

PROJECT TIME AND COST CONTROL USING BUILDING INFORMATION
MODELING

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ABSTRACT

Although the construction industry has been evolving for centuries and researchers have been seeking innovative solutions for decades, diverse challenges still exist for making the construction process faster, safer, cheaper, and more accurate. However, it is now believed that Building Information Modeling (BIM) can lead to greater efficiency through the incremental collaboration. The data in BIM system are extremely useful and can be generated to optimize the project delivery processes. Because BIM increases the design cost and requires a big learning curve, project participants are all concerned about the project cost, hindering the adoption of BIM for the project delivery.

This thesis, using a case study, describes how BIM functions to help cut costs, optimize the schedule, and benefit all project participants. The analysis of project cost and time control focuses on the life cycle. The recommendations for the future use of BIM are made generally.

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TABLE OF CONTENTS

ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES.....	viii
LIST OF FIGURES	ix
LIST OF ACRONYMS	x
1. INTRODUCTION	1
1.1. Project Management	2
1.2. Project Time Control	3
1.3. Project Cost Control.....	4
1.4. Evolution of Computer-Aided Design and Construction	5
1.4.1. From 2D to 3D.....	5
1.4.2. 4D.....	6
2. BACKGROUND	8
2.1. Concept of BIM	8
2.2. Applications of BIM in Project Management.....	9
2.3. BIM Tools.....	11
3. PROBLEM STATEMENT.....	12
3.1. Low Productivity	12

3.2. Construction Rework	13
3.3. Design Process	13
3.4. Complicated Scheduling and Cost-Control Work	14
3.5. Demanded Solutions	15
4. RESEARCH METHODOLOGY	17
4.1. Research Methodology	17
4.2. Thesis Organization	18
5. CASE STUDY AND DISCUSSION.....	19
5.1. Project Overview	19
5.2. Model Analysis and Discussion.....	21
5.2.1. BIM Process.....	21
5.2.2. Real-Time Access Design.....	21
5.2.3. 3D Visualization	23
5.2.4. Information Integration.....	28
5.2.5. Communication and Workflow	33
5.3. Model-Based Cost Estimating	35
5.4. Optimization of Time Schedule.....	36
5.5. Major Challenges and Corresponding Solutions	40
5.5.1. Learning Curve	40
5.5.2. Access/Update Coordination	41

5.5.3. Database Maintenance	41
5.5.4. Prefabrication.....	42
6. SUMMARY AND CONCLUSION	44
7. LIMITATIONS AND FUTURE WORK	46
REFERENCES	47
APPENDIX A. MODEL SNAPSHOTS AND SHEET INDEX	51
APPENDIX B. COLUMN MATERIAL TAKEOFFS.....	63
APPENDIX C. WALL SCHEDULE	65

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. BIM Software	11
2. Project Information Overview	20

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Construction and Non-Farm Labor Productivity Index, 1964-2003.	12
2. View of the Retail Center.	20
3. BIM Process.....	22
4. Wall Example.	23
5. Scheels Retail Center-3D View.	24
6. Scheels Retail Center: East View.	25
7. Scheels Retail Center: North View.....	25
8. Scheels Retail Center: Top View.....	26
9. BIM Process vs. Traditional Process.	27
10. Define a Door in Revit.....	29
11. Door Properties in Revit.	30
12. Properties of a Bolt in Revit.	30
13. Main Floor Plan.	31
14. Part of Column Material Takeoffs.	32
15. Wall Material Takeoff Drawing Sheet.....	32
16. Relationships Based on BIM.	34
17. Wall Material Takeoffs in Microsoft Excel.....	36
18. Dialog of Creating a New View in Revit.....	38
19. Dialog of Creating a New Schedule View in Revit.	38
20. Dialog of Schedule Properties in Revit.....	39
21. Part of Wall Schedule.	39

LIST OF ACRONYMS

2D.....	Two Dimensional
3D.....	Three Dimensional
4D.....	Four Dimensional
AEC.....	Architecture, Engineering and Construction
BIM.....	Building Information Modeling
CAD.....	Computer-Aided Design
CII.....	Construction Industry Institute
CPM.....	Critical Path Method
CURT.....	Construction Users Roundtable
FTP.....	File Transfer Protocol
GC.....	General Contractor
GDP.....	Gross Domestic Product
IT.....	Information Technology
LEED.....	Leadership in Energy and Environmental Design
MEP.....	Mechanical, Electrical, and Plumbing
NIBMS.....	National Building Information Model Standard
ODBC.....	Open Database Connectivity
PM.....	Project Management
QA/QC.....	Quality Assurance/Quality Control
RFI.....	Request for Information

1. INTRODUCTION

The architecture, engineering and construction (AEC) industry is the largest industry in the United States and is even one of the largest in the world accounting for one-tenth of the world's gross domestic product (GDP) (Murie, 2007). It is also known as a low-tech and low-efficiency industry (Gallaher, O'Connor, Dettbarn, & Gilday, 2004). It is common that a business can keep running because it makes profits; there is no exception in the AEC industry. One purpose for people delivering construction projects is to achieve economic targets, but there is nothing to guarantee that a profit is going to be made. Project-based businesses have to go through a variety of challenges in order to survive. While these challenges vary for the diverse projects involved, all endeavors strive to complete the projects within time and budget. In the history of construction, numerous large construction projects have been plagued by cost overruns and schedule delays. A comprehensive study of cost overrun reported that almost 90% of public-work projects had problems with cost overruns (Flyvbjerg, Holm, & Buhl, 2002).

According to Baccarini, a successful project should meet not only the quality output standards, but also time and budget objectives (Baccarini, 1999). Westhuizen also stated that "within time", "within budget" and "according to requirements" are three main objectives to complete a project successfully (van der Westhuizen & Fitzgerald, 2005). The main barriers to overcome are the uncertainties in the project environment. Project management such as, planning, scheduling, and estimating, is believed to be an effective approach to forecast the contingencies, which, furthermore, can improve project and company profitability.

1.1. Project Management

Project management, as defined in Wikipedia, “is the discipline of planning, organizing, securing, managing, leading, and controlling resources to achieve specific goals” (Wikipedia). Its function is to assure the accomplishment of project objectives, in other words, to assure project profits (Nielsen, 2006). The purpose of project management is to predict as many dangers and problems as possible to insure a successful project (Lock, 2004). According to R.A. Yamin and D.J. Harmelink, to accurately plan, predict and control the construction process is critical for the successful project management (Harmelink & Yamin, 2001). They also recommended that schedules should always be used by project managers (PM) to perform their work.

Time, cost and quality are the three elements that are considered in the process of project management. In fact, they are not separate elements, but are tightly connected. When estimating the cost of a given project, the standards of quality and time required to complete it have to be considered. Likewise, to pursue a high level of quality, a certain amount of time and cost have to be contributed. In this thesis, the research focuses on time and cost.

Time and cost management for a construction project have been the most important issues since the advent of the construction industry. Various factors are involved in the uncertainty of project development. Many efforts have been made to integrate schedule and cost in construction projects, leading to the development of various integration methods and models in several studies. The following sections include a literature search and discuss related areas for a project’s time and cost control.

1.2. Project Time Control

Time for the performance of a construction project is usually a particularly important consideration for the parties involved. However, it is very common that projects are seldom completed on time (Nassar, Gunnarsson, & Hegab, 2005). To minimize the disparity between the real practice and the original plan, a lot of researchers are dedicated to search for solutions. Currently, a number of tools regarding time control exist, some of which differ for their functions, and some of which are only designed for certain projects (Harmelink & Yamin, 2001). Researchers are still looking for a more integrated tool to unify the standards

Critical path method (CPM) networks and bar charts are two basic approaches used to lay out the project schedules. The CPM schedule is mainly used from the beginning of the planning phase to the end of the project. It shows the logical relationships between project activities in the form of network diagrams, which can give the user a conceptual idea about how to carry out the project. However, Nassar, Gunnarsson, and Hegab (2005) pointed out that the CPM scheduling is still lacking realistic expectation regarding actual performance. Kim and de la Garza (2003) also stated the reason that CPM overlooks the limitation of resources in practice. Koo and Fischer (2000) associated the drawings with the related activities for presenting the schedules, which showed the importance of using two-dimensional (2D) drawings when planning.

Therefore, as more information is considered when planning, the more closely the plan will be to actual practice. The theory is true, but it will lead to another challenge: how to put all the information together. Although a lot of tools are used in traditional processes, no one can carry all the information. Furthermore, linkage between tools can be another

issue, which sometimes may become the communication barrier because many parties are involved with a project.

1.3. Project Cost Control

Proper cost control is also a vital ingredient for a successful project. The first step of cost control is to identify the factors that affect project costs. The existing factors can be divided into two major categories: quantitative factors and qualitative factors. Currently, the AEC industry researchers have given many efforts to develop techniques that only consider quantitative factors and ignore qualitative factors such as “client priority on construction time, contractor’s planning capability, procurement methods and market conditions including level of construction activity” (Elchaig, Boussabinaine, & Ballal, 2005, page 539-540).

Due to a great number of factors that need to be considered, it is difficult to predict the exact cost to complete construction projects (Gould, 2004). It is common to see that the final project cost is higher than the budgeted cost. It was reported that a cost overrun is one of the main problems in the AEC industry (Reina & Angelo, 2002). Peeters and Madauss (2008) stated the biggest cause of cost overruns is inaccurate estimation at the beginning of a project.

An estimate is a general evaluation of the future project cost, and the budget represents the amount of money that the stakeholders would like to invest. The more accurate the estimate is, the closer the budget is to the actual cost, which means the profit is closer to what the project participants expect.

1.4. Evolution of Computer-Aided Design and Construction

1.4.1. From 2D to 3D

Currently, the AEC industry is facing enormous technical and institutional transformations with their resulting difficulties and challenges. One very important instrument to such change is the use of information technology and the application of sustainable practices. The advanced technology has simplified the project delivery in many ways: computerized design, electronic communication networks, electrical project documentation, etc. Productivity has been highly improved compared to the past.

A 2D CAD approach, such as AutoCAD, has been adopted as the main design tool in the AEC industry. Designing on paper drawings is really complicated and requires the high-level skills of drafters. Because the CAD age is taking over, there are no such requirements for hand drawings any more, and the revision of work also becomes much easier. With the introduction of innovative and more efficient construction techniques, equipment, materials, management initiatives, and project delivery methods (Pena-Mora & Park, 2001), the AEC industry has improved remarkably over the last few decades. Meanwhile, more complex construction projects become possible.

However, CAD is only for electronic drafting, and the lack of diverse information has limited its development. Most people involved with construction projects believe that the only use of 2D instructions is an imperfect method of planning and managing complex projects. With traditional processes, projects are mainly managed based on the drawings, plans and specifications. These resources provide the layout of building components and the scope of construction activities (Benjaoran & Bhokha, 2009). Then, PMs have to mentally generate 3D building models from these 2D resources and to associate these 3D

building models with construction schedules. In this process, people use 2D information to communicate, and the 2D information helps form 3D visualizations in each person's mind which is his own understanding of the information. Then every time the information moves between individuals, it requires a 2D-to-3D translation, until the information finally needs to be visualized correctly by the person who constructs the project. These steps may allow oversights and errors to go undetected until it is too late to address them effectively.

1.4.2. 4D

Most people in construction believe that only using 2D instructions is an imperfect method for planning and managing complex projects. Thus, it requires the project manager to have a strong background and a long time of spatial-time analysis to redraw the construction process in his mind. This high requirement has become an obstacle for understanding and controlling construction schedules. However, it is important to ensure that all project participants involved to exactly understand the entire process and schedules in an accurate and timely way.

In such cases, an integrated model is needed. The model should be able to facilitate efficient planning by integrating the schedule and cost, and easily control both schedule and cost. The emergence of 3D CAD software simplifies the use of 3D graphical models in construction projects, which can directly provide a project visualization before it is constructed. These models are used to resolve constructability problems, conduct interference problems, and to perform scheduling and hazard analysis. Koo and Fischer (2000) linked a 3D model to a schedule to create a 4D model, which showed great usefulness for interference analysis and space conflict identification. The 4D models can not only represent the project in a 3D CAD environment, but can also connect the objects of models

with their corresponding schedule. It is like watching a manual made in a movie for building a house. Chau, Anson, and DeSaram (2005) also successfully developed a 4D model for site utilization to demonstrate its impact on efficiency. However, this concept of 4D modeling has just begun, and it still needs more research to identify its potential value, and more practical use to testify its application.

2. BACKGROUND

This chapter discusses the concept of Building Information Modeling (BIM), and its functions and role are introduced. Current BIM software is also discussed mainly focusing on the project-management needs.

2.1. Concept of BIM

Referring to the National Building Information Model Standard (NBIMS), BIM is defined as “a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward” (Smith & Edgar, 2009). Thus, BIM is a concept for a series of techniques that enable the process and practice of virtual design and construction through the project life cycle.

BIM is primarily a three dimensional (3D) digital representation of a building. The model consists of 3D animation of actual building components, which also carry the projection information including the physical location of components, materials, manufacturers, structures’ fire rating, etc. From the first element put into the model, the properties are well defined and will always stay in the model. In addition, the models also form a platform for project participants to share knowledge and to communicate. The process of BIM is to develop models involving information management.

This new technology has been implemented by AEC firms because the productivity gains and long-term benefits compared to existing practices are evident. BIM technology is taking the architecture and design industry by storm. As early as 2005, design programs across the globe began to investigate BIM, and many decided to add this event to their

curriculum. In 2007, it was reported that the number of licensed seats of AutoDesk Revit had grown from 100,000 to 200,000 worldwide (AutoDesk Press Releases Archive, 2007). The development of technology has promoted the evolution of the AEC industry, but whether new techniques can satisfy the industry's desire still requires further proofs. Of course, as more people learn about BIM, this number will keep growing faster, which indicates that the AEC industry is firmly heading in the BIM direction.

Experience shows that there are many questions that need to be answered before BIM could be implemented for a project. What is the purpose of using BIM? What type of relevant information is required in the model to provide value to each project participant? Who is going to develop, update, and maintain the BIM? Does the modeler have enough expertise to update the work? How many models will there be? Are these models going to be interoperable? How is the BIM going to be shared? What BIM tools are going to be used? Is the contract language conducive to the use of BIM in the project? Although the concept of BIM is already accepted in the construction field, its application and potential value need much more research.

2.2. Applications of BIM in Project Management

BIM is not a kind of software, but is a new concept which can improve the quality and efficiency of every link in the AEC industry chain. Lately, practitioners are embracing new modes of interdisciplinary information sharing and are focusing on one emerging and fast growing concept: BIM. Because BIM enables users to have an overview of the physical and functional characteristics of a building from 3D visualization and allows information to be shared among the designers, architects, engineers, contractors, subcontractors, and others, the BIM use can benefit all the stakeholders involved with the

design, construction, ownership, and operation of buildings all through the project life cycle. In this section, the main BIM functions for project time and cost control is introduced, and the application is explained. BIM is a great visualization tool. It provides three-dimensional virtual representations of the building. During the project's bidding phase of the project, the construction manager can provide renderings, walkthroughs, and sequencing of the model to better communicate the BIM concept in a 3D format.

Visualization provides a detailed outlook of the final product. By working on the same model, users can have a common understanding of the project. It takes away the thought process of bringing the different traditional 2D views together to create the 3D view. BIM techniques simplify the preparation of mock-ups, such as building envelopes or building components. Virtual mock-ups can be provided to the designer and the owner during project meetings. The virtual mock-ups enhance the process of communication and collaboration. The developers can use them to visualize, understand, and make decisions on the aesthetics and the functionality of the space. The utility of mock-ups also promotes planning and sequencing construction activities based on model components.

Virtual mock-ups are cost efficient in comparison to physical ones. By creating 3D virtual mock-ups of complex building components, such as curtain walls, the architects can quickly make decisions on design alternatives. The virtual mock-ups enable the architects to work with contractors on constructability analysis, which reduces risk, saves time, and solves potential design issues in advance of construction. Physical mock-ups may not be fully replaced because they are still required if the members need physical testing. Hence, virtual mock-ups could become a good standard to initiate the mock-up process and an actual mock-up may be necessary after the virtual mock-up is approved.

2.3. BIM Tools

As the BIM concept spreads, a great number of tools are developed to achieve its perspectives. These tools vary depending on the end user, the use purpose, and the construction stage at which they are used. Table 1 shows the main BIM software used for construction management. Some of these software is designed to collect as much information as possible, while others are developed for special purpose depending on the user's needs. However, adopting BIM techniques involves much more than simply switching to its supporting software. The basic function of BIM is to enable 3D modeling and information management. Supporting by the software, BIM will lead to a unified system consisting of all interacting parts.

Table 1. BIM Software

Product Name	Manufacturer	Primary Function
Navisworks Manage	AutoDesk	3D model-based design and clash detection
Bentley Navigator	Bentley	Dynamic coordination between models and disciplines
Digital Project Suit	Gehry Technologies	Full featured suite: design, review and information management
Solibri Model Checker	Solibri	Quality Assurance/Quality Control (QA/QC)
Synchro Professional	Synchro Ltd.	Scheduling system and planning simulations
Tekla Structures	Tekla	3D structural modeling and detailing
Vico Office	Vico Software	Various 3D model analysis for coordination, scheduling and estimating

3. PROBLEM STATEMENT

3.1. Low Productivity

Acknowledged as having low-productivity, the AEC industry is declining progressively and will continue the decline if traditional processes remain unchanged.

Figure 1 (Teicholz, 2004) describes the productivities of construction and non-farm labor from 1964 to 2003. It indicates that the construction productivity decreased through those decades while the productivity of non-farm labor kept rising. This trend is extremely alarming and indicates that the traditional project delivery processes no longer fit the time as the whole world is moving forward.

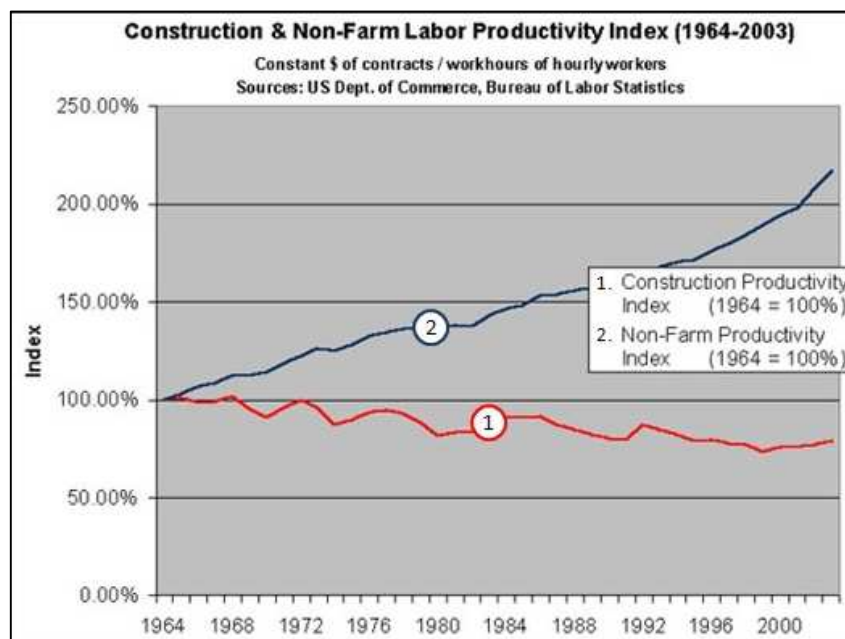


Figure 1. Construction and Non-Farm Labor Productivity Index, 1964-2003.
Source: U.S. Dept. of Commerce, Bureau of Labor Statistics.

There are various factors that cause a loss of productivities, such as, weather, unexpected disruption, congestion and unavailability of manpower. Many researches have

been done on these and other factors (Thomas & Npolitan, 1995; Dai, Goodrum, & Maloney, 2009; Jarkas, 2012). Changes have to be made to the AEC industry to avoid being eliminated. More productive methods for project delivery method should be developed. Currently, a lot of efforts have been focused on the support of advanced technology.

3.2. Construction Rework

Construction projects often experience time and cost overruns, most of which are usually caused by construction rework. Rework has been defined as: "The unnecessary effort of re-doing a process or activity that is incorrectly implemented the first time" (Love & Edwards, 2004). According to the research engaged by Construction Industry Institute (CII), the direct costs caused by rework ranges from 0.5% to 19% of the total project costs (CII, 2005).

Rework can have severe consequences, such as cost and time overruns. Besides these direct consequences, there might also be indirect consequences, such as stress, demotivation or loss of future clients. Therefore, rework must be considered a significant factor affecting cost performance in the construction industry. Rework events can have many different origins, and for this research they have been categorized into four categories: changes, errors, omissions and damages. This thesis focuses on how to use BIM to reduce the rework due to changes, errors, and omissions.

3.3. Design Process

It is true that the AEC industry has moved to the CAD stage. With this advanced technology, the AEC industry is brought to a higher level: the design process is simplified;

data can be conveniently stored and shared; the quality of drawings is improved; etc. However, the contradiction between the architect and constructor, as before, remains unresolved. Frequently with building projects, some special parts are non-constructible. Even if they could be completed, the cost is very high. With CAD, this issue is unpredictable at the design stage. Once these issues are encountered in the construction process, contractors have to submit their request for information (RFI) and then wait for the engineers' response. If the RFI is processed, change orders are issued to let the contractor continue construction work according to the revised drawings and specifications. Every time the above process happens, additional time and/or cost is incurred. Meanwhile, since a lot of organizations are involved in this process, productivity is also affected because of ineffective communication and coordination. Therefore, the current AEC industry lacks a more effective approach to optimize its design process.

3.4. Complicated Scheduling and Cost-Control Work

The AEC industry consists of many separate layers, and the amount of information a construction project contains is tremendous. Project time and cost are the two main elements that concerns all stakeholders. These elements are vital to the project, and they can be the basic foundation for decision-making, collaboration, procurement, etc. The accuracy of the information source determines where the project goes.

Cost estimation for construction projects usually starts with quantification, which is a time-consuming and high-pressure process. Estimators produce the cost estimate following these steps: (1) identify quantitative data used for estimating according to project drawings and specifications; (2) analyze data generated and (3) produce plans. In the traditional approach, this process is primarily completed manually with a high possibility

of human errors. The problem becomes even worse when preparing estimates for large and complex projects. Obviously, the stakeholders do not want to spend their money and efforts to obtain inaccurate results.

Problems may also be found at the end of the construction phase, or even after the construction is done: well-furnished walls still need punching through to add attachments; warning signs are hung all over the buildings to remind people be cautious; after a water pipe blowout, it takes too long to go through the drawings to find the right valve; etc. These issues are also the factors that increase project time and cost. Unlike earthquakes, or other acts of God, such problems are evitable with thorough preparation. This challenge is still a great issue that the AEC industry is currently facing. There is also a demand for a more advanced tool to manage the building information throughout its life cycle.

3.5. Demanded Solutions

On the other hand, the technology that supports the AEC industry keeps growing, but few companies have embraced this development very effectively. In today's AEC industry climate, the information world is at a point of transferring from two dimensional (2D) systems to three dimensional (3D) systems. Many companies and organizations have started investing and reorganizing to get involved in the implementation of 3D technology as much as possible.

BIM is one of the 3D modeling solutions that is being given close attention. It suggests that the best way to build and maintain a construction project is to create a digital 3D model that illustrates everything about the building, from its basic geometry to the model number of its connecting bolts. Using BIM presents plenty of potential, and researchers believe that this new technology will bring the AEC industry to a whole new

generation. It was reported that almost “50% of the AEC industry is using BIM; 87% of expert users are experiencing positive return on investment with BIM; 93% of BIM users believe that more return can be achieved for the potential value of BIM” (Young, Jones, Berstein, & Gudgel, 2009, page 4).

To make full use of BIM, significant changes need to be made to a project’s traditional plan-build-operate life cycle. Because starting BIM increases the firm’s cost and requires a big learning curve, owners, designers, and contractors are all concerned about the project’s cost, which might limit the use of BIM from many perspectives of cost. It is obvious and important to further investigate how a project’s time and cost can be impacted by using the BIM process and technology.

4. RESEARCH METHODOLOGY

The main purpose of this research is to conduct a pilot and case study of using BIM to help control the project's time and cost. The objectives of this study are: (1) to examine the benefits of using BIM for project time and cost control and (2) to study the challenges of applying BIM to a case project during its life cycle. This project is being achieved by introducing AutoDesk Revit Architecture (The 2009 version was used in the study.) as the BIM software to develop project control and by generating data from the case-study project with a local architect and construction firm for discussion and analysis.

4.1. Research Methodology

This thesis was based on a case study to discuss the impact of applying the BIM technique to project time and cost control. The BIM models were supplied by the architect, and other project-related information was obtained and organized through meetings with architects. The methodology used basically contained a (1) literature review and (2) case-study model analysis.

First, a literature review was conducted mainly considering the approaches of project time and cost control, and CAD and BIM applications. Basic concepts and current methods of project time and cost control were reviewed and presented. Existing problems that cause time and cost overruns in the AEC industry were described.

Then a local architect and construction management firm was consulted to work together with a real project's BIM model. The process and model were analyzed. Data analysis based on the 3D models was conducted to illustrate how this new project delivery

method can help optimize a project's time and cost control. Major challenges for the BIM process were stated, and the solutions to address these challenges are also addressed.

In the end, the benefits of using BIM to deliver the project were highlighted. Recommendations for the future use of BIM, in general, were made. The main barriers that constrain the applications of BIM were also discussed.

4.2. Thesis Organization

The thesis is organized basically following the research methodology. Chapter 1 introduces project management. Chapter 2 summarizes the literature review conducted, and new technologies including BIM and its applications are discussed. Chapter 3 explains Problem Statement. The Research Methodology is described in Chapter 4. Chapter 5 reports the case study. A brief summary of the project information is presented. Major challenges, solutions, features and applications are summarized in this chapter. Chapter 6 concludes the benefits of using BIM to deliver projects and makes recommendations for the future use of BIM. Chapter 7 discusses the main barriers that constrain the development of BIM as well as the limitations and future work. Case-study model data and information are included in the thesis as appendices.

5. CASE STUDY AND DISCUSSION

In this chapter, a case study is developed to discuss how the application of BIM affects time and cost control in practice. The Revit model is studied to analyze the BIM applications. Major benefits and challenges from the project are summarized.

5.1. Project Overview

The case project is to build a Scheels All Sports retail center in Springfield, Illinois. Scheels Sporting Goods chain is the owner; R.L. Engebretson Architects serves as the lead architectural design team. The original models and data studied in the case are all obtained from R.L. Engebretson. Table 2 is a summary of the basic project information, and Figure 2 shows how the retail center will likely be rendered in AutoDesk Revit 2009. This project is a two-story store which will include 90 specialty shops; a gift lodge; virtual golf and shooting galleries; a 60-foot Ferris wheel; a giant aquarium; and a hall of presidents, including an animated Abraham Lincoln. The site area is over 200,000 square feet. It is planned as the anchor for a larger retail and commercial development at the south end of the MacArthur extension at Interstate 72. In fact, the Springfield store is a new property for the North Dakota-based chain of 23 stores.

R.L. Engebretson is the one of the first companies that is using the BIM process to develop a project. The company is a full-service professional corporation offering architectural, interior design, and construction management services with its corporate headquarters in Fargo, North Dakota. It has a long business relationship with the Scheels Sporting Goods chain. The following sections report the analysis and discussion of the

case-study project as a summary for the model data. However, much more information can be found in the appendices attached to this thesis.

Table 2. Project Information Overview

Project Name	Scheels All Spots Retail Center
Location	Springfield, IL
Area	200,000 sq.ft.
Complete Date	June 2011
Owner	Scheels Sports Goods Chain
GC	Sampson Construction
Architect	R.L. Engebretson



Figure 2. View of the Retail Center.

5.2. Model Analysis and Discussion

5.2.1. BIM Process

The BIM concept has already existed for a period of time. Interested people have learned about plentiful benefits that it can bring. At the same time, some people are confused about what the BIM process is, additionally what it can specifically do is still a confusing question. In this section, further discussion about the impact of BIM to the building project is given based on this project's case study.

Figure 3 shows the basic BIM process of project delivery. The project usually starts with the development of 3D BIM models. This stage is complex; during it the architects design and test the models, back and forth until no more clashes are detected visually. At that time, the coordinated BIM model is formed. Quantities can be extracted from this model for estimating, scheduling, etc. During construction, BIM models are used for directing, decision making and change management. After the project is finished, an as-built model is prepared for future use, bringing the model to another project cycle. The BIM models act as interactive connections to coordinate all project participants throughout the design, pre-construction, facility management, and renovation project life cycle.

5.2.2. Real-Time Access Design

The BIM process first benefits the design team. With traditional design processes, drawings for different views are completed separately. This method is a very time-consuming and work-loaded process which also increases the possibility of conflicts. In addition, if there is a change to one of the drawings, the architect will have to revise all of the others. However, BIM has introduced new methods to improve the design process. AutoDesk Revit, known as BIM software, is the main tool for design. Its diverse functions

offer a 3D parametric world, allowing the architect to build projects, and information about the models is stored in its database.

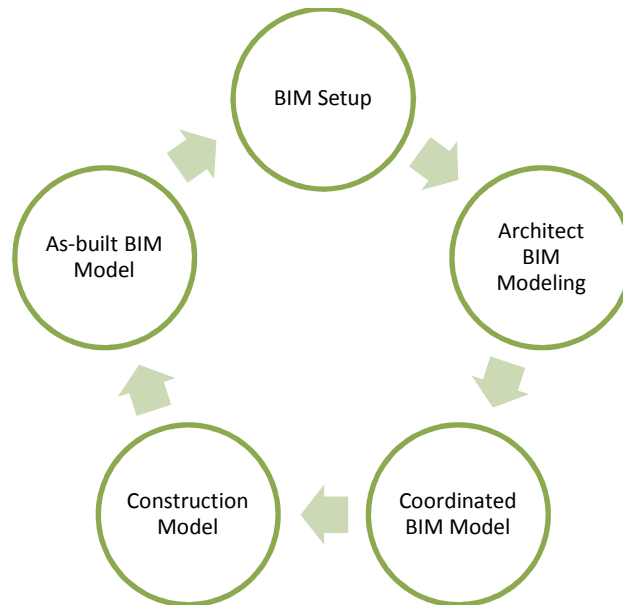


Figure 3. BIM Process.

An example is given to describe the design process for simply creating a 3D wall in AutoDesk Revit Architecture 2009. The steps are as follows:

- 1) Open Revit Architecture 2009, create a new project;
- 2) Go to the *Design Bar* on the left side of the window, click on *Wall*, as shown in Figure 4a;
- 3) Use cursor to finish drawing the wall. When moving the cursor, the dimension of the wall is automatically shown (Figure 4b). However, this dimension is editable after completing the drawing;
- 4) Once the wall is finished, it will be like the one shown in Figure 4c. At this point, the 3D wall is completed, too. Go to the *Tool Bar*; click on *3D*; and Figure 4d shows up.

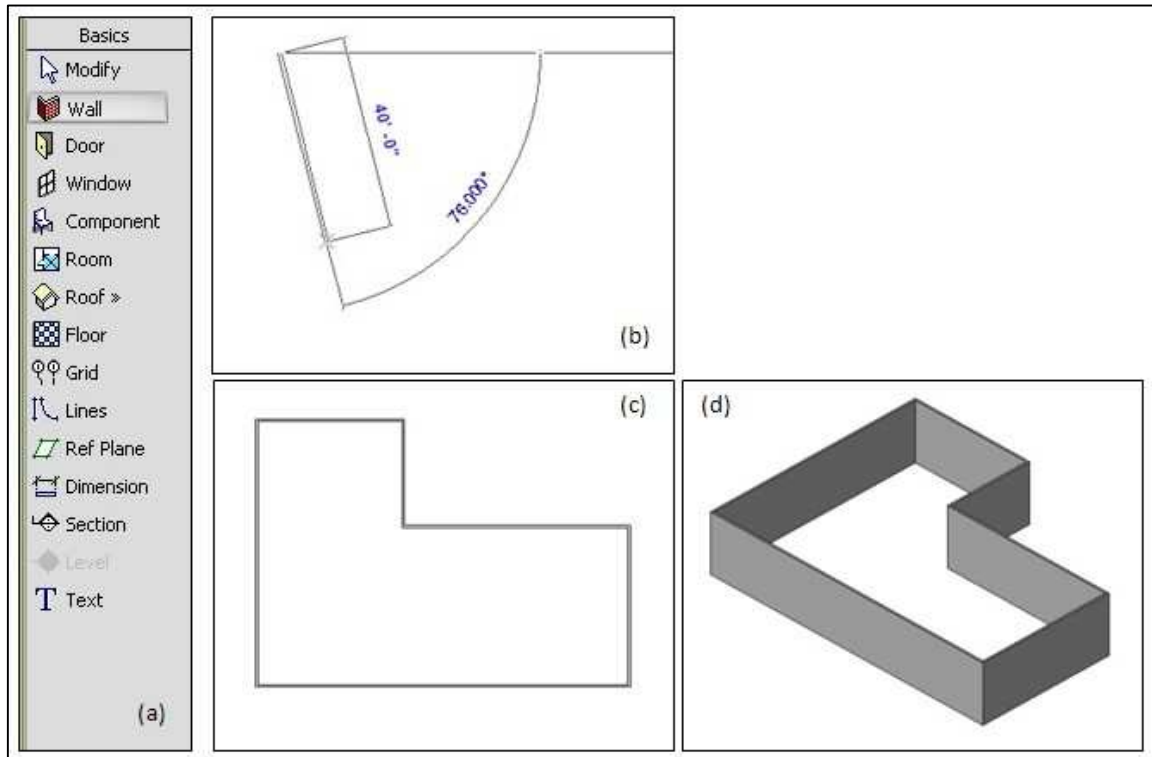


Figure 4. Wall Example.

As described above, in Revit, to create the wall, one only needs to draw the shape on one elevation, and the other elevation drawings are created simultaneously. Not only are the walls done this way, but the entire BIM model is produced this way. This real-time access supplies a dynamic environment where all architects for the same project can work individually on their parts, and then merge the different parts of the work files together to form the complete model. This process saves a lot of time in the design stage, and much more work is achieved.

5.2.3. 3D Visualization

Visualization is the apparent benefit that users have with BIM. BIM models are created by accurately simulating the actual project field. These models enable the users to see the building before the ground is broken. This function is tremendously important for

all the project stakeholders because it can be difficult to visualize the structure from a stack of 2D drawings.

Figure 5, Figure 6, Figure 7, and Figure 8 show the different views of the Scheels retail center model created in AutoDesk Revit Architecture 2009. The parametric flexibility offered in Revit is compelling. Unlike 2D applications, the views in BIM models are very similar to the real world. Each model is visible both vertically and horizontally; one can look over and under the models as well as from side to side without any other tools. Furthermore, Revit also enables the users to virtually walk through the space and to view the interiors and exteriors from a variety of angles prior to the start of any construction. Thus, the 3D visualization provides the client with a directly accurate impression for how the finished project would look.

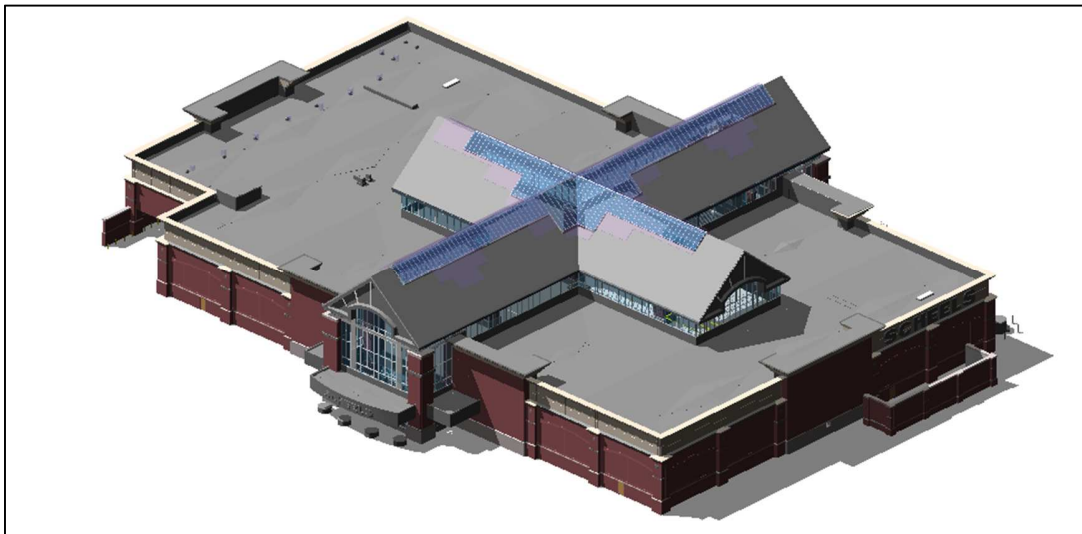


Figure 5. Scheels Retail Center-3D View.



Figure 6. Scheels Retail Center: East View.

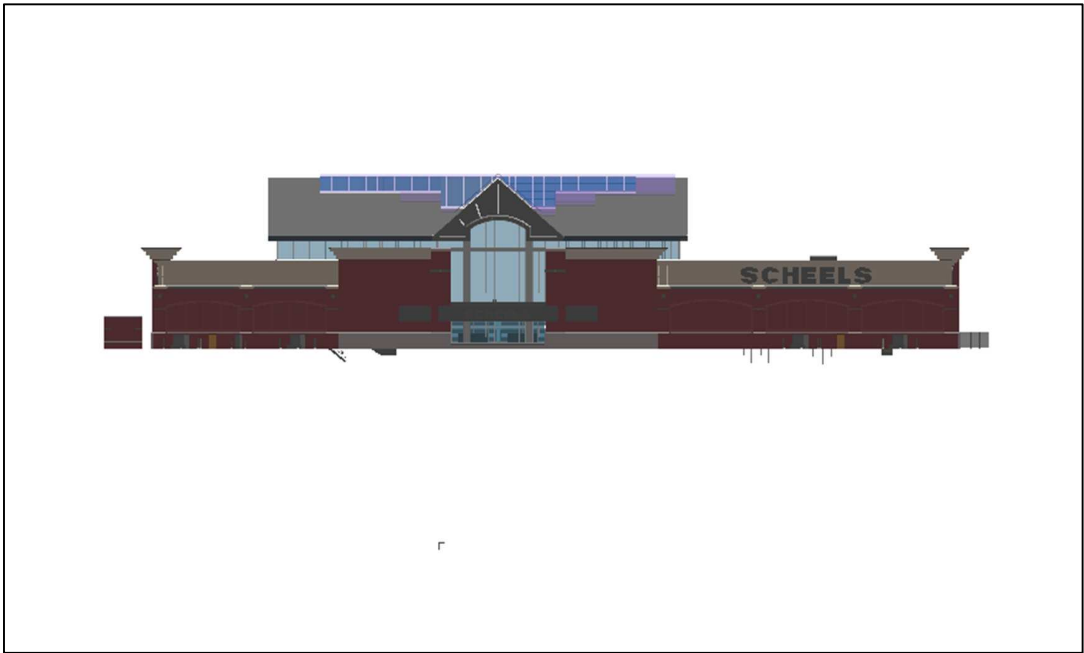


Figure 7. Scheels Retail Center: North View.

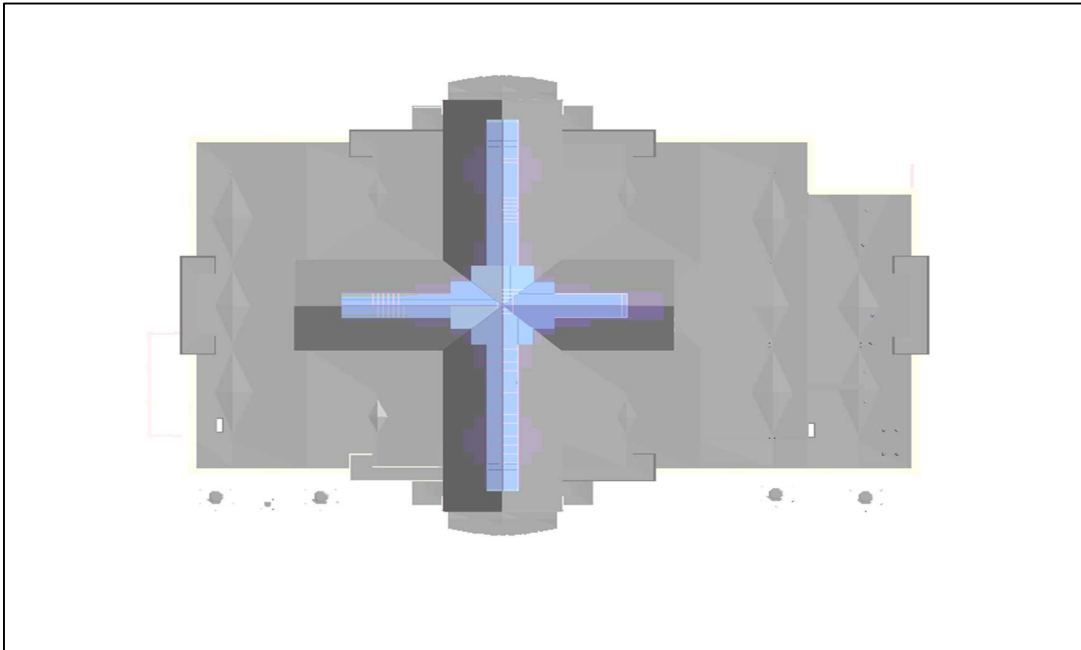


Figure 8. Scheels Retail Center: Top View.

In addition, the 3D environment in Revit makes it very convenient to carry out conflict detection to identify the physical clash of building components. This function is used mostly for structure and MEP installation, but can also be used to detect design mistakes based on the 3D visualization. It is a common problem that design teams are working under pressure to complete their work at the lowest price to remain competitive. Shortcuts, which may cause design mistakes, are often taken. In traditional processes, people have to go through complex procedures to locate the interferences during the design phase. Otherwise, the mistakes remain hidden until problems are encountered when the project is moved to the construction phase. With this circumstance, change orders are the common way to keep the project moving. This process, inevitably, will affect the original plan, resulting in overtime and extra cost. Therefore, the later conflicts are found, the harder they are to control.

Figure 9 is a better illustration to show this issue. This figure is called the McLeamy Curve (Construction Users Roundtable, 2004), where curve 1 represents the “ability to control cost,” curve 2 represents the “cost of design changes,” curve 3 represents the “traditional process,” and curve No.4 represents the “BIM process.” It is very clear that, as the project moves through the stages, the ability to control project cost goes down, and the cost to make changes increases. Compared with curve 3, most of the project costs for the BIM process occurs at the beginning of the project cycle when it is easier to control cost and less money is needed to make changes.

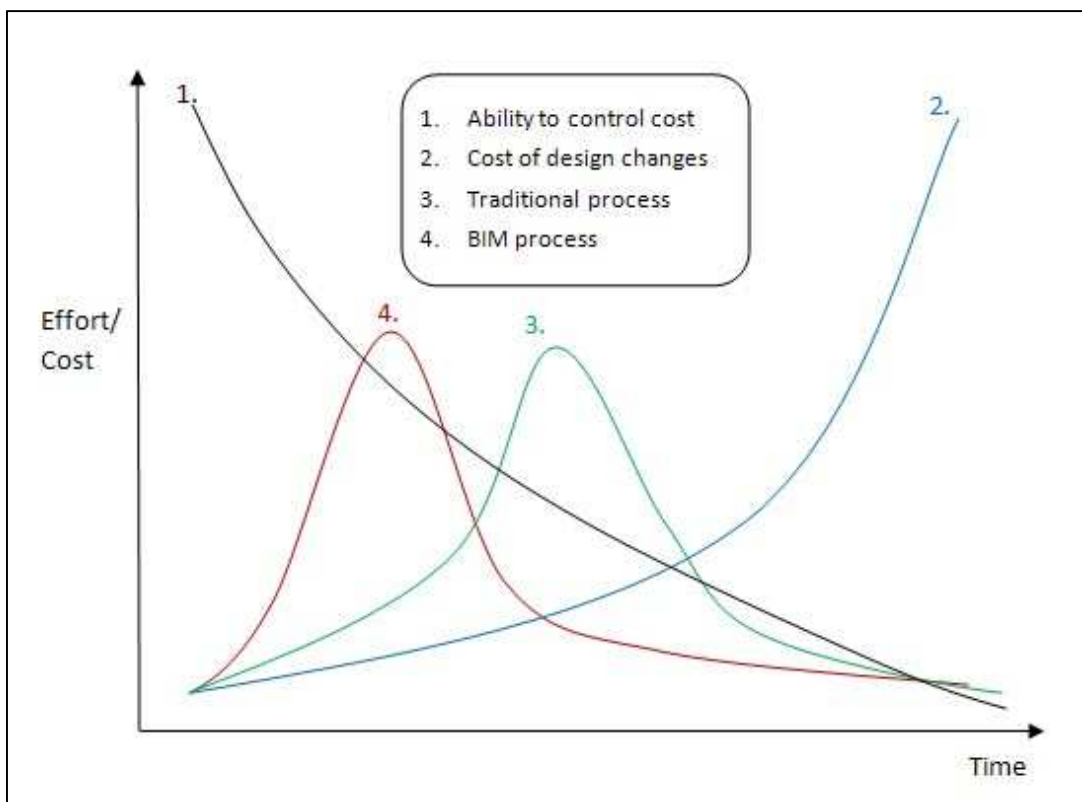


Figure 9. BIM Process vs. Traditional Process.

With the BIM process, the coordinated models allow users to check for design conflicts and potential constructability issues among all the building systems at the front

end of a project from the office instead of at the job site. This way can drastically reduce the number of change orders, save thousands of dollars in wasted effort, and accelerate the build process and time to market.

5.2.4. Information Integration

The information silo and information gap, resulting in the lack of data-exchange standards and information-integration mechanisms during the development of information for the construction industry, have made it difficult for the exchange and sharing of information during the different phases and different application systems, and have blocked the application of information technology in the construction area. Therefore, it has become a research direction and trend to construct the building life cycle management framework and to develop an integrated information management system in order to enhance the application level of information technology (IT) in the building industry.

The core essence of BIM is “I”, which represents the information that the BIM models can carry. Unlike a 2D drawing, the 3D models created in Revit are not only simple graphics of the future building; but they also record all data for a project throughout the project life cycle. Each element input into the Revit model must be defined in detail. As Figure 10 shows, when a door is created in Revit Architecture, its basic properties, such as material, type, thickness, height, width, fire rating, etc., are defined. When the information is input, the data are saved in the database corresponding to the component.

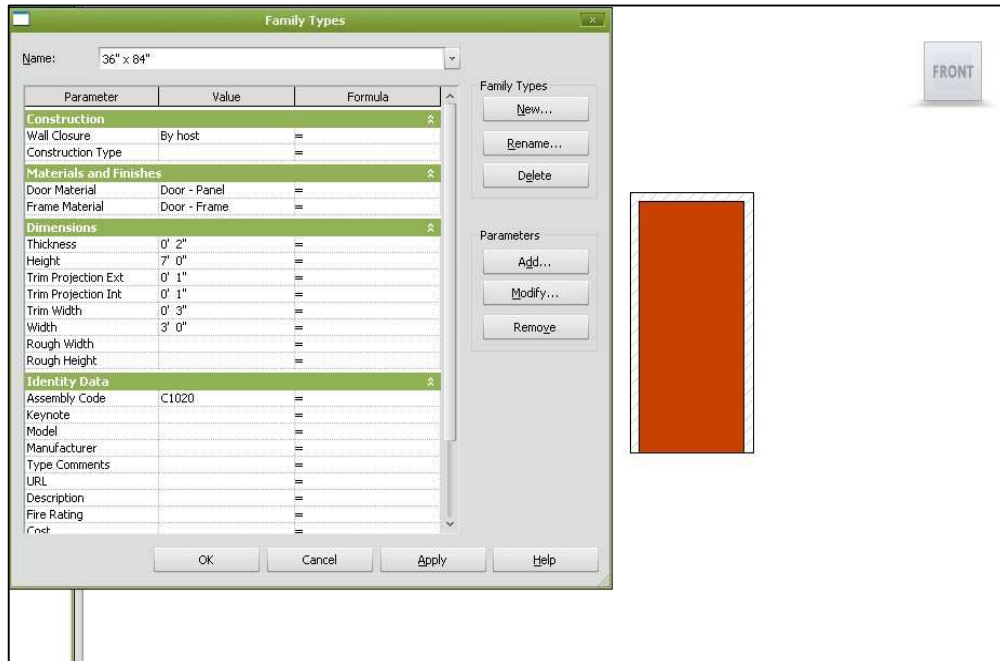


Figure 10. Define a Door in Revit.

When using traditional processes, the design and construction teams are disconnected. The architect creates a building component with 2D drawings, but when the contractor reviews the drawings at the job site, a different one may form in his mind. To minimize the probability of this error happening, BIM seeks to reconnect the information and the people. Figure 11 shows the detailed properties for the door created as well as its 3D view. This function gives all the viewers direct and highly detailed information. The components can be as detailed as a small bolt used in the structures as shown in Figure 12. The information is changeable according to the project plan anytime.

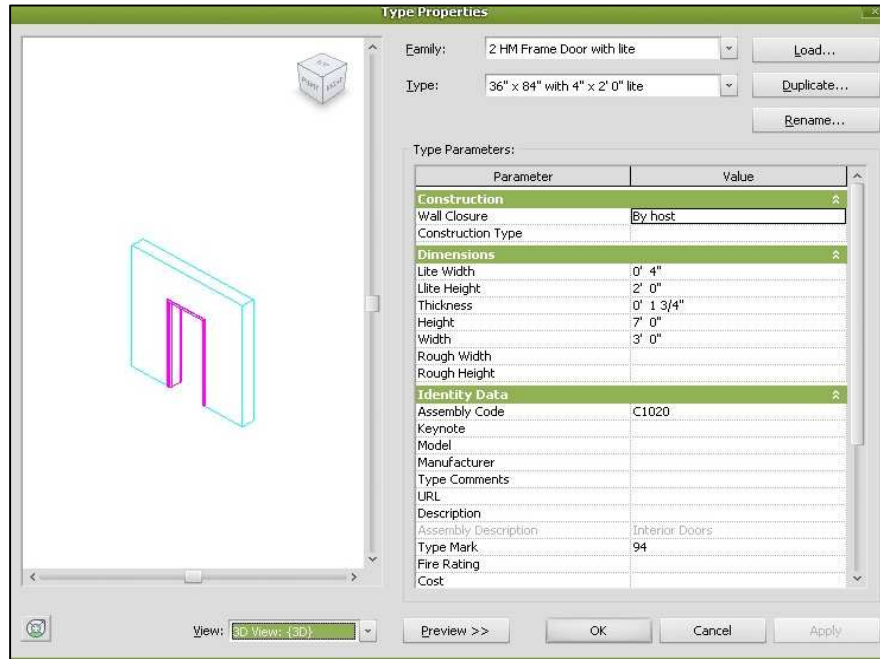


Figure 11. Door Properties in Revit.

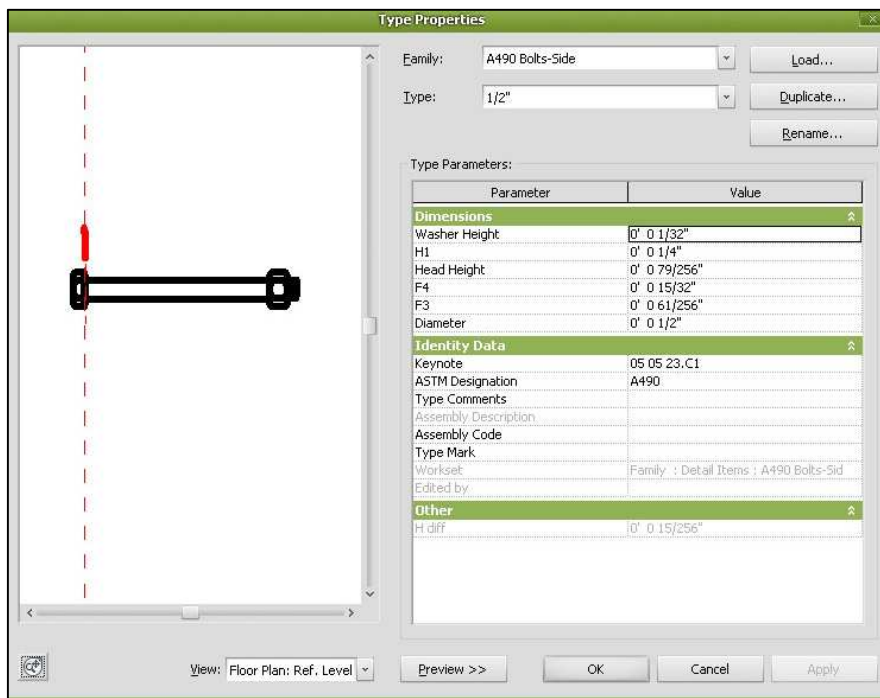


Figure 12. Properties of a Bolt in Revit.

Meanwhile, the information in the database is not isolated by itself but linked with each other. Therefore, if one item is changed, the other related items are automatically updated. Likewise, the plans, drawings, specifications, takeoffs, etc. are all saved electronically in the same database at the time they are created. They can all be generated through relevant views. For example, Figure 13 is the main floor view; Figure 14 is part of the column material quantity takeoffs; Figure 15 is the drawing sheet for the wall material takeoffs. They are all automatically recorded in the database during the design process, saving a large amount of time compared to the traditional process.

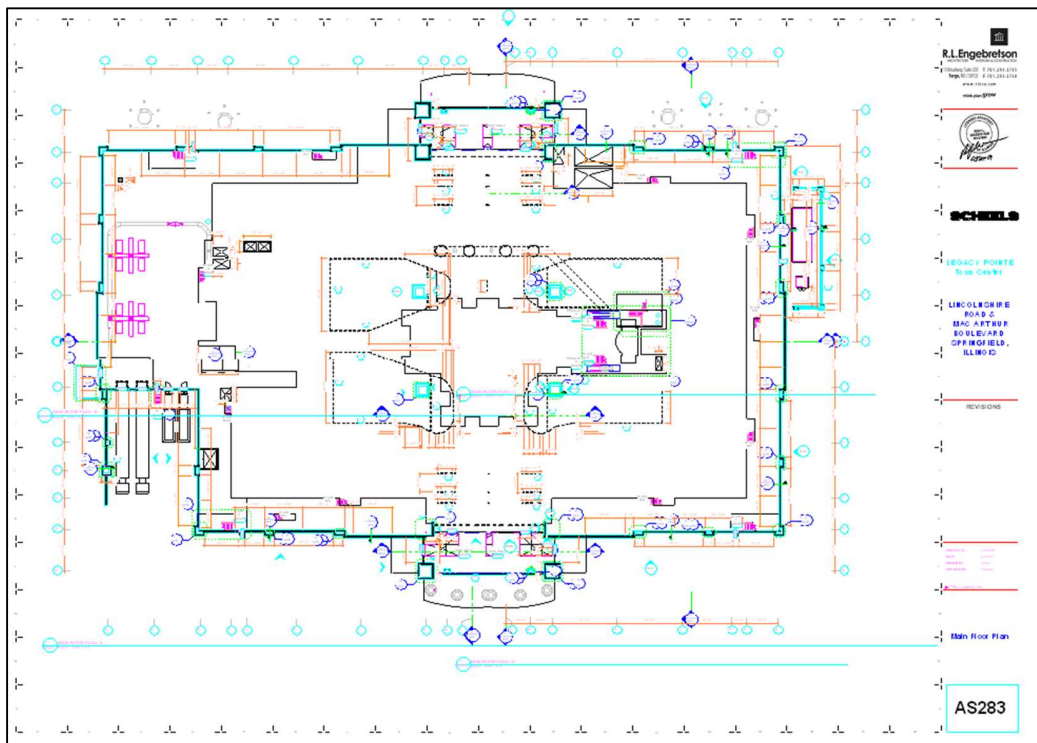


Figure 13. Main Floor Plan.

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3D

Content Search Online

Headers: Group Ungroup Rows: New Delete Show

Basics

Views (Phase - Bid Package)

Legends

Schedule/Quantities

OPNG SCHEDULE-Fit-up

OPNG SCHEDULE-Shell

ROOM SCHEDULE

Room Schedule 2

room temp

SHEET INDEX - Building S

SHEET INDEX Interior Fit

Structural Column Mat

Wall Material Takeoff

Wall Schedule

Sheets (Phase)

AS205 - EAST & WEST E

AS206 - RAIL ELEVATIO

AS206 - TYPE 1 ALUMIN

BUILDING SHELL

AL 0 - DRAINAGE PLAN

AL 1 - MAIN FLOOR REF

AL 1A - MAIN FLOOR ME

AL 2 - SECOND FLOOR R

AL 2A - SECOND FLOOR

AL 3 - MAIN FLOOR PLA

AL 4 - MAIN FLOOR PLA

AL 5 - MAIN FLOOR PLA

AL 6 - MAIN FLOOR PLA

AL 7 - MAIN FLOOR MEZ

AL 8 - MAIN FLOOR MEZ

AL 9 - MAIN FLOOR MEZ

AL 10 - MAIN FLOOR ME

AL 11 - SECOND FLOOR

AL 12 - SECOND FLOOR

AL 13 - SECOND FLOOR

AL 14 - SECOND FLOOR

AL 15 - SECOND FLOOR

AL 16 - SECOND FLOOR

AL 17 - SECOND FLOOR

View

Modelling

Drafting

Rendering

Site

Structural Column Material Takeoff

Type	Assembly Description	Length	Material Area	Material Name
HS53X31/4	Superstructure	7' - 11 1/2"	14 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS53X31/4	Superstructure	7' - 11 1/2"	14 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS53X31/4	Superstructure	8' - 6 3/4"	15 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS53X31/4	Superstructure	8' - 6 3/4"	15 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	8"	2 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	20' - 0"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	20' - 0"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	20' - 0"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7 1/2"	49 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7 1/2"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	25' - 0 1/2"	62 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	25' - 0 1/2"	62 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	25' - 0 1/2"	62 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	25' - 0 1/2"	62 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	45' - 5 1/2"	134 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	45' - 5 1/2"	134 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	17' - 0"	50 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7 1/2"	58 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	19' - 7 1/2"	58 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	17' - 3"	51 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	16' - 11"	50 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HS4X41/4	Superstructure	17' - 3"	51 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
W10x49	Superstructure	7' - 11 1/2"	39 SF	Metal - Steel - ASTM A992
W10x49	Superstructure	7' - 11 1/2"	39 SF	Metal - Steel - ASTM A992
Grand total:			92	

Figure 14. Part of Column Material Takeoffs.

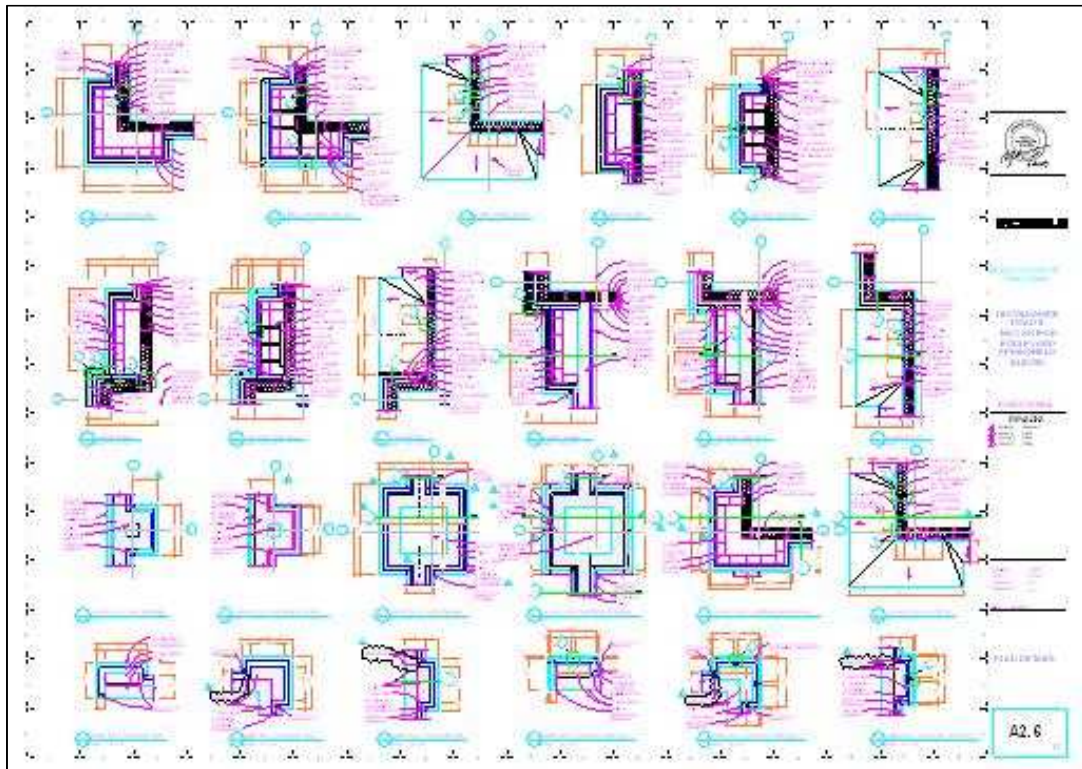


Figure 15. Wall Material Takeoff Drawing Sheet.

The files carrying the building information can also be exported for other specific purposes. The function of BIM and its supporting software make the information transmission and storage highly efficient. Significantly, the information in the databases stays with the building throughout its life cycle, meaning that even after the construction the information can still be significant for future maintenance or other purposes.

5.2.5. Communication and Workflow

Today, standard practice is very disjointed. Each party is responsible for its own element of the design, and each design change requires numerous documents to be revised, checked and approved by at least one other party. This procedure is very labor intensive and can cause significant project delays. A 3D computer model is an extremely useful tool for communicating design ideas, recognizing construction conflicts, or supplementing the fundraising campaigns. For this case project, the BIM models brought the stakeholders together early in the conceptual design stage. Based on the same 3D models, all project participants can finally understand each other better.

Figure 16 shows that BIM acts as a connection medium among the owner, architect, contractor, and engineer. Through each link to BIM, these four parts are indirectly connected. The collaborations between different parties are all achieved based on BIM. BIM significantly improves information sharing and communication between the different project parties, resulting in improved efficiencies and, therefore, substantial project savings.

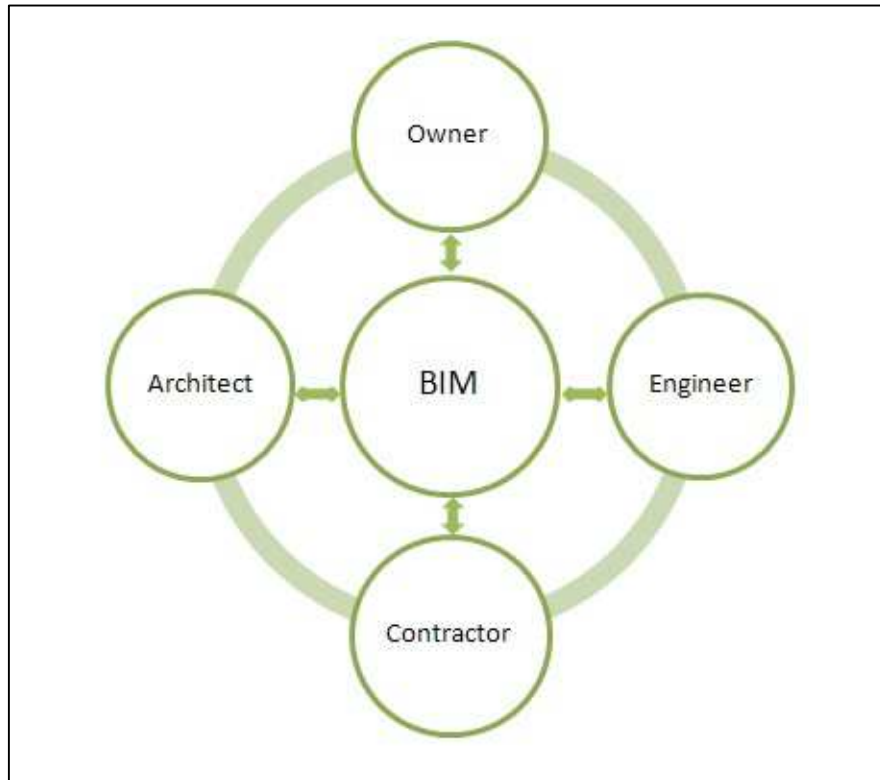


Figure 16. Relationships Based on BIM.

For this project the flow of information was entirely fluid throughout the design and the construction process. Because the design team members used the BIM models in a linked format, they were able to constantly coordinate on issues as they occurred and to immediately confirm that changes were picked up in the model. Expectations for consistent electronic and verbal communication were made from the outset. By interfacing with team members and the client on a regular basis, the team was able to assess changes and make any necessary updates to the model in a timely manner. This coordination amplified the team's ability to use the BIM modeling system to efficiently deliver their designs.

Throughout the design process, models were shared via a FTP site. This FTP option is also

be available at the job site, through a computer, so that this information and the model can continue to be quickly accessed throughout construction.

5.3. Model-Based Cost Estimating

The first step of estimating is to identify the quantitative data that can be used because the accuracy of the data collection method is extremely important for the plan's outcome. BIM offers a new way to record data as real building components. For example, when all the properties of a window are defined in Revit, they are always grouped together. This means that part of the model can be scheduled or quantified as the window is created, which extremely decreases the amount of work for cost estimation.

Revit, as the design tool, automatically records and calculates the data input into the program, carrying information about quantity, cost, and types. These data are not independent. The function of Revit enables users to export data. For example, one can export the material takeoffs in Revit, put them into a Microsoft Excel spreadsheet (Figure 17), and then send them to the cost estimator. The function of Revit enables users to export them out. For example, one can export the material takeoffs in Revit, put it into a spreadsheet, and then send it to the cost estimator. Besides the function embedded in Revit, data can also be extracted with various tools, which are developed by a third party for to extend the use of Revit.

Revit, as a platform, provides accurate data for project participants. As long as all the data input into Revit are correct, Revit can process them without faults. Because Revit runs all by itself to generate quantity takeoffs for cost estimation, the time spent by the estimator on quantification as well as the possibility of human errors are significantly

reduced. The takeoffs generated in Revit can be used as the basis for cost estimating, decision making, procurement, etc.

Family and Type	Material: Name	Material: Area
Air Barrier - Air Infiltration Barrier		
Basic Wall: Scheels Base @ Low Wall of Vestibule - 2-Cast Stone - 3 5/8"AS-12" CMU	Air Barrier - Air Infiltration Barrier	16 SF
Basic Wall: Scheels Base @ Low Wall of Vestibule - 2-Cast Stone - 3 5/8"AS-12" CMU	Air Barrier - Air Infiltration Barrier	16 SF
Basic Wall: Scheels Base @ Low Wall of Vestibule - 2-Cast Stone - 3 5/8"AS-12" CMU	Air Barrier - Air Infiltration Barrier	17 SF
Basic Wall: Scheels Base @ Low Wall of Vestibule - 2-Cast Stone - 3 5/8"AS-12" CMU	Air Barrier - Air Infiltration Barrier	17 SF
Basic Wall: Scheels Base @ Low Wall of Vestibule - 2-Cast Stone - 3 5/8"AS-12" CMU	Air Barrier - Air Infiltration Barrier	76 SF
Basic Wall: Scheels Base @ Low Wall of Vestibule - 2-Cast Stone - 3 5/8"AS-12" CMU	Air Barrier - Air Infiltration Barrier	76 SF
Basic Wall: Scheels Base @ Low Wall Vestibule Behind Column - 2-Cast Stone - 3 5/8"AS-12" CMU 2	Air Barrier - Air Infiltration Barrier	10 SF
Basic Wall: Scheels Base @ Low Wall Vestibule Behind Column - 2-Cast Stone - 3 5/8"AS-12" CMU 2	Air Barrier - Air Infiltration Barrier	10 SF
Basic Wall: Scheels Base @ Low Wall Vestibule Behind Column - 2-Cast Stone - 3 5/8"AS-12" CMU 2	Air Barrier - Air Infiltration Barrier	12 SF
Basic Wall: Scheels Base @ Low Wall Vestibule Behind Column - 2-Cast Stone - 3 5/8"AS-12" CMU 2	Air Barrier - Air Infiltration Barrier	12 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	161 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	161 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	161 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	162 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	237 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	237 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	237 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	237 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	426 SF
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	482 SF
Basic Wall: Scheels Base High Wall End - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	23 SF
Basic Wall: Scheels Base High Wall End - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	23 SF
Basic Wall: Scheels Base High Wall End - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	23 SF
Basic Wall: Scheels Base High Wall End - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	23 SF
Basic Wall: Scheels Base High Wall End - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8"	Air Barrier - Air Infiltration Barrier	23 SF

Figure 17. Wall Material Takeoffs in Microsoft Excel.

5.4. Optimization of Time Schedule

The application of the BIM process also improves the way engineers develop the project schedule. To plan a project with BIM, a fourth dimension, time, is added to the 3D model, forming the 4D model. This concept is still new to most people due to technical challenges for its application, but the emergence of BIM has totally changed the situation. The 4D scheduling model allows people to link components in the 3D BIM model to the corresponding tasks and time. This represents a visual representation of a project timeline, which again raises the probability to resolve conflicts before the construction of projects.

With the 3D building model linked to schedules, the project constructors can evaluate various construction options off the job site.

There are also schedules stored in the Revit model; they specify the quantities of components, such as wall length, wall area, and the numbers of doors/windows. In fact, these schedules are also views. The following steps show how to achieve a wall schedule in Revit:

- 1) In the opened Revit project, go to *Tool Bar*; find the *View* tab; click on *New*, select *Schedule/Quantities*; this process is shown in Figure 18;
- 2) A dialog similar to Figure 19 opens. Revit supplies many categories for users to select. Find *Walls*; click *OK*;
- 3) In this dialog (Figure 20), the properties of the wall schedule can be defined by adding expected fields, and then, click *OK* to see the schedule (Figure 21).

The schedule created in Revit can be saved as views, and can also be exported for other purposes. For example, the schedule for the windows is exported to Excel for the manufacturer because, sometimes, they do not need drawings. Back to the 4D scheduling model, various tools, such as AutoDesk Navisworks Manage, Vico Software, and Tekla BIM sight, are available now to support this scheduling method as the technology grows.

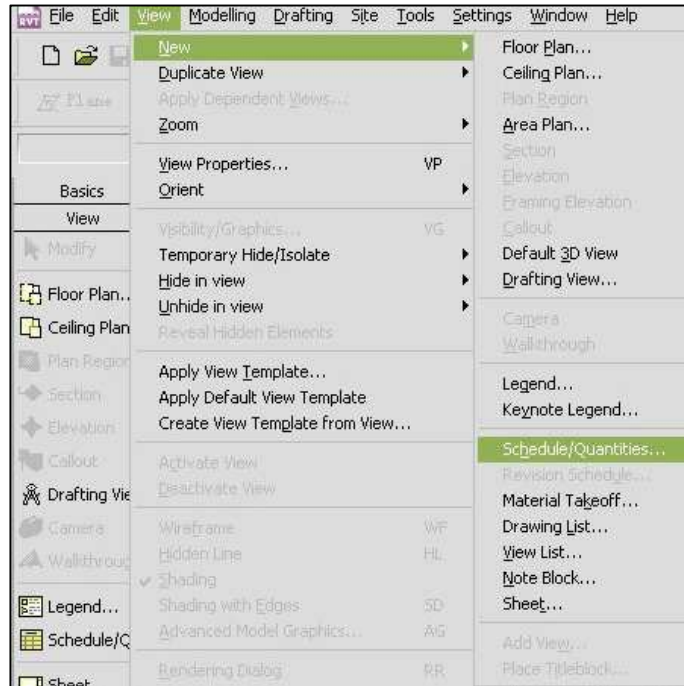


Figure 18. Dialog of Creating a New View in Revit.

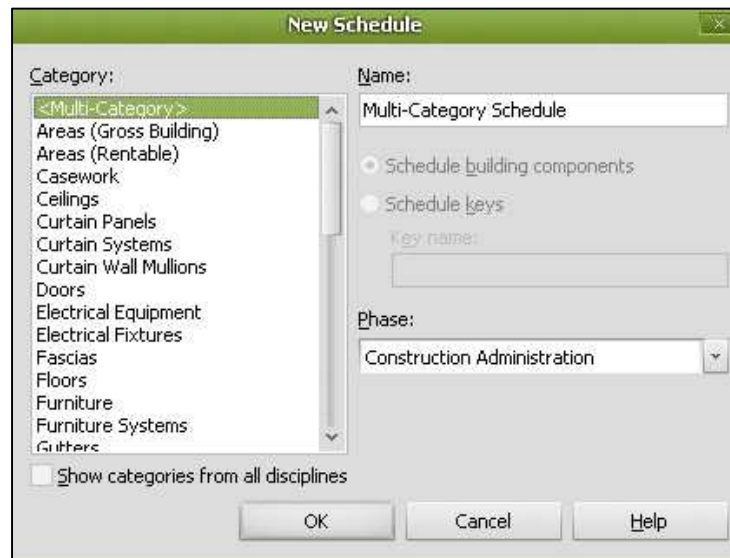


Figure 19. Dialog of Creating a New Schedule View in Revit.

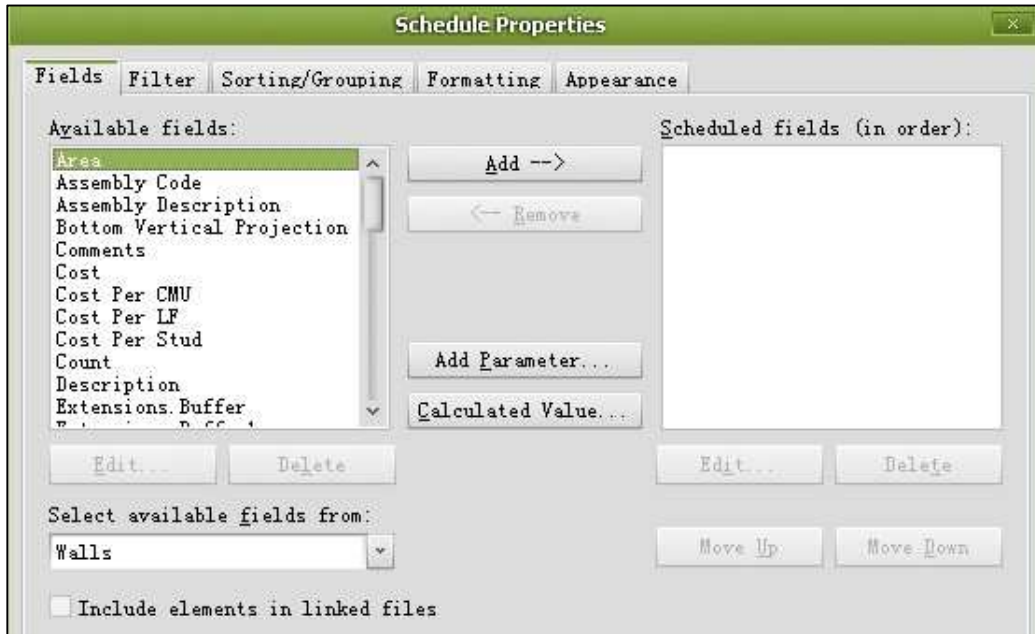


Figure 20. Dialog of Schedule Properties in Revit.

Wall Schedule			
Family and Type	Assembly Code	Assembly Description	
Basic Wall: 8" CMU - 2" Rigid	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Ext - 8" CMU Actual	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Ext - 12" CMU	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Ext - Elev Chase Wall - Dog House- 8"stud - 1/2" Gyp - 1/2" Coverboard	B2010180	Ext. Wall - Wood Stud w/ Siding & Shingles	
Basic Wall: Ext - Mt1 - 8" - 1/2" Gyp - 1" Rigid	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Ext - Scheels Atrium Sill-	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Int - Mt1 - 6" - 5/8" Gyp - 1/2" Gyp	C1010145	Partitions - Drywall w/ Metal Stud	
Basic Wall: Int - Mt1 - 6" - (1)5/8" Gyp	C1010145	Partitions - Drywall w/ Metal Stud	
Basic Wall: Int - Mt1 - 6" - (2) 5/8" Gyp	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Int - Mt1 - 6" - (2) 5/8" Gyp - 1 Hour	C1010145	Partitions - Drywall w/ Metal Stud	
Basic Wall: Int - Mt1 - 8"	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Int - Mt1 - 8" - 1" Rigid - 1/2" Gyp - 5/8" Gyp	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: Int - Mt1 - 8" - 5/8" Gyp	B2010175	Ext. Wall - Metal Siding Panels	
Basic Wall: M5e - Ext - SAS Canopy - 6" - 1/2" Gyp - 1" Metal Panel	B2010180	Ext. Wall - Wood Stud w/ Siding & Shingles	
Basic Wall: Pallet Storage			
Basic Wall: RoofWall- Mt1 - 6" - (1)1/2" Sheath-(1)1/2" Densdeck-epdm	C1010145	Partitions - Drywall w/ Metal Stud	
Basic Wall: SAS Pilaster @ Loading Dock Base - Brick - 3 5/8" AS- 11 5/8" CMU-AS-3 5/8"	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: SAS Pilaster @ Loading Dock Upper -15' Brick - 3 5/8" AS-CMU 11 5/8"	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: SAS Stud 8" - Gyp 5/8" (1 side)	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS Back wall - top	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS back wall Mid 1	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS Back wall-Base 1	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS End 2	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS End @ glass	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS End base	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS End base @ glass	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS End Top	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS End Top @ glass	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS Front wall - base 2	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS Front wall - Mid 2	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS Front wall -top 2	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS wall Typ - Mid	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS wall Typ base	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels - High Parapet EIFS wall Typ-top	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels Atrium Pilaster Base - Cast Stone - 3 5/8" AS- 3 5/8" CMU-AS-5/8" Gyp	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels Atrium Upper Pilaster - Brick - 3 5/8" AS-5/8" GypBD-8"Stud	B2010158	Ext. Wall - Brick Veneer w/ Stud	
Basic Wall: Scheels Base - Brick - 3 5/8" AS-1" Rigid-1/2" GypBD-8"Stud-5/8" GYP	B2010158	Ext. Wall - Brick Veneer w/ Stud	

Figure 21. Part of Wall Schedule.

5.5. Major Challenges and Corresponding Solutions

The researcher contacted the R.L Engebretson Group, and submitted requests to using its BIM models. Once approved, the case study started with understanding the models. The information sections helped the data collection and organizing. Detailed discussion about the case study is presented in the following sections.

Through the information sections, major challenges during the application of BIM were first found by the architects, and corresponding solutions for those problems were addressed. They are summarized as follows.

5.5.1. Learning Curve

For the application of BIM in the case studied, the R.L. Engebretson architects used AutoDesk Revit Architecture 2009 as the design software to start the project. To fully benefit from this tool, high-level operating skills are required. Because the concept of BIM is still relatively new, the company was at the stage of transferring from AutoCAD to Revit. Although most architects in the company are AutoCAD professionals, that knowledge of using AutoCAD would not help too much when learning Revit. Affected by the time required for the learning curve, the time for design work was going to be extended. As a result, the project would be delayed, and extra cost would be added, going against the original purpose of using the BIM process as the project-delivery method. Several means were sought to solve this learning curve problem:

- 1) Hire Revit professionals to train current architects;
- 2) Recruit new employees who are skillful in Revit;
- 3) Cooperate with colleges and universities to get well-trained personnel.

These solutions produced good results. Especially, the newly hired employees brought strong supports for the work

5.5.2. Access/Update Coordination

For the project, architects were divided into several teams to perform each assigned task. This process involves simultaneously working on and saving different portions of the project. Revit enables users to work on individual worksets that are subdivided from the original Revit project, the central file. When the users finish their worksets, they can save them on the individual user end and publish it to the central file. The challenge here is that a data-access rule is defined in Revit to prevent possible project conflicts, once a user starts accessing or updating his work to the central file, it remains unchangeable to others until the authority is released. This principle means that all the design teams have to import their work in the central file one by one. For large projects, such as Scheels Sporting Goods retail center, a large number of design teams are involved. Throughout the BIM process, the possibility of conflicts can be limited to a lower level. The time for data accessing can be much more challenging, and this issue can be the factor that affects the total project time. During this process, two measures were implemented as solutions for this problem:

- 1) Before the starting the design, a clear schedule of data access for each design team must be developed;
- 2) A control manager is assigned to supervise the implementation of the data-access schedule, enhancing the collaboration among design teams.

5.5.3. Database Maintenance

An ambitious company always wants to keep the project database in the company profiles, because it shows the quality and ability of the company in the industry. Another reason to maintain a project database is that it can also be used for similar projects or

rebuilding projects in the future. Although the highly developed technology has enabled companies to save their projects electronically, a systematical database storage method with multi-aspect compatibility is still needed. The Revit database is used because Revit has its own method to maintain the database of building information, and the database can be exported to Open Database Connectivity (ODBC) for other uses.

Although challenges exist in the application of BIM for building projects, the company has the confidence that adopting BIM would be the most efficient and suitable way to achieve its goals based on many years in this business. Using BIM, company architects can quickly evaluate design schemes, make the right decisions at early project stages, and efficiently cooperate with the organizations involved. The advantages of this highly advanced technology will also benefit the participants throughout the project life cycle.

5.5.4. Prefabrication

One of the most important goal of project control is safety on the construction site. The contractors always want to control the size of field crews, the number of large equipment and the materials storage on site. Prefabrication is considered to be an effective method to help reduce potential hazards. By fabricating most of the building components in workshops, the amount of labors and equipment in job site can be reduced. Fewer materials are necessary to be stored, which lowers the chance of losing and wasting. However, prefabrication can also cause problems. Preparing for fabrication is a time consuming process which involves many complex factors. Ordering the wrong parts would endanger the project outcome, and late delivery would delay the project duration sequentially. So the

great challenge here is how to determine whether the component can be prefabricated and how to fabricate it precisely.

BIM brings construction parties to get involved at early project stage. This facilitates the communication among them. On this case project, the contractor had sufficient time to look for manufacturers and schedule delivery with them. The subcontractors joined the team in time to collaborate with contractors working on BIM models. These digital models can be easily broken down to fabrication workflows. Outstanding for accurate real-time design, BIM effectively cuts down errors during fabrication errors. The combination of BIM and prefabrication is proved to be logical, doable, and profitable.

6. SUMMARY AND CONCLUSION

Undeniably, from paper-based design to CAD, the remarkable technology leap has taken the AEC industry to a computer-based age. What BIM can bring is not only another leap, but also a subversive change for the entire industry. In this new era, the design is not merely about drawings, but is more a series of virtual processes of building models. The application of BIM can spread throughout the project life cycle, from the planning stage to construction and installation, and even rebuilding or dismantling. BIM is improving the AEC industry to a high-tech and high-productivity industry.

The overall objective of this research was to see if BIM can reduce project time and save money. To find the result, the researchers introduced a BIM-centered project delivery process. The case study developed for this thesis showed the application of BIM in practice. This study compared the BIM processes with the traditional processes for project delivery, combining the actual use of BIM, and found the benefits of applying BIM to the project: fast real-time design; accurate 3D visualization with multiple design views; automatic document management; enhanced collaboration and communication; fast and accurate model-based estimating; and optimized 4D scheduling.

Although there are various benefits when using BIM for project time and cost control, the learning curve required and the initial cost for BIM setup could be the main barriers for the spread of this advanced technology. A long-sighted company should be confident that the rewards of bringing in BIM are more significant. The application of BIM also meets the standard of sustainability in various ways: shortening the field-cycle time, increasing on-site renewable opportunities, reducing the waste produced through

construction, saving energy, increasing labor productivity, etc. In summary, the impact of BIM on time and cost control is all about minimizing cost and accelerating progress.

7. LIMITATIONS AND FUTURE WORK

After seeing the outcomes of this study, it would be beneficial to conduct further study about the use of BIM. Because the AEC industry is still at a stage transferring into the 3D world, a lot more research would be required to promote the development of new techniques. Overall, the cost of the BIM and its supporting technologies can be expensive at the start. However, the powerful uses of BIM increase profits, lowers costs, and shorten scheduling time. This nature determines that BIM will be the trend of the AEC industry. Thanks to the advanced technology, various software is developed to extend the BIM application. But not all of them are suitable for any kind of projects. So the new technologies still need time for researchers to test.

In this study only one case was studied, and the type of project were limited. Therefore, a direction for future work on this subject is to develop more studies on various projects. More research about the connection and compatibility of BIM tools with other software will also be inquired. Because multi-dimensional models are becoming more attractive for multivariate data visualization, their application would require further review.

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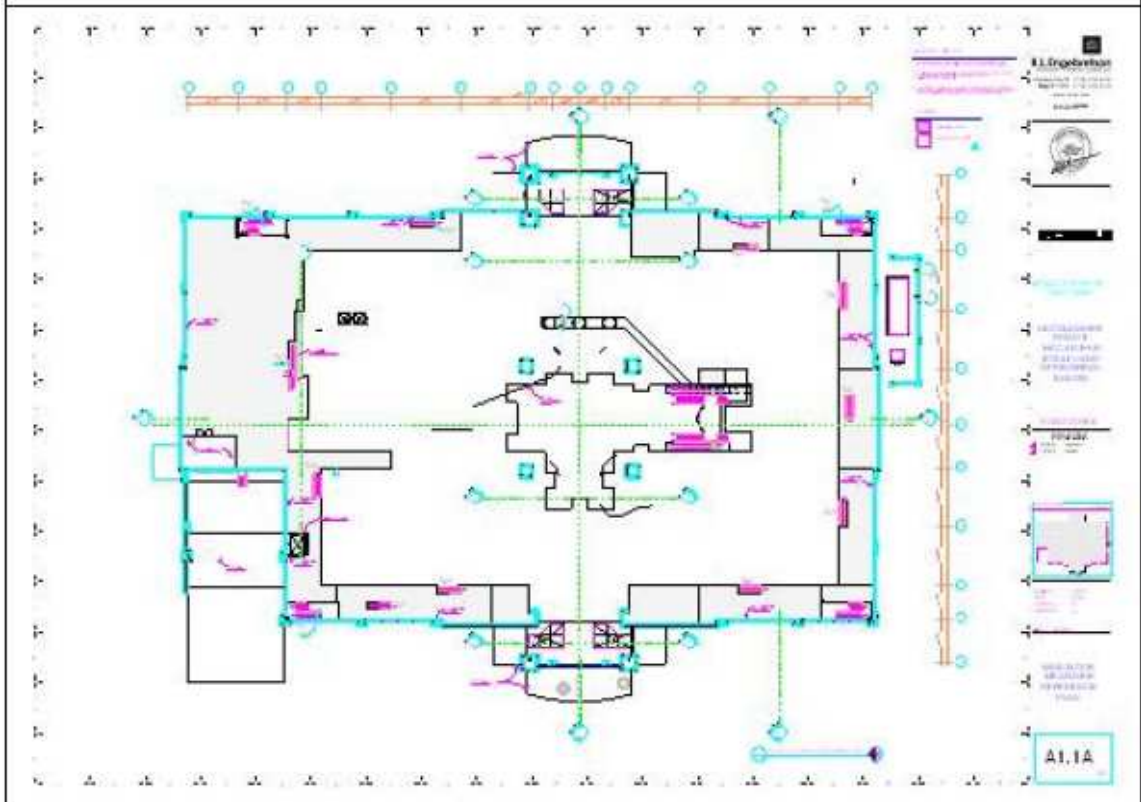
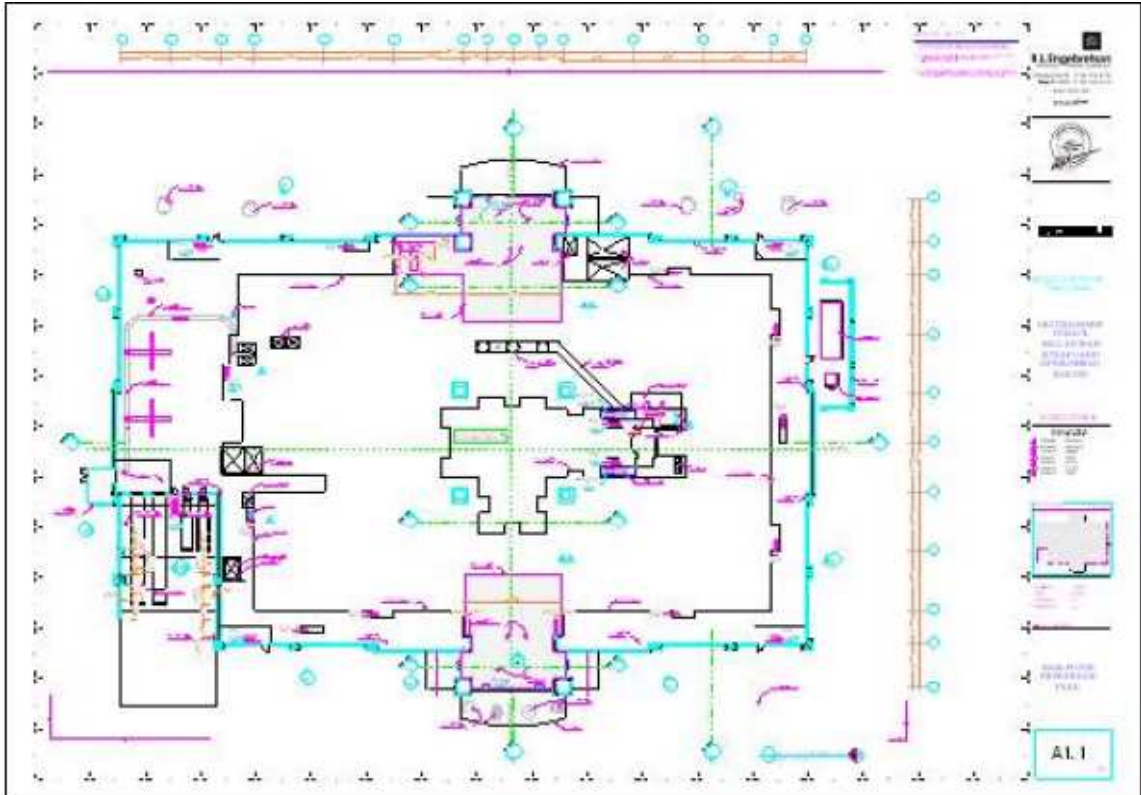
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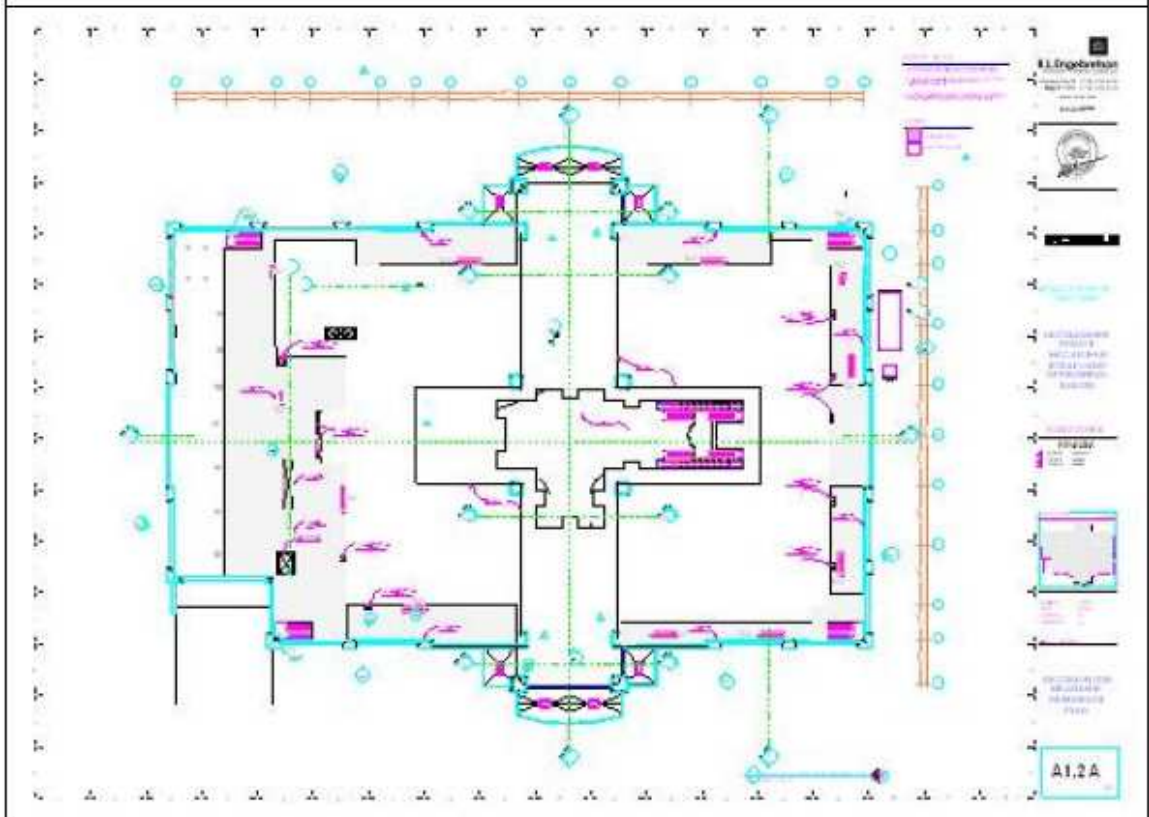
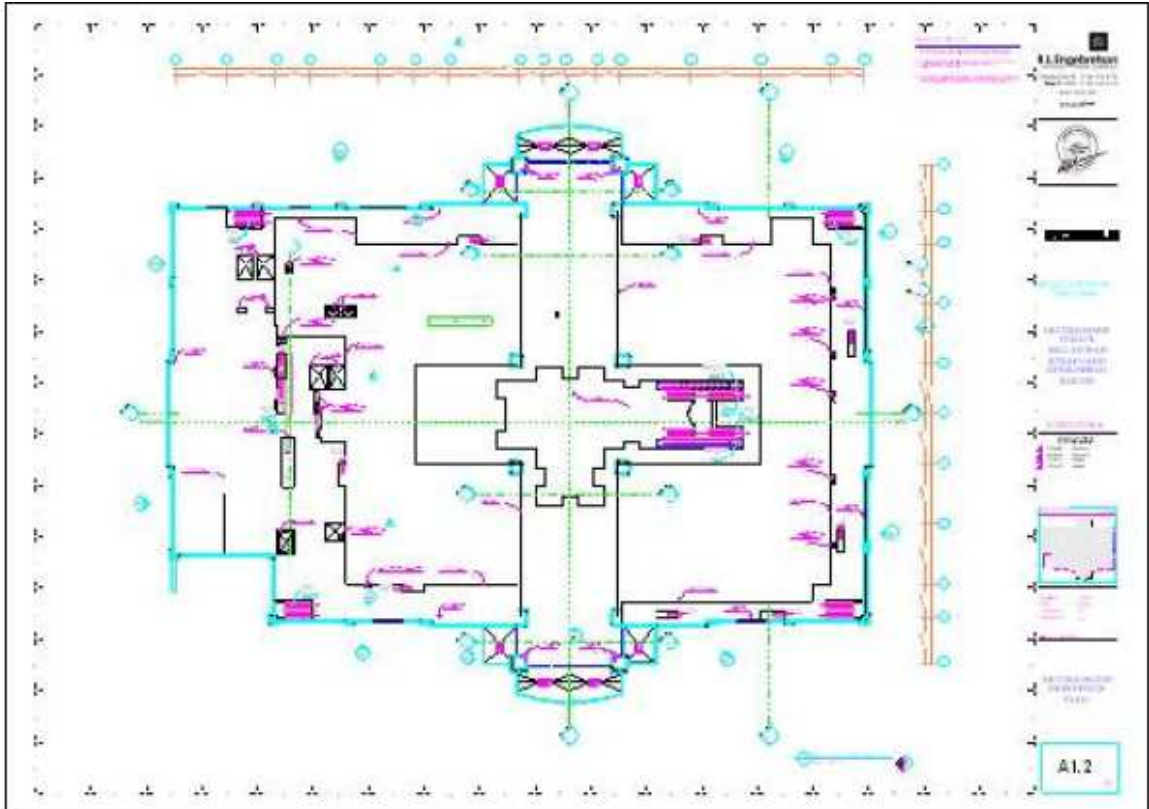
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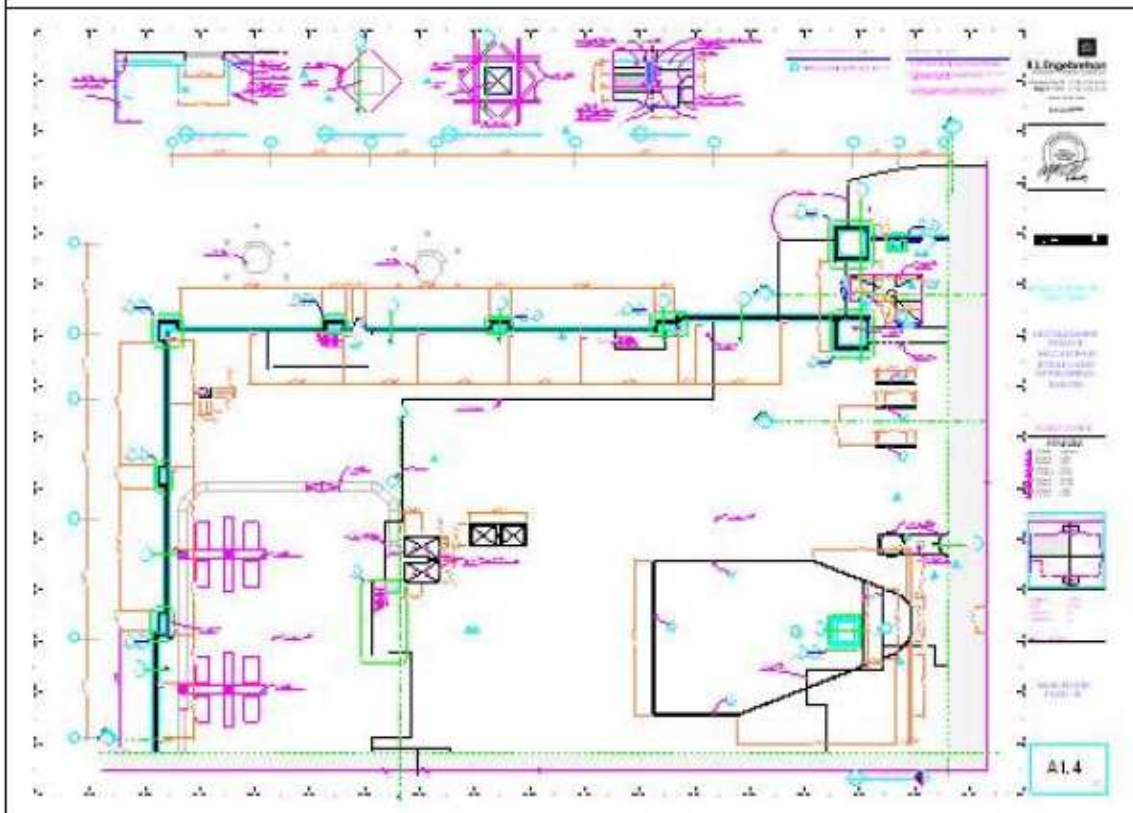
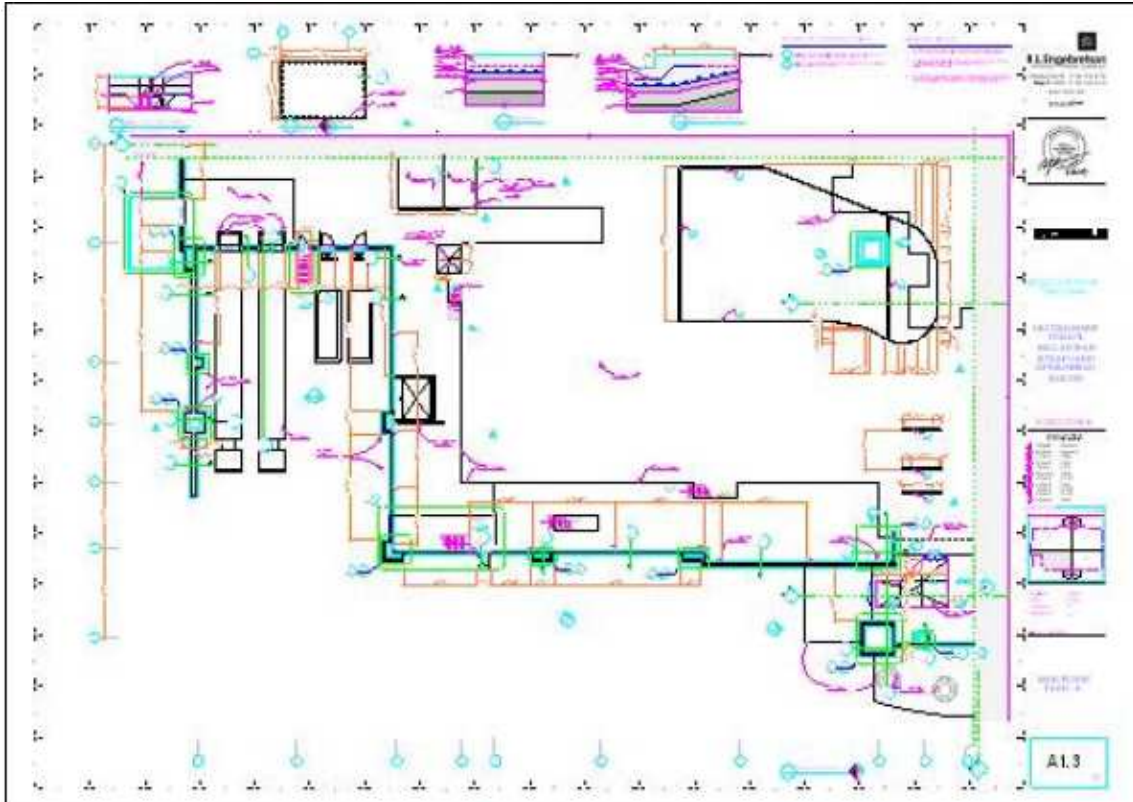
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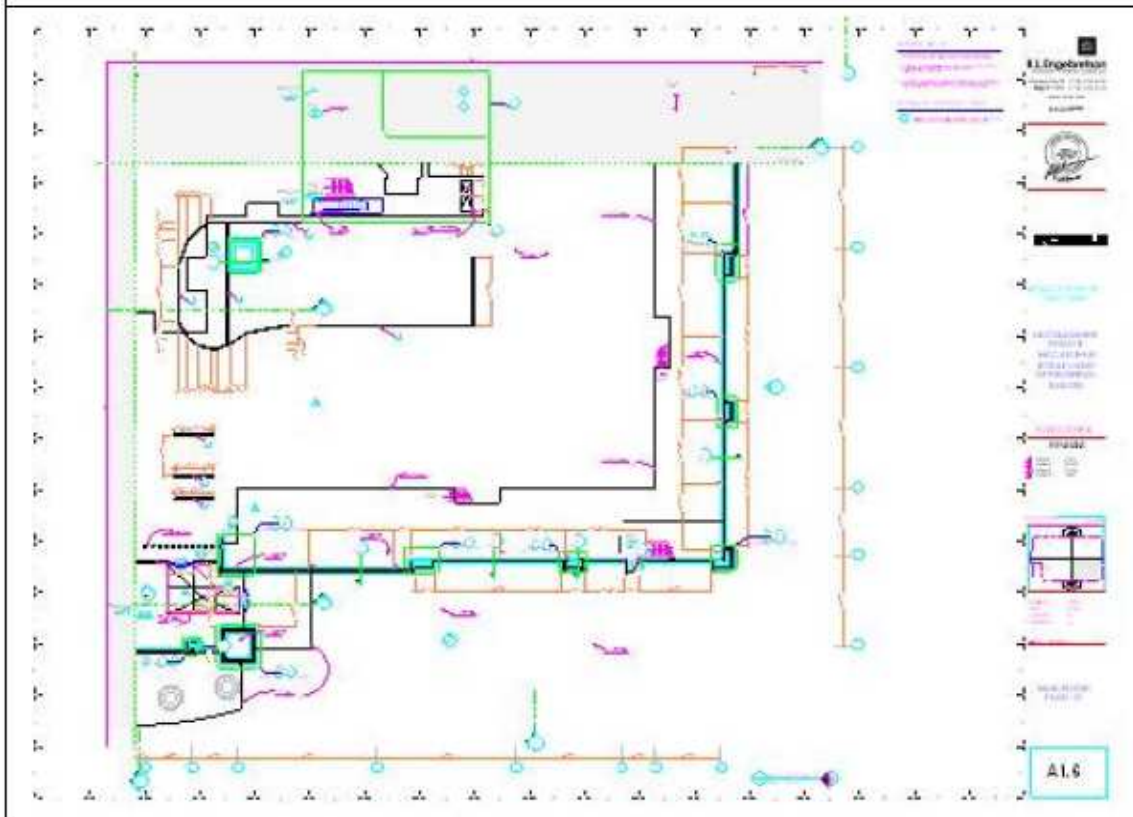
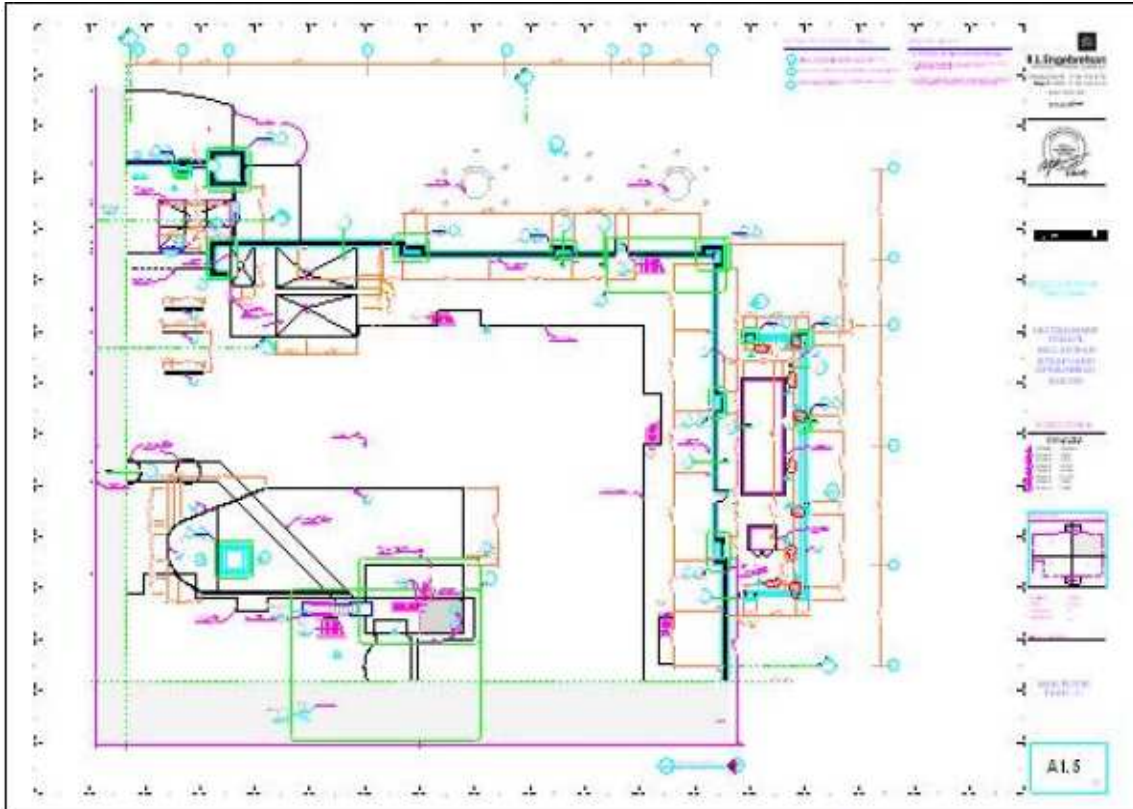
APPENDIX A. MODEL SNAPSHOTS AND SHEET INDEX

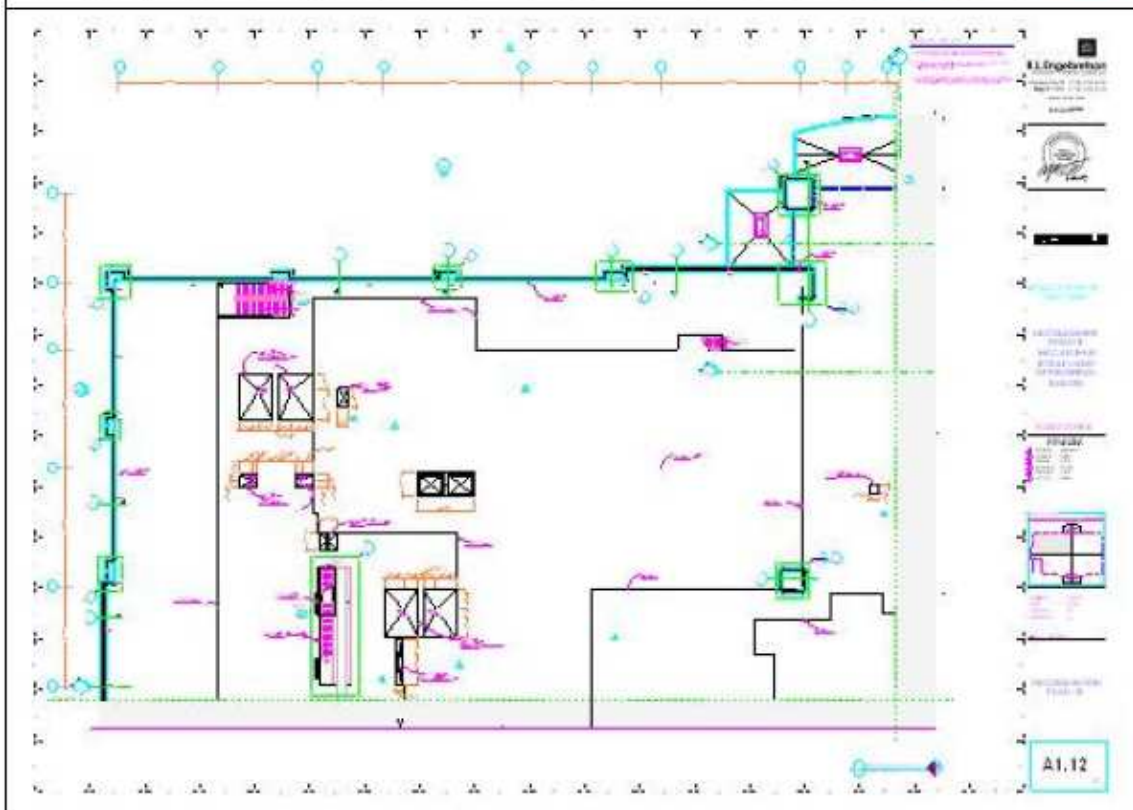
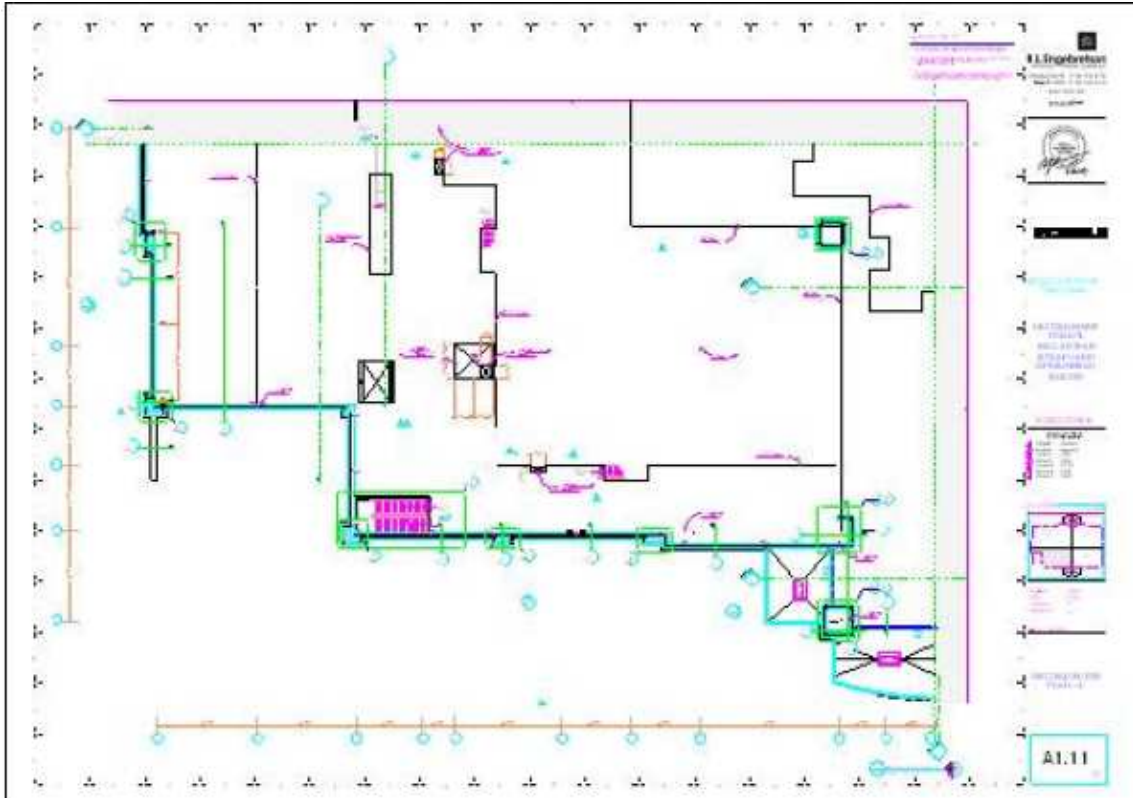
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A1.1A	R2	MAIN FLOOR MEZZANINE REFERENCE PLAN
A1.2	R2	SECOND FLOOR REFERENCE PLAN
A1.2A	R2	SECOND FLOOR MEZZANINE REFERENCE PLAN
A1.3	R1	MAIN FLOOR PLAN - A
A1.4	R1	MAIN FLOOR PLAN - B
A1.5	R1	MAIN FLOOR PLAN - C
A1.6		MAIN FLOOR PLAN - D
A1.11	R1	SECOND FLOOR PLAN - A
A1.12	R1	SECOND FLOOR PLAN - B
A1.13		SECOND FLOOR PLAN - C
A1.14		SECOND FLOOR PLAN - D
A1.19	R1	WEST ATRIUM CURTAIN WALL PLAN
A1.20	R1	EAST ATRIUM CURTAIN WALL PLAN
A1.21		STUD FRAMING PLAN, RAILING ELEVATIONS & DETAILS
A3.1	R2	BUILDING ELEVATIONS
A3.2	R1	BUILDING ELEVATIONS
A3.3	R2	BUILDING ELEVATIONS
A3.4	R1	BUILDING ELEVATIONS
A4.1	R1	BUILDING SECTION
A4.2	R1	BUILDING SECTION
A4.3	R1	BUILDING SECTION

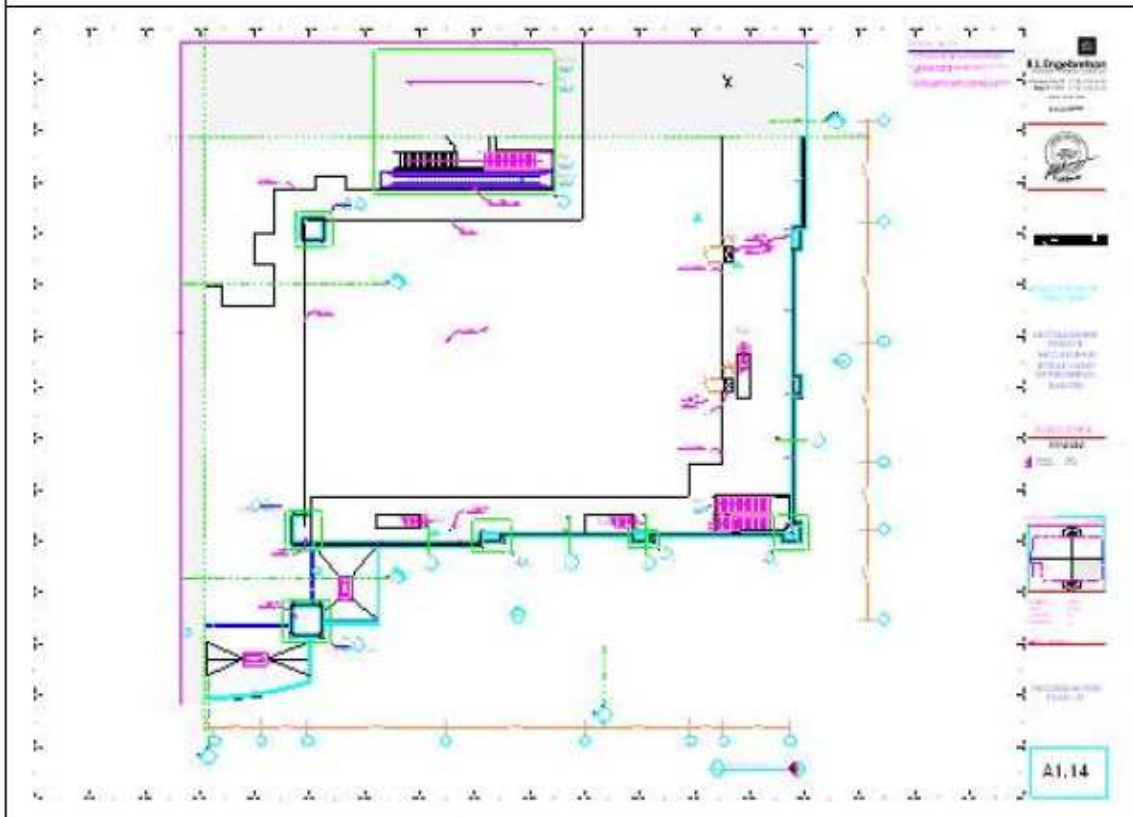
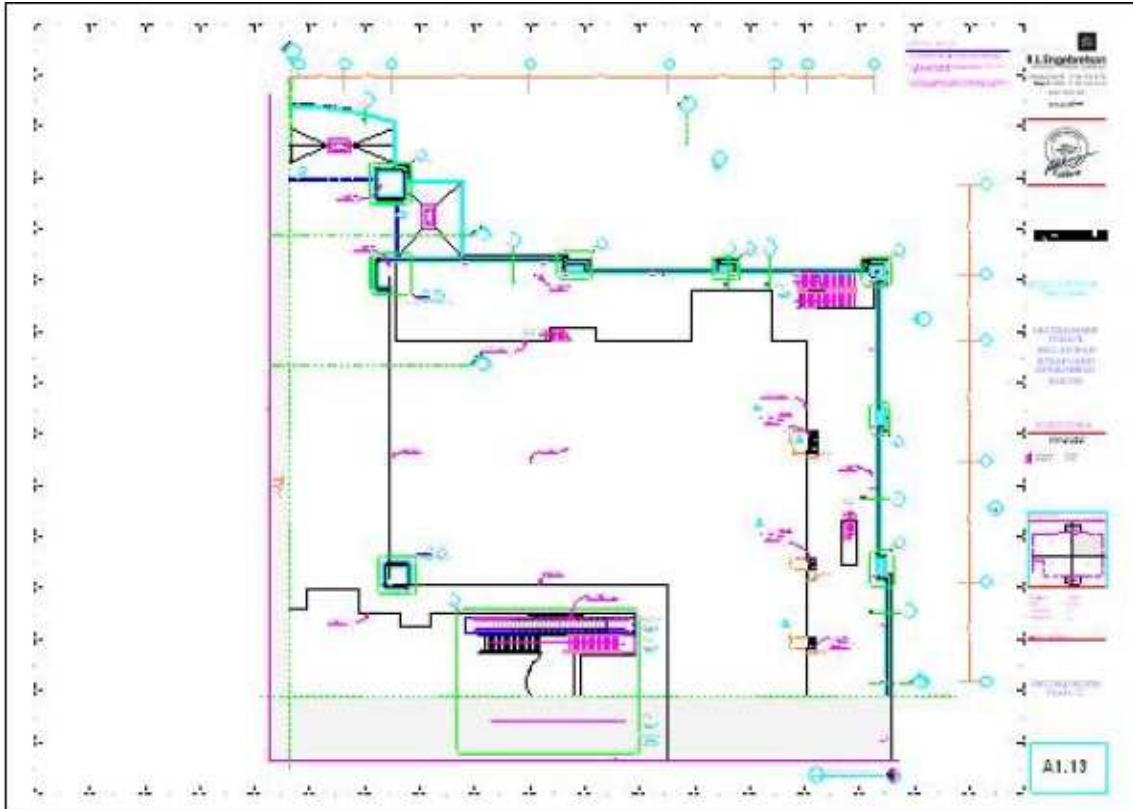


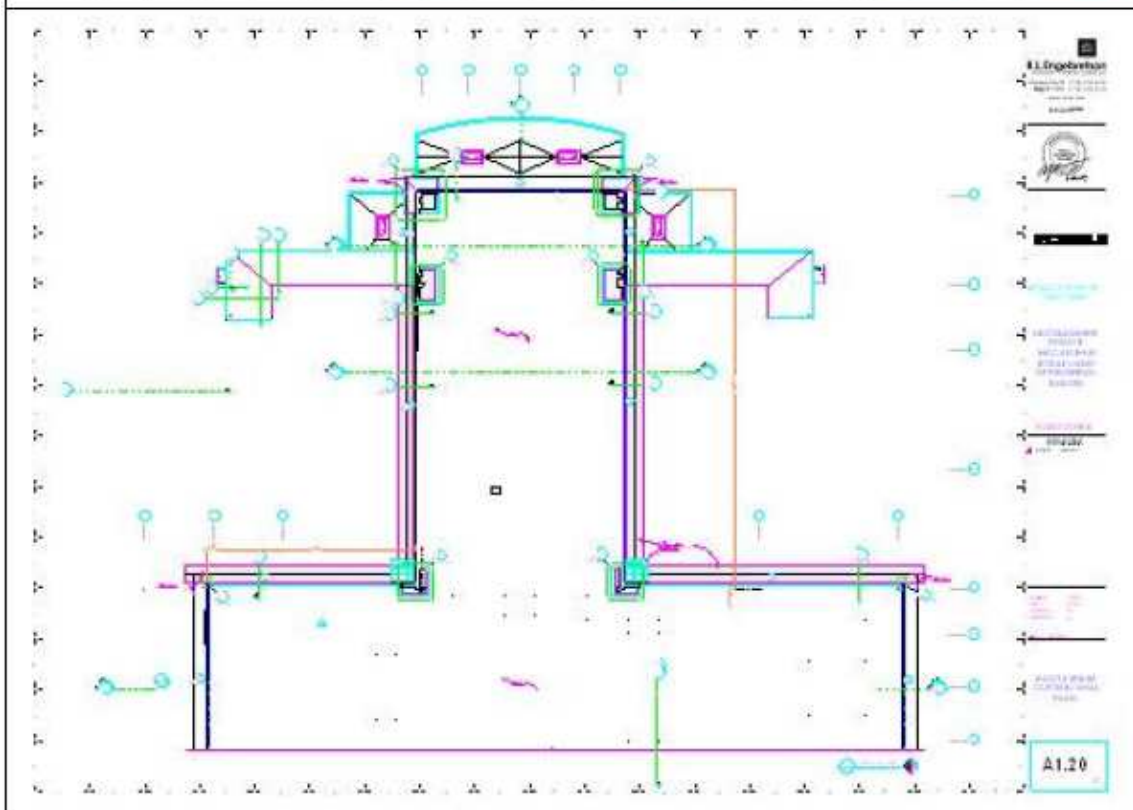
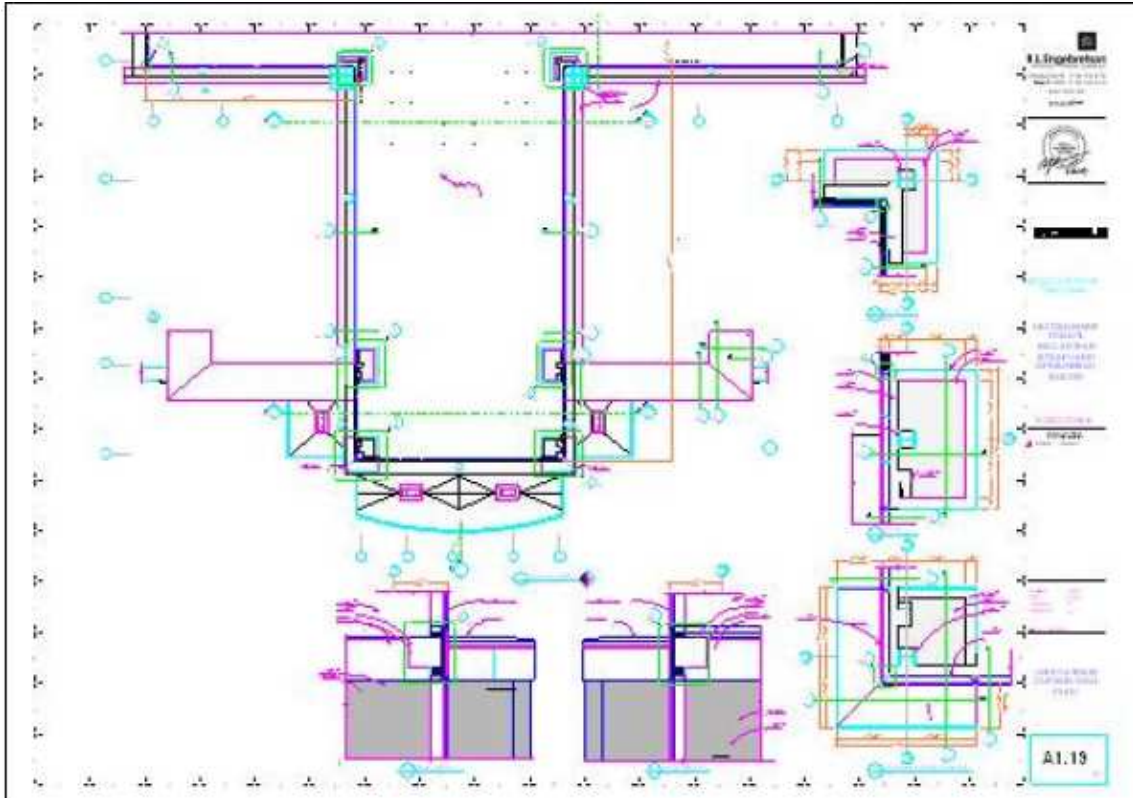




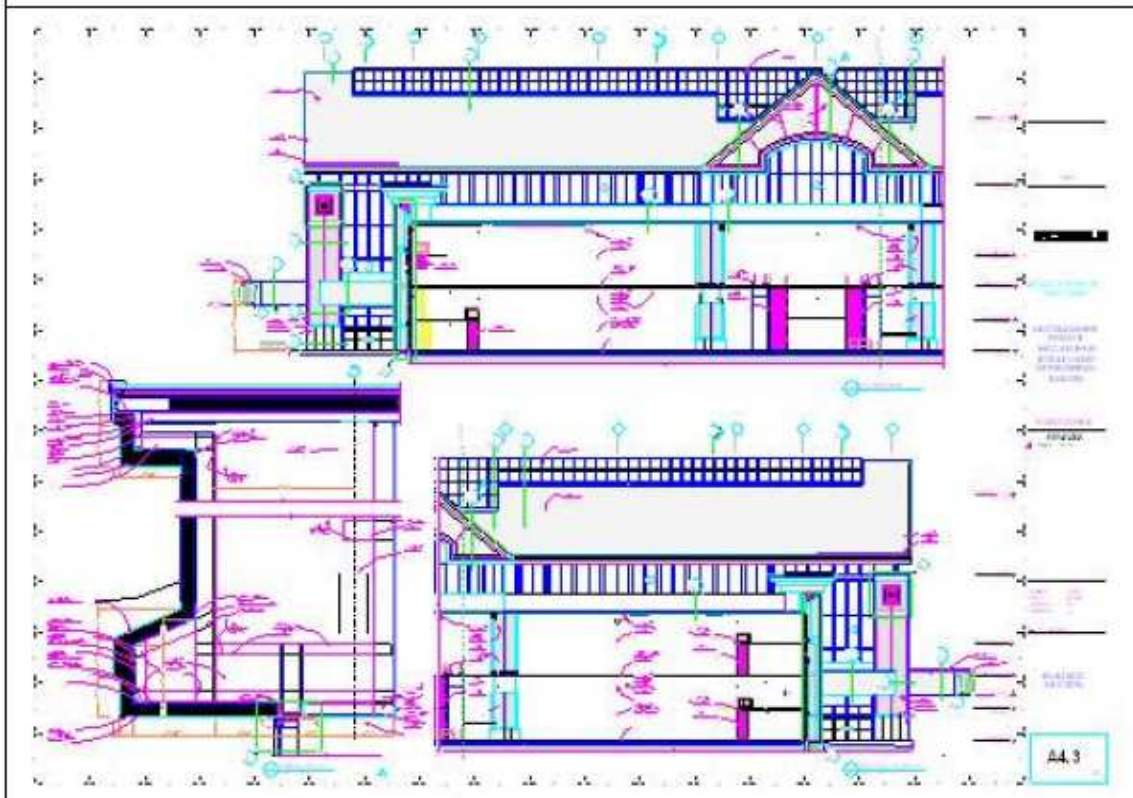
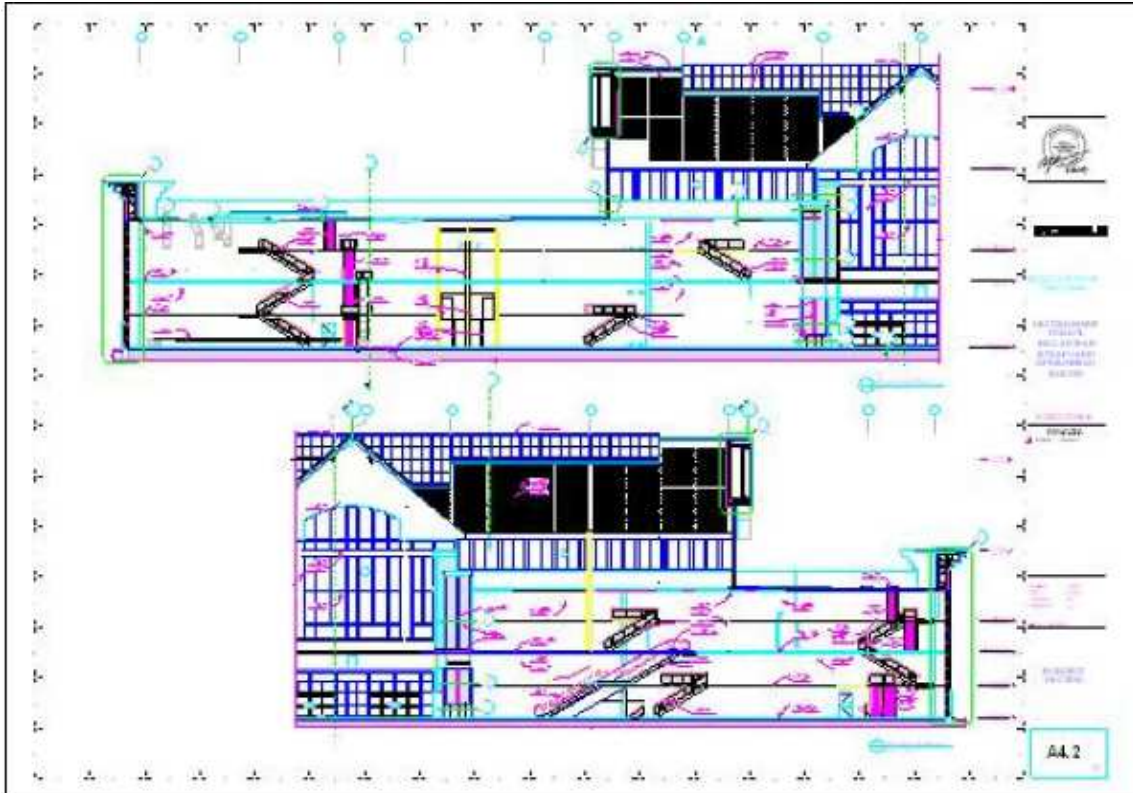












APPENDIX B. COLUMN MATERIAL TAKEOFFS

Structural Column Material Takeoff				
Type	Assembly Description	Length	Material: Area	Material: Name
HSS3X3X1/4	Superstructure	7' - 11 1/2"	14 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS3X3X1/4	Superstructure	7' - 11 1/2"	14 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS3X3X1/4	Superstructure	8' - 6 97/256"	15 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS3X3X1/4	Superstructure	8' - 6 97/256"	15 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	8"	2 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	20' - 0"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	20' - 0"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	20' - 0"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	9' - 8 5/8"	23 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X1/4	Superstructure	19' - 7"	47 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X3/16	Superstructure	19' - 7 1/2"	49 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X3/16	Superstructure	19' - 5 1/2"	48 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X3/16	Superstructure	25' - 0 1/2"	62 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS4X4X3/16	Superstructure	25' - 0 1/2"	62 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square

(continues)

Structural Column Material Takeoff (continued)				
Type	Assembly Description	Length	Material: Area	Material: Name
HSS6X4X3/8	Superstructure	45' - 5 1/2"	134 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS6X4X3/8	Superstructure	45' - 5 1/2"	134 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS6X4X3/8	Superstructure	17' - 0"	50 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS6X4X3/8	Superstructure	19' - 7 1/2"	58 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS6X4X3/8	Superstructure	19' - 7 1/2"	58 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS6X4X3/8	Superstructure	17' - 3"	51 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS6X4X3/8	Superstructure	16' - 11"	50 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
HSS6X4X3/8	Superstructure	17' - 1"	51 SF	Metal - Steel - ASTM A500 - Grade B - Rectangular and Square
W10X49	Superstructure	7' - 11 1/2"	39 SF	Metal - Steel - ASTM A992
W10X49	Superstructure	7' - 11 1/2"	39 SF	Metal - Steel - ASTM A992

APPENDIX C. WALL SCHEDULE

Wall Schedule		
Family and Type	Assembly Code	Assembly Description
Basic Wall: 8" CMU - 2" Rigid	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Ext - 8" CMU Actual	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Ext - 12" CMU	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Ext - Elev Chase Wall - Dog House- 8"stud - 1/2" Gyp- 1/2" Coverboard	B2010180	Ext. Wall - Wood Stud w/ Siding & Shingles
Basic Wall: Ext - Mtl - 8" - 1/2" Gyp - 1" Rigid	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Ext -Scheelsl Atrium Sill-	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Int - Mtl - 6" - 5/8" Gyp - 1/2" Gyp	C1010145	Partitions - Drywall w/ Metal Stud
Basic Wall: Int - Mtl - 6" - (1)5/8" Gyp	C1010145	Partitions - Drywall w/ Metal Stud
Basic Wall: Int - Mtl - 6" - (2) 5/8" Gyp	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Int - Mtl - 6" - (2) 5/8" Gyp - 1 Hour	C1010145	Partitions - Drywall w/ Metal Stud
Basic Wall: Int - Mtl - 8"	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Int - Mtl - 8" - 1" Rigid - 1/2" Gyp - 5/8" Gyp	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: Int - Mtl - 8" - 5/8" Gyp	B2010175	Ext. Wall - Metal Siding Panels
Basic Wall: M5e - Ext - SAS Canopy - 6" - 1/2" Gyp - 1" Metal Panel	B2010180	Ext. Wall - Wood Stud w/ Siding & Shingles
Basic Wall: Pallet Storage		
Basic Wall: RoofWall- Mtl - 6" - (1)1/2" Sheath-(1)1/2" Densdeck-epdm	C1010145	Partitions - Drywall w/ Metal Stud
Basic Wall: SAS Pilaster @ Loading Dock Base - Brick - 3 5/8" AS- 11 5/8" CMU-AS-3 5/8" Brick -no wrap	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: SAS Pilaster @ Loading Dock Upper -15' Brick - 3 5/8" AS-CMU 11 5/8"	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: SAS Stud 8" - Gyp 5/8" (1 side)	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS Back wall - top	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS back wall Mid 1	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS Back wall-Base 1	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS End 2	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS End @ glass	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS End base	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS End base @ glass	B2010158	Ext. Wall - Brick Veneer w/ Stud

(continues)

Wall Schedule (continued)		
Family and Type	Assembly Code	Assembly Description
Basic Wall: Scheels - High Parapet EIFS End Top	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS End Top @ glass	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS Front wall - base 2	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS Front wall - Mid 2	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS Front wall -top 2	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS wall Typ - Mid	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS wall Typ base	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels - High Parapet EIFS wall Typ-top	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Atrium Pilaster Base - Cast Stone - 3 5/8" AS- 3 5/8" CMU-AS-5/8" GypBD-8"Stud 2	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Atrium Upper Pilaster - Brick - 3 5/8" AS-5/8" GypBD-8"Stud	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base - Brick - 3 5/8" AS-1" Rigid-1/2" GypBD-8"Stud-5/8" GYP	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base - Cast Stone - AS - 4" CMU -AS- 6" Stud	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base @ Low Wall of Vestibule - 2-Cast Stone - 3 5/8"AS-12" CMU	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base @ Low Wall Vestibule Behind Column - 2-Cast Stone - 3 5/8"AS-12" CMU 2	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base Ext Pilasters - Cast Stone - 3 5/8" -(2) 8" CMU	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base Ext Pilasters - Cast Stone - 3 5/8" -Rigid - 8" CMU - 6" CMU	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base High Wall - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8" GYP 2	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base High Wall End - Cast Stone - 3 5/8" AS-4" CMU- AS-1" Rigid-1/2" Gyp BD-8"Stud-5/8" GYP	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base Int Pilaster Wall End Wall- Block - 2" Rigid-1/2" GypBD-8"Stud-5/8" GYP Int	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base Interior 1st Fl Pilaster Cart Corral- Cast Stone - 3 5/8" AS-4" CMU- AS-1"-5/8" Gyp BD-8"Stud-5/8" GYP	B2010158	Ext. Wall - Brick Veneer w/ Stud

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Wall Schedule (continued)		
Family and Type	Assembly Code	Assembly Description
Basic Wall: Scheels Base Interior 1st Fl Pilaster-Cast Stone - 3 5/8" AS-4" CMU- AS-1"-5/8" Gyp BD-8"Stud-5/8" GYP	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base Interior 1st Fl Pilaster-Cast Stone - 3 5/8" AS-4" CMU- AS-1"-5/8" Gyp BD-8"Stud-no gyp	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Base Under Loading Dock - Brick - 3 5/8" AS-1" Rigid-1/2" GypBD-8"Stud-5/8" GYP	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Brick - 3 5/8" AS 3 1/8" Sheathing 5/8"	B2010158	Ext. Wall - Brick Veneer w/ Stud
Family and Type	Assembly Code	Assembly Description
Basic Wall: Scheels Brick - 3 5/8" AS 3 3/4" 2" Rigid	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Brick - 3 5/8" AS 3 7/8" Sheathing 1/2" 1" Rigid	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Brick - 3 5/8" AS 4 3/4" Sheathing 1/2"	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Brick - 3 5/8" AS 4 3/4" Sheathing 5/8"	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Brick - 3 5/8" AS 4 7/8" Sheathing 1/2"	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Brick - 3 5/8" AS 5 3/4"	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Brick - 3 5/8" AS 5/8" Gyp 6" Stud	B2010158	Ext. Wall - Brick Veneer w/ Stud
Basic Wall: Scheels Ext High Parapet Back Wall - Mtl - 8" - 1/2" Cover Board - 1/2" Gyp	B2010180	Ext. Wall - Wood Stud w/ Siding & Shingles