design team on consecutive similar projects has a large impact on the design review and lessons learned process which directly impacts the amount of change orders on a project.
- BIM is not the only factor in reducing change orders but it does play a role, specifically in change orders due to design errors/omission.

Although it may be difficult to quantify exactly what kind of impact these factors have, they assuredly do have an impact and must be taken into consideration when interpreting this data. Further research is needed in order to quantify and analyze exactly what type of effect these factors have on University projects. Once all the factors are taken into consideration, a more accurate picture of the effect BIM has on change orders will take shape.

CHAPTER 6

RECOMMENDATIONS

With the goal in mind of reducing change orders, it is imperative to have some sort of change order prevention program in place. The University of Alabama already has this program in place and the proof is in the results. While most Universities experience an increase in the contract prices of a project around 5-10% the two projects studied at The University of Alabama averaged just over 3% (Mrozowski et al. 2004). Even though this is an admirable number, there is room for improvement. The use of Building Information Modeling (BIM) on the North Engineering Research Center (NERC) shows up specifically in Divisions 15 and 16 where the design errors/omissions were reduced substantially. BIM's impact on Division 15 and 16 is made even more obvious when the project team reviewed the data from the South Engineering Research Center (SERC). They discovered that the use of BIM would have saved over $150,000 through eliminating 20 change orders; 80% of those coming from Divisions 15 and 16. With results like this it will be tempting to become more reliant on BIM to catch any and all design errors/omissions; however the University must maintain a proactive approach to change order prevention. First, they need to place great value on the data collected from change orders in order to learn and improve from them. Secondly, they need to maintain and update regularly the checklist that is used in the design review process. Finally, the Construction Administration personnel need to continue to acquire information from their lessons learned program so they can implement the knowledge on all projects.

In order to identify the cause of the change, a way to record the reason for the change is necessary. It is the University's intent that the Reason for Corrective Action (RCA) be put into the Change Order Request Approval Form (CORAF). Unfortunately, the majority of the time, the RCA is left off of the CORAF form which results in sometimes being written in later by hand. It is recommended that a data field be placed on the CORAF form that requires the input of the RCA so that more useful data can be collected for lessons-learned reviews. This will allow a higher quality of data to be collected, and problem areas will become easier to recognize. This will also aide in the updating of the preventative checklists that are used in the design review process.

During the design review process it is essential that the reviewers identify areas that are a common cause for change orders and review the contract documents in order to prevent them from showing up on additional projects. The current checklist that is in use is good, but needs to be updated, and more than likely it will need to be updated again and again. The construction process is dynamic. The design review process needs to be able to adapt in order to continue to highlight items that could cause potential problems. As a result of this study the checklist is updated in a way that should help the design reviewers catch items that the BIM software might miss. For example, is there proper conduit in place for wiring of special equipment? Is there the proper amount of fire extinguishers in labs? The updated check list can be found in Appendix A.

Having a proactive change order management program is critical. BIM is a great tool when used correctly, but if used incorrectly it can add little value. It is critical for the project team to review the previous lessons learned from similar projects in order to avoid those mistakes in the future. The project team must make a deliberate attempt to review past change orders and the reasons for the change orders in order to learn from them and prevent them from happening in the future. Having the same project team going from SERC to NERC played a critical role in reducing the cost of change orders because they were able to review the change orders from SERC through a lessons learned process and apply what they learned in the design phase of NERC. This needs to be a high priority for anyone who is constructing a project that has the resources to look back at similar projects.

Summary of Recommendations

- Acquire accurate and detailed information that can be reviewed during the lessons-learned process. Adding a section labeled “Reason for Corrective Action” to the Change Order Request Application Form may help this.
- Maintain and update regularly the checklist that is used in the design review process in order to catch things that the Building Information Modeling may miss.
- Study and implement the conclusions from previous lessons-learned meetings. Review previous and similar projects in order to acquire more applicable information.

With the benefits of BIM helping to drastically reduce the cost of change orders and the recommendations that have stemmed from this research, the authors expect the number and cost due to errors/omissions will continue to decrease. Obviously, it will be nearly impossible to eliminate change orders altogether, but to see a continued reduction is not unachievable. If the University Construction Administration continues to strive for excellence and predictability they will continue to see positive results, but they must maintain their proactive approach and never be complacent with the results they already achieved.

CHAPTER 7

CONCLUSIONS

The University of Alabama's Construction Administration has made great strides in the past few years in its change order management and prevention. The original goal of the Construction Administration was to reduce the cost of preventable change orders; however, it is now feasible to believe that soon preventable change orders due to design errors/omissions will not exist. Even that might have seemed like a somewhat lofty goal for large capital projects until recently. The introduction of Building Information Modeling (BIM) will allow a design review and coordination effort that was never possible with the traditional 2-Dimensional modeling. Even though it has only recently been introduced in The University of Alabama Construction Administration office, the program already impacts many areas. This is such a unique occasion to have the opportunity to analyze two projects that are similar in size, cost, and type while one was designed and built in the traditional sense and the other was designed and built using BIM. With the South Engineering Research Center (SERC) incurring 94 change orders and the North Engineering Research Center (NERC) only encountering 23, it is easy to see that even though these two projects are very similar, something is very different. While it was determined that BIM was not the sole reason for the reduction in change orders it did have a significant impact on reducing the amount of change orders due to design errors/omissions from 45 on the SERC project to only nine for the NERC project.

Summary of Conclusion

- The implementation of BIM will prevent additional change orders design review and lessons-learned typically miss.
- The most substantial change order reduction was found when BIM was implemented on a project.
- There is still a need for a strict design review and lessons-learned process to catch issues that BIM may miss.
- The research has shown that the implementation of The University of Alabama's change order management and prevention plan as proven to be successful. Their decrease in change orders over the course of back to back projects shows their lessons-learned process is producing positive results.

Going forward from this point it is vital that the University continues to seek to improve its data collection from lessons learned. This will allow them to continue to improve upon their change order management and prevention plan so that it may adapt and compensate for the areas that are lacking from the BIM software. It might become necessary for the University to conduct further research once more projects are completed using the BIM software to further confirm the findings of this study. Although having the opportunity to study these two projects is one of a kind, only analyzing two projects does not accurately quantify the true impact of BIM. This research hopefully lays the groundwork for further research on the continuous improvement of the change order management and prevention at The University of Alabama.

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APPENDIX

Design Review Checklist (Research/Classroom Facilites)

	Division 2: Site Construction	
Utilities:	Are utility line locations on drawings accurate and up to date?	________
	Are utilities adequate to support any building package alternates?	________
	Are the utility meters in an acceptable location?	________
	Will the utilities be able to support any new construction in the near future?	________
Earthwork:	Is grade adequate for any alternate building packages or additions?	________
	Will grade effect any shoring requirements?	________
Storm drainage and	Are storm inlets in the right locations?	________
Containment:	Is the storm sewer system adequate?	________
	Are additional inlets or catch basins necessary to handle excessive run-off?	________
Site Amenities:	Is there enough fencing?	________
	Is the proposed fencing in the right location?	________
	Does the fencing match existing?	________
	Are there enough sidewalks and are they in the right location?	________
	Will the construction entrance need to be relocated at any time during the project?	________
Pavements:	Will designed pavement support campus public transportation?	________
	Are the temporary construction entrances accessible and safe?	________
Landscaping:	Is the landscaping scope well-defined?	________
	Does landscaping meet University standards and matach surrounding buildings?	________
	Are irrigation lines in the right locations?	________
	Division 3: Concrete	
General:	Are there any missing concrete structural elements?	________
	Have all changes made by addenda been incorporated into the plans and specifications?	________
	Are there enough control joints and are they in the right locations?	________
	Is location, size, and quantity of concrete reinforcement adequate?	________
	Division 4: Masonry	
General:	Does brick/concrete/stone masonry comply with University Standards?	________
	Is there any recently demo'd brick that could be reused?	________
	Are there enough control joints and are they in the right locations?	________
	Are the weep holes in the proper locations?	________
	Divison 5 Metals	
General:	Are there any missing steel structural elements?	________
	Is framing adequate for trash chutes and other similar amenities?	________
	Division 6: Woods and plastics	
General:	Is wood moldings shown in all units?	________
	Is wood molding consistant throughout?	________

Division 7: Thermal and Moisture Protection

Waterproofing:	Are the following elements waterproofed?		________
		Foundations	________
		Tie-Back Wall	________
		Below Grade Walls	________
		Brick and Cast Stone	________
		Elevator Pit	________
		Windows and Doors	________
		Labs	________
Roof:	Is roof pitch acceptable?		________
	Are roof shingle types compliant with University standards?		

Division 8: Doors and Windows

General:	Are kick plates needed.	________
	Are door closers in line with egress plan?	
	Are the door contacts at appropriate door locations?	

Division 9: Finishes

Ceilings:	Is ceiling type and location adequate?	________
Carpet:	Is carpet shown in the right location?	________
	Is the carpet type appropriate for a given area?	

Division 10: Specialties

General:	Are there ADA grab bars in all public bathrooms?	________
	Will fire extinguishers be provided in labs?	

Division 11: Equipment

General:	Is the type and quantity of appliances shown correctly?	________
	Will lab equipment fit through openings?	

Division 12: Furnishings

General:	Are room furniture layouts provided?	________
	Are data and electrical outlets coordinated with furniture?	

Division 13: Special Construction

Lightning Protection:	Is lightning protection shown for all buildings?	________
Fire Protection:	Are ceiling mounted smoke detectors shown in all appropriate locations?	________
	Is there a fire alarm and smoke detector at ever elevator location?	________
	Is the fittings and bracing appropriate for the fire lines?	

Division 14: Elevator

General:	Are standard equipment and finishes shown for elevators?

Division 15: Mechanical

General:	Are the mechanical plans coordinated with other trades?	________
Plumbing:	Is there adequate downspout drainage piping?	________
	Is fire department standpipe in an accessible location?	________
	Do floor drains and trap primers meet code requirements?	________
HVAC:	Is A/C provided in elevator equipment rooms?	________
	Are Emergency remote boiler shutdown switches shown?	

Division 16: Electrical

General:	Are the electrical plans coordinated with other trades?		________
Lighting:	Are light fixtures consistent on similar rooms on different floors?		________
Wiring:	Is there power supplied to these elements:		________
		Fire Alarm Annuciator Panels	________
		Appliances	________
		A/C units	________
		Duct Heaters	________
		Security Systems	________
		Hand Dryers in Restrooms	________
		Water Fountains:	________
		AEDs	________
		Rolling Doors	________
Communications:	Is conduit provided for telecommunications?		________
	Is there sufficient data outlets in all rooms?		________