

**BUILDING INFORMATION MODELING FOR CONSTRUCTION  
APPLICATIONS: FORMWORK INSTALLATION AND QUANTITY TAKEOFF**

by

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## **Abstract**

Recent advancements in Building Information Modeling (BIM) hold great promise for addressing the challenges of the construction industry by allowing project teams to ‘test out’ a design prior to construction. The projects that have successfully implemented BIM demonstrate numerous benefits, including increased design quality, improved field productivity, cost predictability, less rework, and reduced construction cost and duration. However, much of the research to date has focused more on the preconstruction phase with less research on uses for the construction phase. The goal of this research was to evaluate specific uses of BIM in the construction phase of the project. I investigated two construction applications of BIM: (1) BIM for developing lift drawings to support formwork construction on the BC Hydro Substation project, and (2) BIM for quantity takeoff to support life-cycle assessment (LCA) and construction cost estimating on the Pharmaceutical Sciences project. The BC Hydro project provided an opportunity to examine the use of BIM for the field crew. I developed 3D coordinated lift drawings that conveyed the necessary information for forming the components accurately and clearly. I believe that creating the lift drawings increased the crew’s productivity by providing the necessary information for building a component, resolving conflicts prior to construction, and reducing mistakes.

I evaluated the use of BIM for quantity takeoff using the Pharmaceutical Sciences project. I evaluated two BIM-based and one 2D-based quantity takeoff software, and based on several parameters of importance to cost and sustainability consultants. I found that calculating quantities from a BIM model is faster and more accurate as long as the model is created correctly and accurately to suit the needs of the users.

This thesis provides evidence for the benefits of BIM for construction uses at different stages in the project. The BC Hydro case study provides significant detail on how a BIM can be utilized by construction field personnel. The Pharmaceutical Sciences project demonstrates the benefits and challenges of utilizing a BIM for quantity takeoff. More case studies are needed to demonstrate the benefits of BIM for different applications in the project delivery process to enable more widespread BIM adoption.

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*To My Parents*

# Chapter 1:

## Thesis Overview

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### 1.1 Introduction

Time, cost, and sustainability are of critical importance in today's construction market. To meet these constraints, designers require prompt feedback on the cost, schedule and environmental implications of their design decisions, and contractors need to find ways to improve productivity on site. Current approaches that rely on 2D drawings of a project are not sufficient to meet these demands. The increasing complexity of buildings and requirement for more fast-track project delivery has made it more challenging to manage building information and deliver projects on time and under budget (Douglas E., 2010).

Building Information Modeling (BIM) is gaining popularity in the construction industry and holds great promise for addressing these challenges. BIM is defined by the National BIM Standard (NBIMS) as “a digital representation of physical and functional characteristics of a facility. A BIM is 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” (NBIMS 2007, page 21)

Considering that BIM is a relatively new topic in the construction industry, most research to date has focused on identifying applications, benefits and challenges of BIM. The projects that have successfully implemented BIM demonstrate numerous benefits, including increased design quality, improved field productivity, cost predictability, reduced conflicts and changes, less rework, increased fabrication, and reduced construction cost and duration (Staub-French et. al., 2011). However, much of the research to date has focused more on the

preconstruction phase with less research on uses for the construction phase, particularly at the construction work face (Goedert & Pavan, 2008).

The goal of this research was to evaluate specific uses of BIM in the construction phase of the project. Specifically, I investigated two construction applications of BIM:

1. BIM for concrete construction to support formwork crews in the field. This area of BIM use is novel because it focuses on the construction work face and how information can be extracted and visualized to suit the needs of field personnel accustomed to 2D representations.
2. BIM for quantity takeoff to support life-cycle assessment (LCA) and construction cost estimating. I investigated quantity takeoff with BIM because this information is relevant to many different applications, including procurement, estimating, scheduling, and project control. I chose to look specifically at construction cost estimating and LCA because cost and sustainability are such important parameters in the construction industry today.

For each case study, I documented how the BIM was used, and the benefits and challenges of using BIM for these applications. I used two different construction projects to investigate these applications of BIM: (1) The BC Hydro Mount Pleasant Substation constructed by PCL, and (2) The Pharmaceutical Sciences building constructed by Ledcor. The two following sections will describe these case studies in greater detail.

### **1.1.1 BIM for Concrete Construction: BC Hydro Mount Pleasant Substation**

The first case study is a \$25 million project to build the BC Hydro Mount Pleasant Substation (MPT) located in the False Creek area of Vancouver. The building has a

reinforced concrete structure with three main floors and three subfloors, totaling approximately 2,800m<sup>2</sup> gross area and 12,000m<sup>3</sup> of concrete work. The project is unusual in terms of the massive concrete work and complexity of the structure. There is a massive spread footing and lots of concrete walls and slabs in the building. Many of the openings and sleeves pass through each wall. The walls are complex, as two sides of each wall are different. For instance, beams are not aligned and slabs are not on the same elevation on both sides of the wall. As one side of the wall is shown by dash lines on the 2D drawings, it makes the drawings cluttered and hard for the crew to read and understand how they should form each side of the wall using the 2D structural drawings.

The complex geometry of the walls and slabs with lots of openings and steel embeds required, made the formwork challenging. The time spent gathering all the information needed to build the forms accurately could potentially decrease their productivity. Considering the tight schedule of the project with most activities on the critical path, there was a need to increase the crew's productivity in order to avoid delays. PCL was interested in leveraging BIM for the lift drawings to ensure productivity was optimized for the concrete formwork. Specifically, they wanted me to create 3D coordinated lift drawings. A lift drawing provides all the information needed by the forming crew to form a concrete component, such as a concrete wall. This project allowed us to study how BIM could support the field personnel building the formwork.

The research objectives for this case study were to:

1. Understand the process of formwork construction and the needs of formwork crews.

2. Investigate how BIM can be used to develop 3D coordinated lift drawings that are useful for formwork crews.
3. Identify the benefits and challenges of using BIM to support field personnel during concrete construction.

This project gave us the opportunity to examine the use of BIM for field crews, a topic that hasn't been investigated in depth much in the literature. I worked on site for six months and observed the work process and the crew's needs and developed the format for the lift drawings using the BIM. Using the BIM, I created lift drawings that conveyed the necessary information for forming the components accurately and clearly. I believe that creating the lift drawings for walls and slabs increased the crew's productivity by providing the necessary information for building a component, resolving conflicts prior to construction, and reducing mistakes.

In addition to the lift drawings, I performed conflict detection tests between different systems using the different disciplines BIM models, which helped to highlight design errors and conflicts prior to construction. I also created a 4D mock-up to visualize the construction process and highlight scheduling errors prior to construction.

### **1.1.2 BIM for Quantity Takeoff: The UBC Pharmaceutical Sciences Project**

The second case study is a \$155 million building for the Faculty of Pharmaceutical Sciences and Center for Drug Research (Pharmacy) located at the UBC campus in Vancouver. It is a six-storey building with a gross area of 27,900m<sup>2</sup> building that was constructed using a fast-track project delivery. The building provides various spaces for students and researchers, such as lecture halls, classrooms, seminar rooms, and research labs.

The building is a reinforced concrete building with curtain walls as the envelope system. The interior spaces are divided into different areas by partition walls. There are almost 70 different types of partitions used in this project.

These types of large and complex projects with compressed construction schedules require accurate and fast feedback on the cost and environmental impacts of decisions before and during the construction. This project was studied to evaluate BIM-based quantity takeoff in comparison to 2D-based approaches to support life-cycle analysis and construction cost estimating.

The research objectives for this case study were to:

1. Identify the requirements of quantity takeoff tools to support construction cost estimation and LCA.
2. Evaluate and compare 2D and BIM- based quantity takeoff tools.
3. Identify the benefits and limitations of these tools to support quantity takeoff for different types of construction components in meeting the requirements identified in (1).

For this purpose, I studied the process of construction cost estimation and LCA and tried to identify the required quantities. I also studied existing 2D-based and BIM-based quantity takeoff tools and selected the most appropriate pieces of software for this study based on different factors such as the level of popularity among users and ease of use. I selected a popular 2D-based quantity takeoff software called On-Screen Takeoff and compared it with two pieces of BIM-based software, Tocoman and Revit.

The Pharmacy building project was used to evaluate these software tools by completing the quantity takeoff of three different components; foundations, shear walls and

partition walls. I developed criteria to evaluate the software based on an assessment of the user requirements. In essence, the criteria for evaluation included the *availability* of the required quantities, the *consistency* of the results, the ability to *group* components based on user-defined parameters, the ability to provide *visual verification* or presentation of the results, and the *reporting* capabilities. Each piece of software was assessed based on these criteria for each of the different components analyzed. I also identified the benefits and shortcomings of each of these pieces of software.

I found that each piece of software has benefits and limitations in providing the quantities; however, BIM-based software provides the quantities more efficiently and with greater accuracy. However, it is important to note that when assessing the ‘efficiency’ of the software that the level of effort involved is different for 2D-based tools compared with BIM-based software. For 2D-based software the users’ main effort is primarily in the quantity takeoff stage. However, in BIM-based quantity takeoff, the main effort is put into creating the model; therefore, if the model is created accurately and correctly, the process of quantity takeoff is fast and accurate.

## **1.2 Literature Review**

This section discusses the relevant literature on BIM including uses of BIM, impacts of BIM, and construction uses of BIM.

### **1.2.1 BIM Definition**

Building Information Modeling (BIM) can be viewed as both *product* and *process* (Staub-French et al. 2011). Based on the National BIM Standard (NBIMS), a Building

Information Model is defined as “a digital representation of physical and functional characteristics of a facility. As such it serves a shared knowledge source for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward.”

BIM can also be defined as a process. Based on the BIM Project Execution Planning Guide, BIM is defined as: “A process focused on the development, use and transfer of a digital information model of a building project to improve the design, construction and operations of a project or portfolio of facilities” (CIC research group 2009)

### **1.2.2 Uses of BIM**

BIM can be used to support a variety of functions throughout a project. In each project the application of BIM is based on the characteristics of the project and the disciplines that are involved in modeling. Studying current practices, various applications have been identified by different researchers such as 3D coordination, design reviews, design authoring, existing conditions modeling, 3D control and planning, 4D modeling, record modeling, site utilization planning, site analysis, structural analysis, energy analysis, cost estimation, sustainability LEED evaluation, building system analysis, space management, mechanical analysis, code validation, lighting analysis, digital fabrication, asset management, disaster planning, visualization, fabrication/shop drawings, code reviews, facility management (Azhar et al., 2008; Ashcraft, 2008; Foster, 2008; Kreider et al. 2010; Ningappa, 2011).

### **1.2.3 Impact of BIM**

Considering the different uses of BIM, many benefits have been highlighted by different researchers. In McGraw-Hill's "SmartMarket Report on Building Information Modeling: Transforming Design and Construction to Achieve Greater Industry Productivity" (2008) the return on investment for BIM was researched. Based on this research:

- The surveyed companies say they are getting returns of 300% to 500% on their investments for projects in which BIM was used. These companies are actively tracking BIM return on investment.
- 82% of respondents believe that BIM is having positive impacts on their company's productivity.

In a follow-up survey they identified the key areas in which BIM has the most value as: reduced conflicts during construction, improved collective understanding of design intent, improved overall project quality, reduced changes during construction, reduced number of RFI's, and better cost control/predictability (McGraw-Hill Construction, 2009).

Stanford University Center for Integrated Facilities Engineering (CIFE) indicates the benefits of BIM based on 32 major projects, as follows (Gao & Fischer 2008):

- Up to 40% elimination of unbudgeted change.
- Cost estimation accuracy within 3%.
- Up to 80% reduction in time taken to generate a cost estimate.
- A saving up to 10% of the contract value through clash detection.
- Up to 7% reduction in project time.

Therefore, using BIM can have significant impacts on construction industry by reducing cost and time. Looking at various uses and impacts of BIM, and considering the

amount of research that has been done about uses of BIM in different stages of the project, two uses of BIM are going to be studied in greater depth in the two following sections; Construction uses of BIM and BIM for quantity takeoff.

#### **1.2.4 Construction Uses of BIM**

BIM is being used for different stages of the project from the conceptual phase to maintenance and facility management. Most of the studies that have been conducted have focused on the use of BIM in design stages of the project, particularly for visualization and coordination. However, BIM can have significant beneficial impacts in the construction phase as well. Contractors who are applying BIM have found that producing models saves them enough money by avoiding rework that they use BIM regardless of whether or not other trade contractors or general contractors want to create a model (Kymmell, 2009). For instance, during the clash detection process, simple clashes such as a pipe passing through a duct will be discovered which will save the project money and time. Sometimes the savings through not having to re-work, wait for direction, and prefabricate more logical components in addition to resolving conflicts prior to construction, can be on the order of 10 to 30% (Eastman, Teicholz, Sacks, & Liston, 2008).

Contractors are reporting remarkable improvements in their operations because of BIM usage. For example:

- For the Washington National's stadium, instead of the 1,000 to 10,000 RFI normally issued for these types of projects, only 100 RFI were issued. In addition, only 2% of the steel embeds needed to be changed; however, for projects of the same type and complexity, 10% of the embeds typically needed to be changed (Fortner, 2008).

- In the Camino MOB project, the superintendents spent 10-15 hours in eight months dealing with field issues during MEP construction; normally they would spend two to three hours each day dealing with these issues (Khanzode, Fischer, & Reed, 2008).
- The CCC Dubai Mall project reduced the cost of quantity survey and concrete work by 65% using BIM and automated tools. It also helped to improve the quality and efficiency of the process (Bentley Systems Inc, 2008).

Investigating current literature, Goedert & Pavan, (2008) observed that “BIM application stops at the preconstruction phase with a limited amount of research regarding data collection of the construction process”. There are not many case studies available dealing with BIM usage by the workforce and field personnel. DPR Construction is one of the pioneers in leveraging BIM for field personnel. For instance, they modeled metal stud framing for the drywall in several projects. They mentioned that “modeling the framing helped to get accurate takeoff of materials per floor and the field crew know exactly where the posts go and the correct orientation from looking at just one drawing” (Casale, 2010). Sacks et al. (2009) proposed prototypes to visualize the workflow of the crew in the building to make sure there is a smooth flow at the work face.

These case studies demonstrate that BIM can be leveraged efficiently in the construction phase of a project; however, case studies of BIM uses at the construction work face are limited.

### 1.2.5 BIM for Quantity Takeoff

Cost and environmental impacts play a vital role in decision-making about a project. Both of these factors require quantities of the materials being used in the project. Considering the dynamic nature of projects, accurate quantities are needed in a timely manner.

Traditionally, estimators used the 2D drawing sheets to perform the quantity takeoff. Alder (2006) described the challenges of this method as follows: “Unfortunately for large projects, manual takeoff can be a very time consuming and tedious task. An estimator must use a well-organized systematic method of takeoff to avoid missing or double counting items. An estimator must also take special care when transferring measurements to their ledger by verifying that each measurement is recorded correctly. Additionally, the ledger must be organized in a way that when changes occur or measurements must be verified the estimator can easily review the calculations performed” (Alder, 2006).

Many tools have been developed to help estimators get the quantity takeoff completed more accurately and faster. They range from digitizers, on-screen takeoff to BIM. 2D-based quantity takeoff software such as On-Screen Takeoff has some benefits, such as:

- Allowing the user to view a variety of drawing files and to measure items electronically using the mouse rather than a scale or a digitizer tablet,
- Being more organized by using different colors, line styles, count symbols, and area fill patterns,
- Faster quantity takeoff than manual methods (Alder, 2006).

2D drawings lack the rich three-dimensional (3D) context that estimators need in order to identify important cost-sensitive design features; however, some BIM tools have addressed some of these limitations (Staub-French & Fischer, 2003). In addition doing

quantity takeoff using this software is still a cumbersome tedious task, as all the measurements have to be done manually, and handling changes is difficult. Extracting quantities from 2D drawings can take up to as much as 50-80% of an estimator's time in a project; however, with the 3D model the time usage is expected to decrease (Bylund & Magnusson, 2011). This will enable the estimator to dedicate his or her time to other cost factors such as design conditions, preferences, and resources.

Much research has been done on cost estimating using 3D models by creating integrated models that relate components, activities, resources, and costs (Clayton et al., 1996; Marir et al., 1998; Froese et al, 1996). However, they do not account for different design conditions or different estimator preferences in the cost estimation process. Staub-French et al. (2002) formalized a process to customize project activities, resources, and resource productivity rates based on a project-independent representation of cost estimators' rationale and a project-specific feature-based product model. This process creates an integrated model that relates features, activities, resources, costs, and estimator's rationale.

Bylund et al. (2011) believe that model-based cost estimating and quantity takeoff have benefits such as:

- More precise quantities through all project phases.
- Changes create immediate updates in the list of quantities and cost estimates.
- Possibility of very precise planning of material delivery with thorough scheduling.

Although researchers have been studying 3D model uses for quantity takeoff, they are not used much in practice. DPR Construction compared the manual estimating process with the model-based estimating process for the \$320 million, six-storey, and 130-patient bed replacement hospital called Sutter Medical Center Castro Valley (SMCCV). They concluded

that “using the 3D model to estimate rather than 2D drawings utilizes the object attribute of the 3D model rather than “assuming” the same based on the flattened 2D drawings. The process is not only quicker but also eliminates scope for errors and omissions. The cycle time of estimation is reduced from 8 weeks to 3 weeks using the model based approach” (Tiwari et al. 2009). They also mentioned that Model-based cost estimating is not a push of the button process and a lot of upfront work is required to get to a desired level of automation. “It took approximately 3 months of setup time for the cross-functional team of the architects, engineers, self-perform work estimators, and BIM engineers to automate the cost-estimating process on the SMCCV project and generate fortnightly cost estimate updates on design changes” (Tiwari et al. 2009). However, they believe that the advantages of model-based estimating far outweigh the upfront time and effort required to enable the process.

In addition, limited research has been done on evaluating the available software and highlighting the benefits and challenges of the software when compared to 2D-based software. Alder (2006) compared Revit with On-Center’s OST as a user study. He asked the participants to perform quantity takeoff of a small commercial building using Revit and OST and the results were analyzed in terms of time and accuracy. The results showed that those using BIM were able to perform the overall takeoff faster than those using ODT while maintaining equivalent accuracy.

### **1.2.6 Conclusion**

The many advantages of using BIM in the construction industry have increased interest in using BIM for different stages of a project. Considering the complexities and fast track nature of the today’s projects high productivity and effective cost and environmental

impact feedbacks are some of the key factors for a project success. Looking at current practice shows that BIM could be beneficial in various stages of the project; however, there is lack of studies about utilizing BIM to meet these factors.

This thesis has investigated specific novel uses of BIM in the construction phase of a project using two real case study projects. The next section describes the research methodology for each of these case studies.

### **1.3 Research Methodology**

Two separate research methodologies were used for the two case studies.

#### **1.3.1 BIM for Concrete Construction**

The research methodology used for this project is as follows:

##### **1.3.1.1 Conduct Literature Review**

I reviewed the existing literature in the area of BIM uses in different stages of a project, especially the construction phase, to identify the body of knowledge to use and build upon in the case study. The literature review provided me with an understanding of the gaps in these studies and how my research can contribute to the body of knowledge by filling these gaps. The literature review helped to give me a solid background for performing the case study, as well as a point of departure for my research.

### **1.3.1.2 Evaluate 2D Drawings and 3D Models**

To develop the lift drawings and perform the clash detection tests, I reviewed the 2D drawings and the project documents. I also tried to coordinate the 2D drawings with the 3D models provided by the consultants, to identify what was and was not modeled. This helped me to understand how the models could be used and how to extend their use for different purposes.

### **1.3.1.3 Collect Data and Knowledge**

I attended the site for six months on a daily basis and observed the construction process and interviewed the site personnel. I collected information about the crew's needs, the construction process, the methods of creating forms, the ways changes are handled, and how conflicts are identified. This gave me an understanding of what is expected from lift drawings and clash detection tests. It also helped me to identify the source of information that needs to be included in the drawings.

### **1.3.1.4 Analyze Data and Knowledge**

Using the data and knowledge collected, I developed lift drawings according to the crew's needs, performed clash detection tests, and created 4D visualizations. Throughout this process, I identified the challenges and attempted to resolve them by consulting with the crew personnel and using the reviewed literature. In addition, I identified the impacts of using the BIM by talking to and observing site personnel.

## **1.3.2 BIM for Quantity Takeoff**

The research methodology used for this project is as follows:

### **1.3.2.1 Conduct Literature Review**

I reviewed the available literature in the area of quantity takeoff, cost estimating, and quantity takeoff using BIM to identify the body of knowledge. The literature review helped to familiarize me with the body of knowledge and the contribution that I could make. The literature review allowed me to study and analyze the case study with a better understanding.

### **1.3.2.2 Develop User Requirements for Quantity Takeoff Tools**

Looking at the literature review, I identified the information required for cost estimates and LCA. I identified what a user needs to know to be able to perform an accurate cost estimate or LCA for each type of component, including dimensions, areas, and volumes. For specifying the LCA requirements, I also looked at the LCA software and investigated the required information that the software needs to perform the assessment.

### **1.3.2.3 Develop a Set of Criteria to Evaluate Pieces of Software**

Looking at the cost estimation and LCA process, I identified some criteria to evaluate the functionality of the selected pieces of software. The set of criteria shows the ability of the software to answer user's needs. It gives the user the ability to play with data and obtain the required information. For instance, the user's need to calculate the quantities based on levels requires a piece of software with grouping capabilities. Therefore, grouping is one of the criteria that the user will consider when evaluating a piece of software.

#### **1.3.2.4 Evaluate State-of-the-art Software:**

I evaluated software tools for quantity takeoff in order to choose the most appropriate software to be used for the case study. This gave me the opportunity to become familiar with the existing software and have a general idea about the benefits and shortcomings of each. I chose a piece of 2D-based software called “On-Screen Takeoff” and two pieces of BIM-based software called “Revit Architecture” and “Tocoman iLink” mainly because of their popularity in the construction industry. I started learning about the selected pieces of software in depth to be able to perform the case study.

#### **1.3.2.5 Evaluate 2D drawings and 3D Models**

I began looking at the 2D drawings and the 3D models and tried to compare them. This helped me to find out which components are modeled in the 3D model, how they are modeled and if all the materials are assigned to it.

#### **1.3.2.6 Perform Quantity Takeoff Using 2D and BIM-based Selected Software**

Using the selected software, I performed the quantity takeoff for the three major components in the case study. This gave me an understanding of the process of quantity takeoff using each piece of software and the challenges that the user might have while performing the quantity takeoff.

#### **1.3.2.7 Evaluate 2D and BIM-based Quantity Takeoff Software**

I compared the selected pieces of software based on the identified criteria and the requirements for cost estimate and LCA purposes for three major components in the building.

I was able to identify the strengths and weaknesses of each piece of software based on the specified criteria.

The next section identifies the outline of this thesis.

#### **1.4 Outline of Thesis**

This thesis includes an introduction that contains a brief description of the research and a review of existing research that has been done in the same area. It also includes a brief description of the case studies and the methodologies that we used to perform them. The following two chapters constitute the main body of the thesis.

Chapter 2 addresses the use of BIM in concrete construction. In this chapter, we investigated how BIM can be used by field personnel on site to support formwork construction during construction of the BC Hydro Mount Pleasant Substation project. The 3D models were used to create lift drawings, perform clash detection, and create 4D visualizations. I also identified the impacts and challenges of using BIM for this purpose.

Chapter 3 investigates BIM use for quantity takeoff. In this chapter, I used the Pharmaceutical Sciences Building to evaluate two pieces of BIM-based software, Revit and Tocoman iLink, and compared them with a piece of 2D-based software called On-Screen Takeoff. I highlighted the benefits and shortcomings of each piece of software for different types of components.

The last chapter gives the conclusion based on the two case studies and our recommendations for future work.

## **Chapter 2:**

### **BIM for Concrete Construction**

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This chapter investigates BIM for field personnel responsible for concrete construction. I worked directly with the general contractor over a 6-month period during construction of the BC Hydro Mount Pleasant Substation. I develop coordinated 3D lift drawings for their forming crew based on the BIM's provided by the consultants.

The research objectives for this case study were to:

1. Understand the process and needs of field personnel in concrete construction.
2. Investigate how BIM can be used to develop 3D coordinated lift drawings that are useful for field personnel.
3. Identify the benefits and challenges of using BIM to support field personnel.

The next section describes the project in more detail. Then, the remainder of this chapter describes the process I went through to create coordinated 3D lift drawings, the impact of these drawings on the field personnel and the project, and the lessons learned.



**Figure 2.1 Rendered 3D view of BC Hydro Mount Pleasant Substation (Source: Genivar Inc.)**

## **2.1 About the Project**

I studied the concrete construction of the BC Hydro Mount Pleasant Substation, which is located in the False Creek area of Vancouver. The project is a part of the Vancouver City Central Transmission (VCCT) Project. This substation will be served by 230 kV of underground cables and designed to transform and provide up to 300 MVA at 12 kV or 400 MVA at 25kV distribution load.

The substation is located at the corner of Alberta St. and West 6<sup>th</sup> Ave. in Vancouver, BC, and occupies approximately 30,000 square feet. The project area is surrounded by mixed residential and commercial dwellings. Figure 2.2 shows the project's location.



**Figure 2.2. MPT site plan**

## 2.2 Project Participants

The general contractor is PCL Constructors Westcoast Inc. (PCL). It is a \$25 million lump sum contract awarded to PCL through the traditional bidding process in May 2011. The owner is BC Hydro and the structural, mechanical and electrical engineer is Genivar Consultants LP. Genivar is also the project manager. The architectural work is done by PBK Architects Inc. and the landscape architect is Durante Kreuk LTD. Golder Associates LTD. is the geotechnical consultant.

PCL subcontracted some of the tasks with some sub-trades; for instance, Targa Contracting Ltd. is responsible for excavation and backfill for raft slab, grounding, piping

and complete supply and installation of three transmission duct banks. Lockerbie and Hole is providing mechanical systems, including three air handling units, three cooling towers, chiller, DDC system, and its subcontractors are Apollo Sheet Metal, ESC, and Arcwest Mechanical Insulation Inc.

Electrical systems including transmission and distribution ducting throughout the building, and the grounding grid under the slab and throughout the building are done by Western Pacific Enterprises.

LMS reinforcing steel group is responsible for reinforcing components in the building, and Solid Rock Steel Fabrication Co. Ltd. is responsible for providing steel components such as steel embeds. In addition sprinklers, including a deluge system plus an inert gas system, are provided by National Hydraulics.

### **2.3 Building Design**

The building is a reinforced concrete structure with three main floors and three subfloors. 12.5 m of the structure is constructed underground and 17m is constructed above ground. The roof is made of structural steel with deck and concrete topping and the building envelope is a combination of curtain wall, masonry, and aluminum panels.

As it was mentioned before, PBK Architects designed the building concept and the structural, mechanical and electrical design of the building was done by Genivar. The drawings are provided in 2D and a BIM model of each discipline (architectural, structural, electrical, and mechanical) is presented alongside. Figure 2.1 shows the rendered 3D view of the building and Figure 2.3 to Figure 2.8 show the 2D drawings and BIM models of different categories.

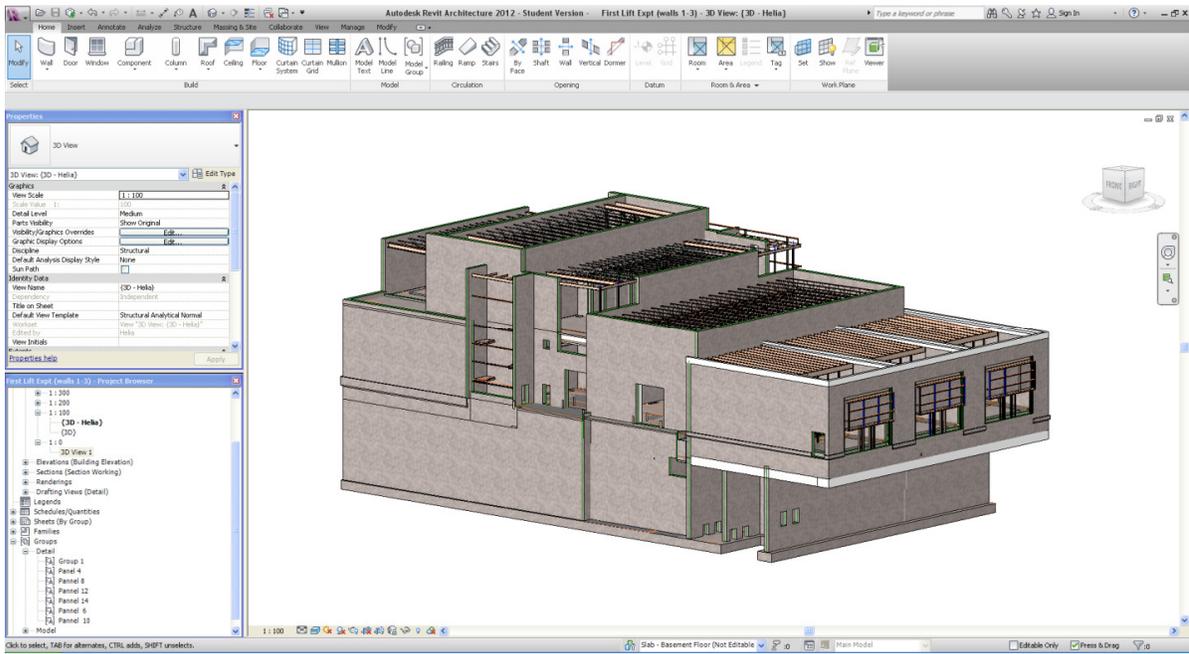


Figure 2.3 MPT structural 3D model

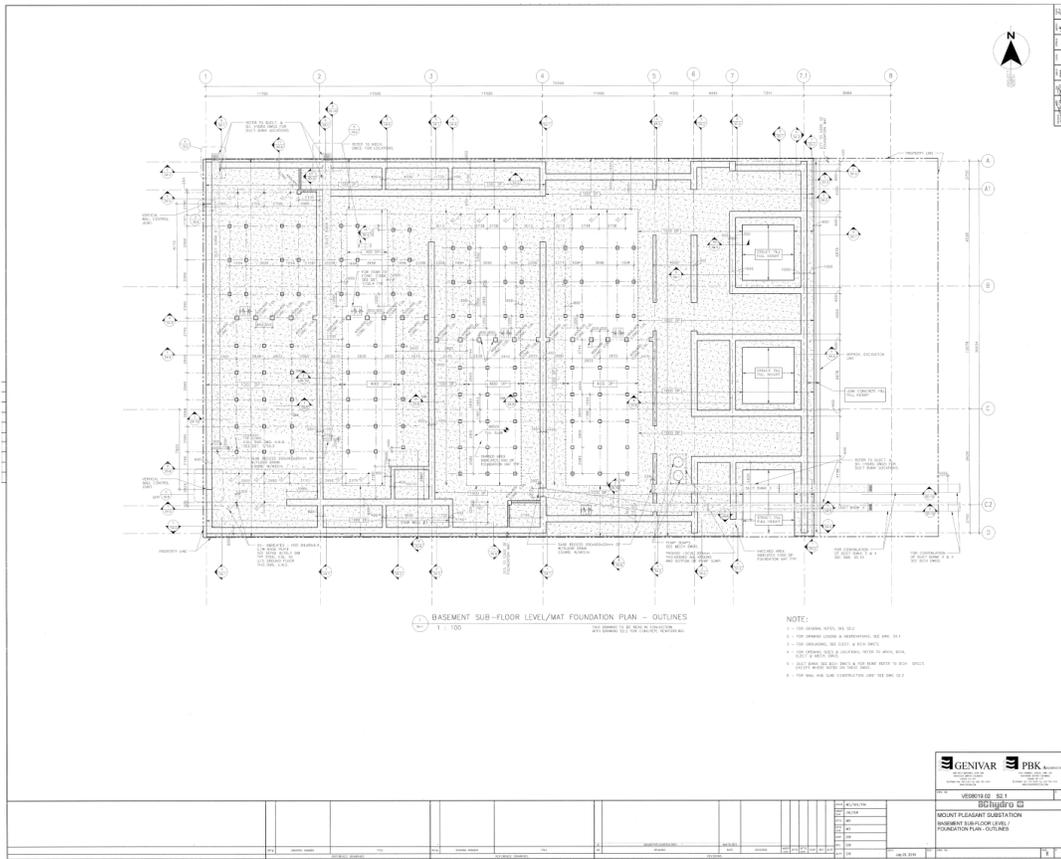


Figure 2.4 MPT structural 2D drawing

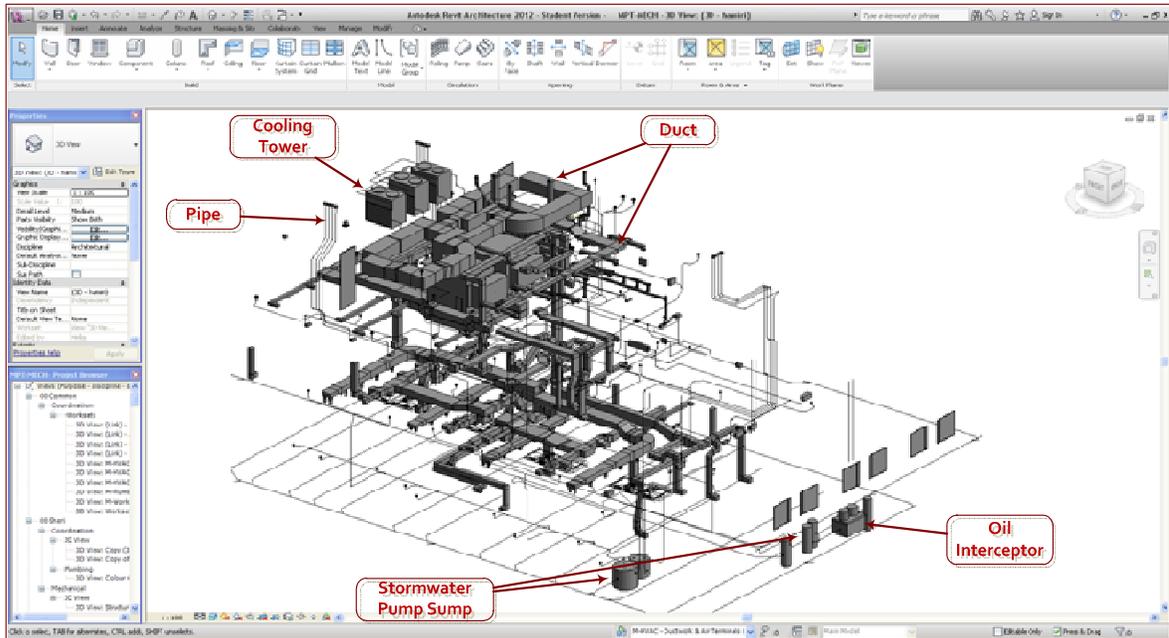


Figure 2.5 MPT mechanical 3D model

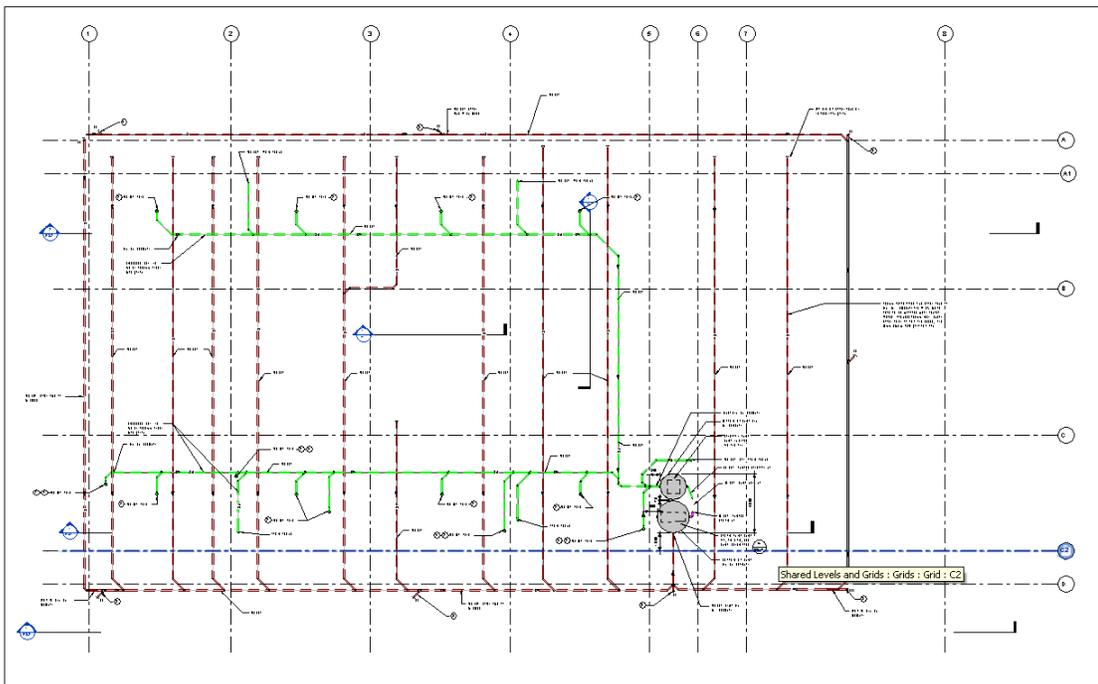


Figure 2.6 MPT 2D mechanical drawing for plumbing— basement sub-floor level

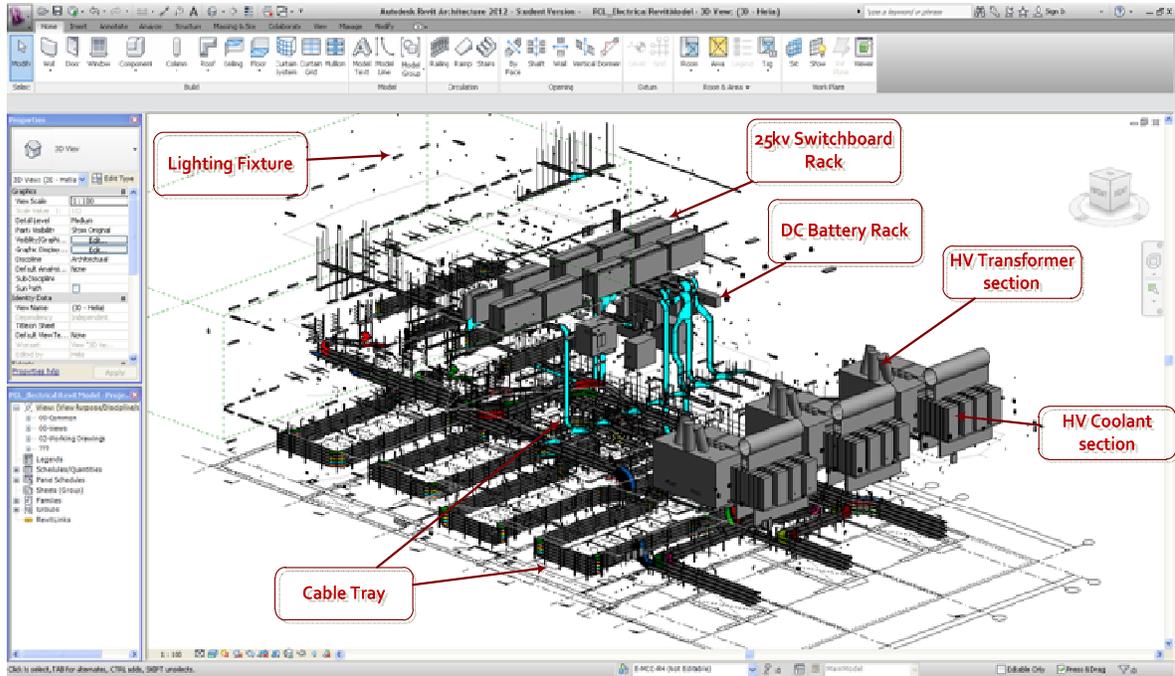


Figure 2.7 MPT electrical 3D model

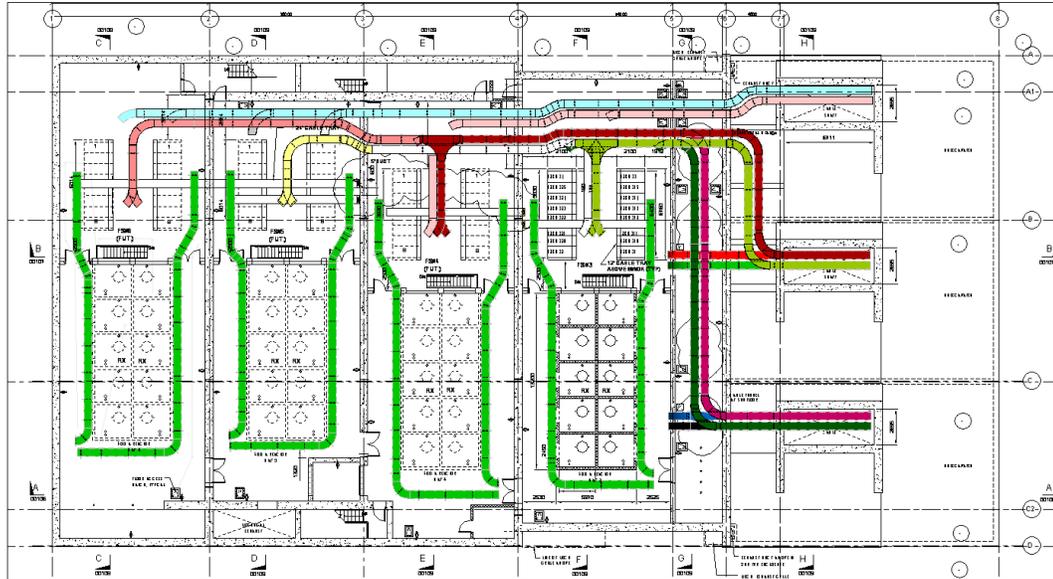


Figure 2.8 MPT electrical 2D drawing— basement sub-floor level

## **2.4 Construction**

The construction phase began in May 2011 with an estimated duration of 17 months. BC Hydro has established sustainable goals for the project's design and construction. The Mount Pleasant Substation is registered with the Canada Green Building Council (CaGBC) under LEED® Canada-NC v1.0 with an anticipated certification level of Silver.

## **2.5 Project Scope**

The work that is going to be carried out by PCL consists of:

- Detail excavation, filling, grading and compaction;
- Complete construction of the new Mount Pleasant Substation Building including:
  - Concrete structure, including formwork, reinforcing steel and concrete.
  - Brick and concrete masonry including all accessories, reinforcement and grout fill when required.
  - Structural steel, miscellaneous iron and steel deck.
  - Carpentry, lumber, plywood and millwork.
  - Roofing, waterproofing, flashing, and sheet metal, membranes, insulation, fireproofing, cladding systems, roof hatches, sealants and caulking.
  - Steel doors and frames, sectional overhead doors, hardware, glazing and curtain wall.
  - Steel stud systems, wall board, acoustical treatment, painting and sandblasting.

- Miscellaneous specialties, access flooring systems, steel plant training systems, and washroom accessories.
- Fall protection system.
- Hydraulic elevator
- Crane operation
- Mechanical Services including:
  - HVAC air handling units and ductwork
  - HVAC fans and ductwork
  - Refrigeration system
  - Water cooling towers
  - HVAC control system
  - Sanitary plumbing system
  - Storm drainage system
  - Ground water drainage system
  - Oil separation and drainage system
  - Fire protection sprinkler system
- Electrical Services Including:
  - Lighting and control system
  - MCC and power wiring for mechanical services
  - Transformers and panel boards for lighting and building power
  - Fire alarm system
  - Empty conduit system for voice, data, PA and security
  - Grounding systems

- Electrical Equipment, conduits, cable trays and wiring for building services
- Conduit and cable tray for substation equipment
- Transmission and distribution feeder ductbanks
- Miscellaneous site works including but not limited to asphalt concrete paving, reinforced concrete slabs-on-grade, concrete sidewalks and curbs, concrete brick paving, site lighting, landscaping and underground utilities, sewers and services.

## **2.6 Site Layout Plan**

Considering the size of the job site, one crane would be enough to cover the whole area; however, due to the tight schedule and heavy concrete work, it was decided to have two tower cranes on site to increase the productivity. In the site layout plan shown in Figure 2.9, loading areas for both cranes are shown.

The job site has two entrances, one for workers that leads directly to the work area and the other, located on the north east side of the site, for visitors. As it can be seen in Figure 2.9, the site office is located on the east side of the job site from which the superintendent has great control over the ongoing tasks and can monitor the productivity. The site office is also close to the entrance to the site so that the visitors can enter the site office without breaking any safety regulations. Sub-trades and workers' trailers are located on the north side of the site, close to the entrance of the work area, making it easy and fast for the workers to enter the site.

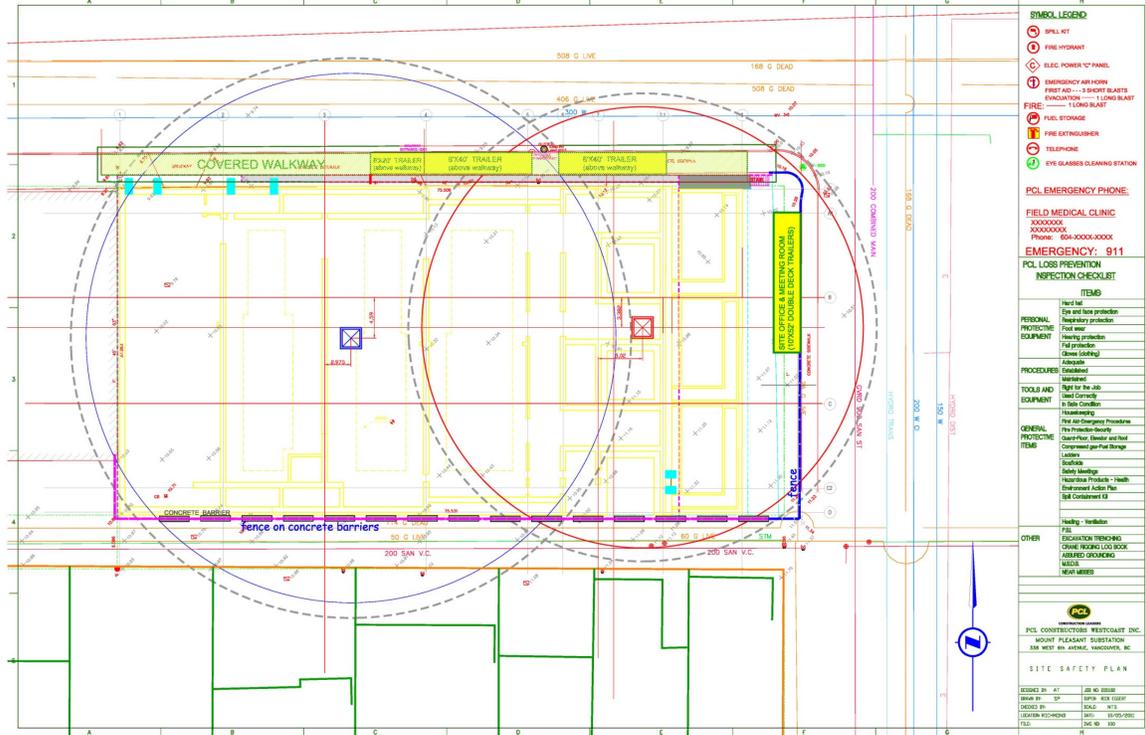


Figure 2.9 Site layout plan

### 2.7 Project Schedule

The project schedule is provided in P6 and reviewed by BC Hydro. The project began in May 2011 with an anticipated finish in August 2012. A part of the project schedule is shown in Figure 2.10 and Figure 2.11. As can be observed, the project has a really tight schedule and most of the tasks, especially the concrete works, are in the critical path. Therefore, there exists no room for mistakes, delays and unforeseen situations.

Figure 2.12 to Figure 2.19 show the construction site at different periods of time







**Figure 2.12. Project site after excavation**



**Figure 2.13. Project site after putting grounding wires and reinforcing crane 1 foundation slab**



**Figure 2.14. Finishing half of foundation slab and reinforcing the other half**



**Figure 2.15. Concrete pouring the other half of foundation slab**



**Figure 2.16. Wood panels for forming the walls**



**Figure 2.17. Formwork for the west side of the wall along grid line 4 with embeds and location of the ducts on it**



**Figure 2.18. Part of a formwork for a wall with the embeds and block-outs**



**Figure 2.19. Forming suspended slab**

## **2.8 Concrete Lift Drawings**

A lift is referred to as the height of the quantity of concrete placed into a form at one time. Therefore, a lift drawing is a drawing that depicts all the information pertaining to that concrete lift. This might include the required dimensions related to the geometry of the component, the embedded items, penetrations and information about the forms. In order to increase the productivity of the crew, these drawings should be complete enough to ensure that there is no need to browse through other sources of information in the field while constructing the component. Figure 2.20 shows a provided wall lift drawing for MPT with all the sources of information used to create it.

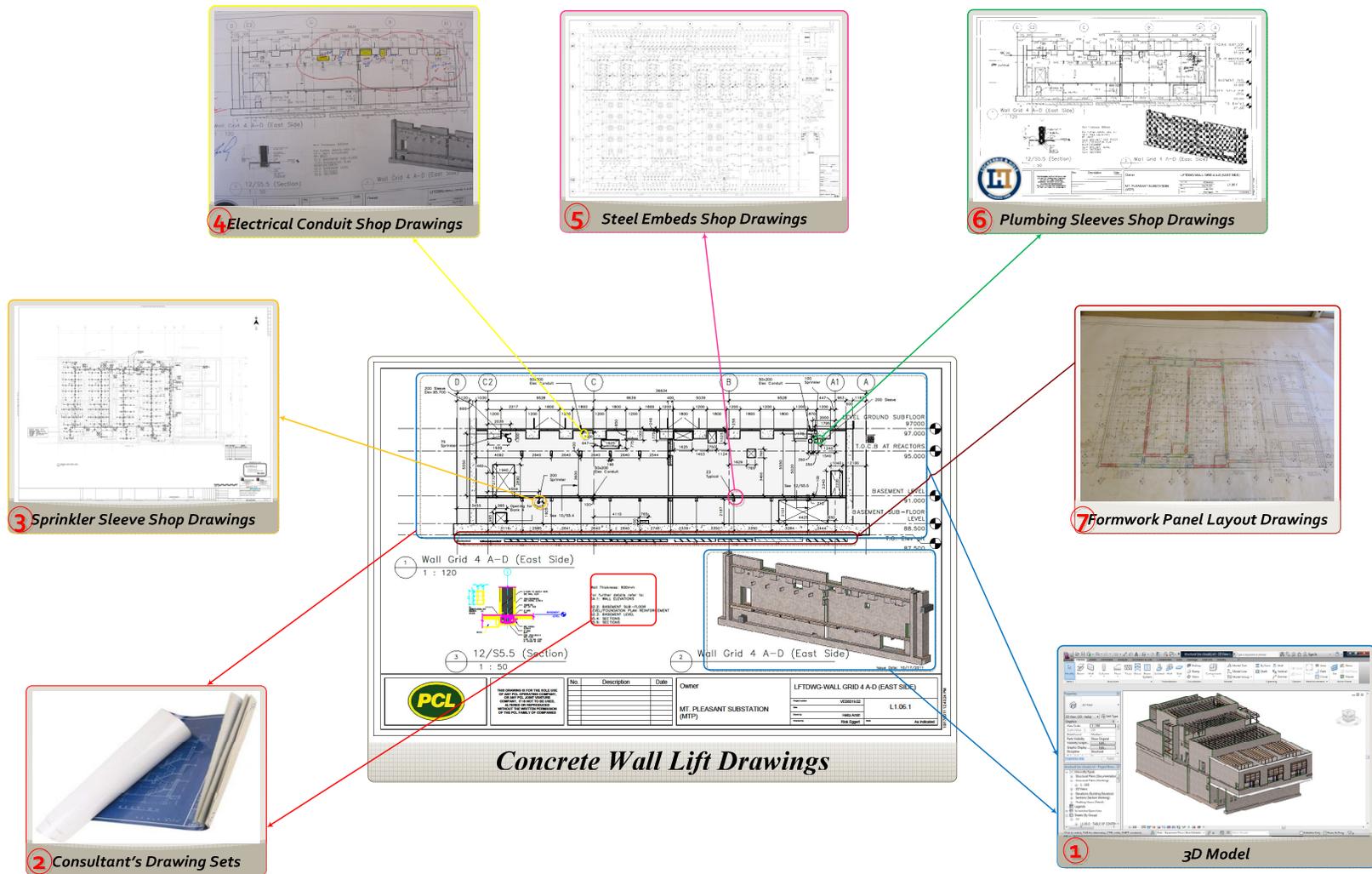


Figure 2.20 Concrete lift drawing with related sources of information

The central image in Figure 2.20 is the wall lift drawing provided for one side of the concrete wall along gridline 4 in the MPT project. The required information was gathered from different sources of information shown in Figure 2.20.

Item 1. One source of information which was a great resource for the lift drawing is the BIM model created by the consultants. From the 3D model, especially the structural 3D model, a 3D view and an elevation view of each side of the concrete component is provided.

Item 2. The second source of information was the complete set of drawings, including structural, mechanical, and electrical drawings which were provided by the consultant in 2D drawing sheets. Information such as dimensions, notes, and a list of related drawings to that side of the components were extracted from the drawing sets.

Item 3. Sprinkler sleeve shop drawings provided by National Hydraulics are another source of information. Incorporating these drawings into the lift drawing helps the crew to locate the required sleeves on the component.

Item 4. Electrical conduit shop drawings provided by Western Pacific is the other source of information which identifies the location of the electrical conduits on the component.

Item 5. Item 5, the steel shop drawings designed by Solid Rock Steel, determines the location of steel components such as embeds and steel plates.

Item 6. Plumbing shop drawings provided by Lockerbie and Hole show the sleeves needed to be considered in the concrete component.

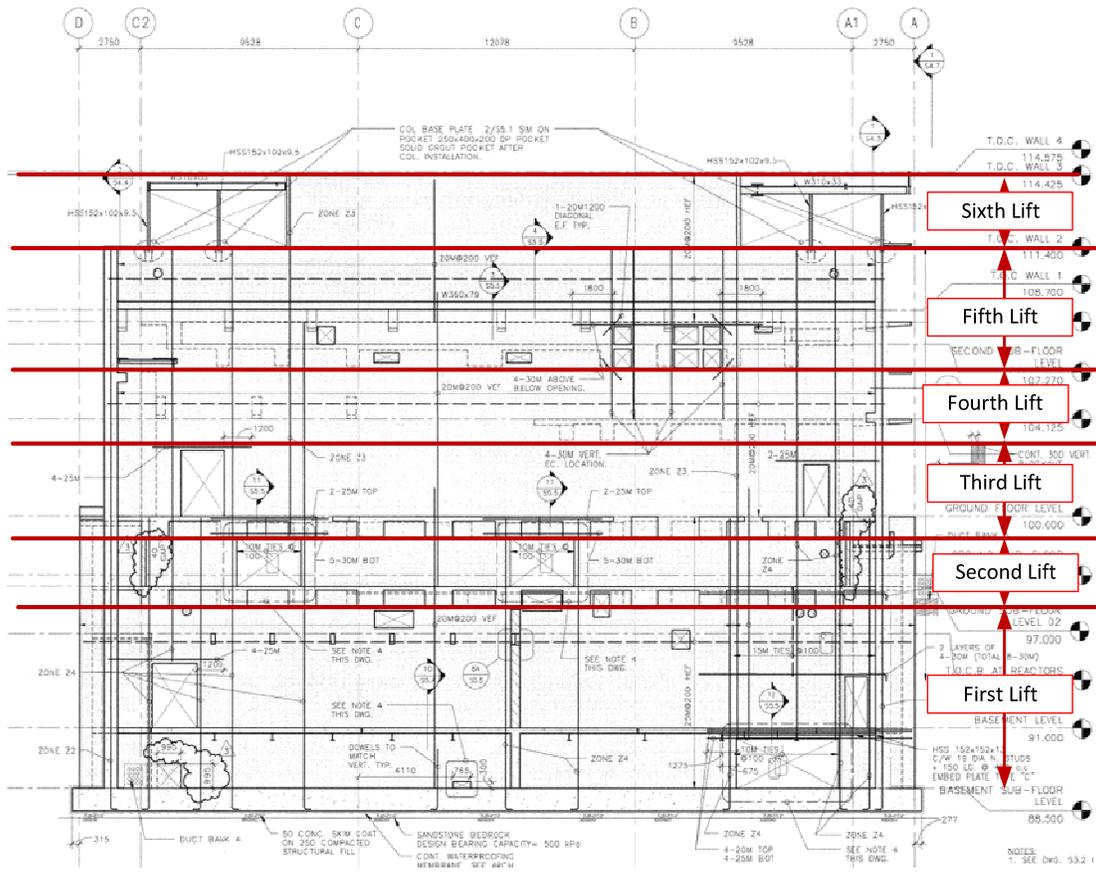
Item 7. The panels needed for building the forms of the component are available at the formwork panel layout drawings.

The lift drawings help to increase construction efficiency by incorporating all the required information needed to build a concrete component from the different sources. The next section describes the traditional method of creating lift drawings and subsequent sections describe my process for creating lift drawings from a BIM.

## **2.9 Concrete Wall Lift Drawings**

Based on PCL's financial estimate, about 27.8% of the project's total cost is dedicated to forming, placing and finishing the concrete components, the majority of which are walls and slabs. Looking at the project's schedule shows that these tasks are mainly in the critical path. Concrete walls, in particular, are one of the major tasks among the concrete works in the project.

There are occasions when about 33 feet (10 meters) height of concrete is poured using 40 foot height panels in a single lift. On each wall, there are many openings and sleeves which the forming crew should consider while building the formworks. Rebar zones and steel embeds on the walls should also be laid out prior to concrete pouring. Considering these complexities, there was a need for lift drawings from which the crew could obtain all the information they needed for building the formwork. Figure 2.21 shows the 2D view of wall along gridline 4. The red horizontal lines show the height of each pour (lift). The complexity of the wall, different rebar zones passing through the wall, and several openings with different sizes which make casting the wall a challenging task can be easily observed in the drawing.



**Figure 2.21 Elevation view of the wall along gridline 4 (Structural Drawing)**

Traditionally the lift drawings are drawn by hand. This method would not be productive for complex projects like this one as the information needed to be included in the drawings is too complex to be conveyed in 2D. It was possible to use the structural drawings issued by the consultant for the lift drawings; however, structural drawings only provide information about those elements that are included in the drawings. To find information such as embed types and layouts, or panel sizes, the crew would have to browse through other sources, making it time consuming and prone to error. Specifically, the crew might find it challenging because:

1. Both sides of the concrete walls are quite different due to the complex design. For instance, the elevations of the slabs differ on either side or the beams are not aligned on both sides. On the structural drawing only one side of the wall is shown with solid lines and objects on the other side are shown via dashed lines; this makes it confusing and prone to error, especially for the sides shown by dash lines.
2. Figure 2.22 shows the structural drawing of one of these walls. The slab and beams on the west side of the wall are shown via dash lines on the structural drawings. Some instances of missing information or sources of confusion such as beams not aligned are pointed out as well.
3. Not all of the required dimensions are included on the structural drawings because it would be too crowded if both sides of the wall were shown on a single drawing. In this case reading the information is time consuming with a high risk of making mistakes.

As was mentioned previously, due to design complexity, the architectural, structural, mechanical, and electrical BIM models were created by consultants in Autodesk Revit. Having this great tool at hand and considering the complexity of the substation in terms of heavy concrete work, large number of rebars, congested work area, and the tight schedule, it was decided to make the best use of the BIM models. Therefore, as an effort to potentially increase the productivity and considering the availability of the BIM model at hand, it was decided to provide lift drawings from the BIM models for the use of formwork crews.

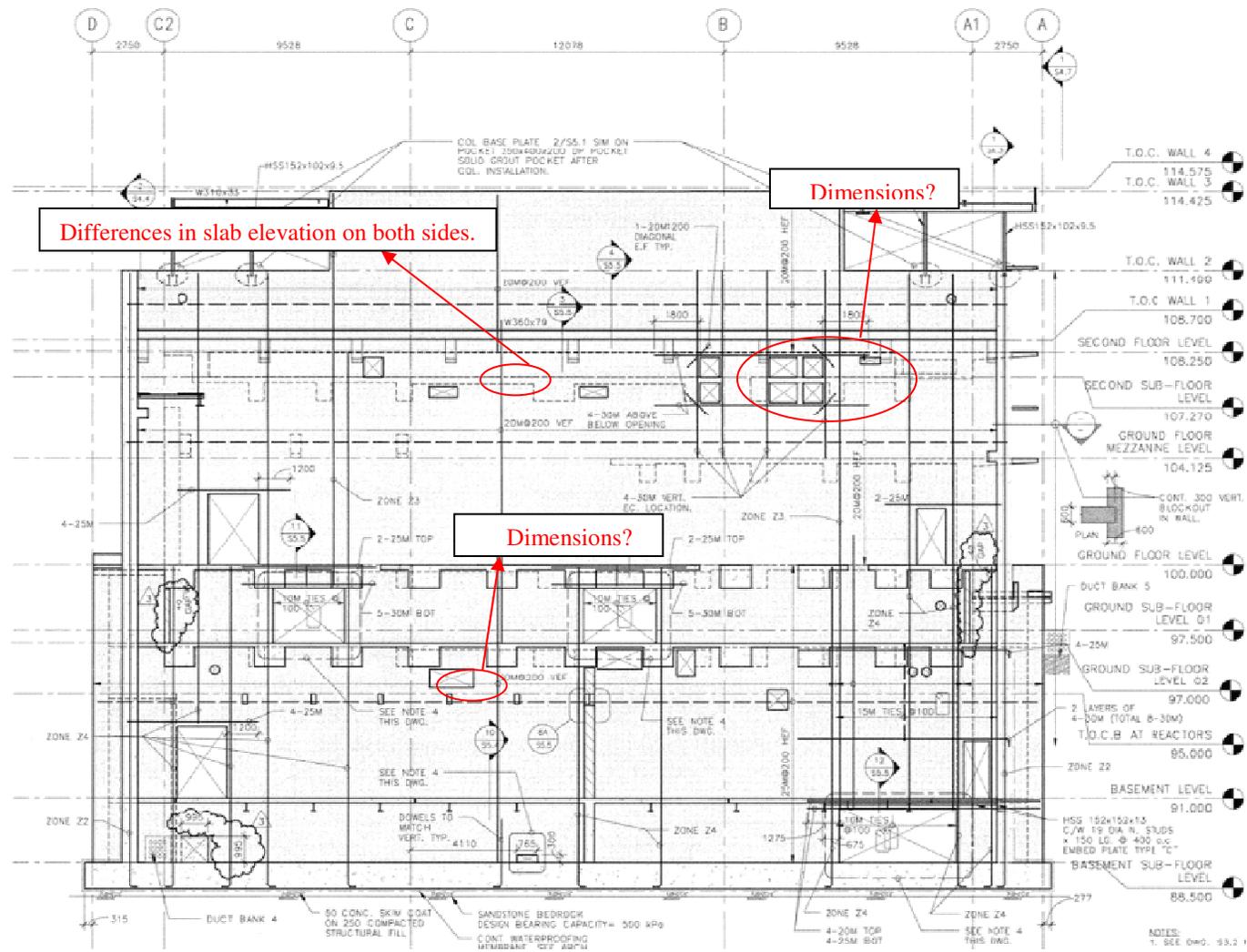


Figure 2.22 Wall elevation along gridline 4

## **2.10 Preparing the Lift Drawings**

The purpose of providing lift drawings is to have all the information needed by the crew for casting the concrete component on a single sheet. In this way, the crew doesn't need to browse through several different drawings and extract the information themselves which is a time consuming and error-prone process. As was mentioned in the previous section, various resources were used to create a comprehensive drawing.

Figure 2.23 shows the process for creating each wall lift drawing. For each wall there are two sides and the wall is going to be poured in several lifts. The process described is for one side of the wall for each lift and includes the possibility of issuing Design Change Notices (DCN) being issued from the consultant during the project.

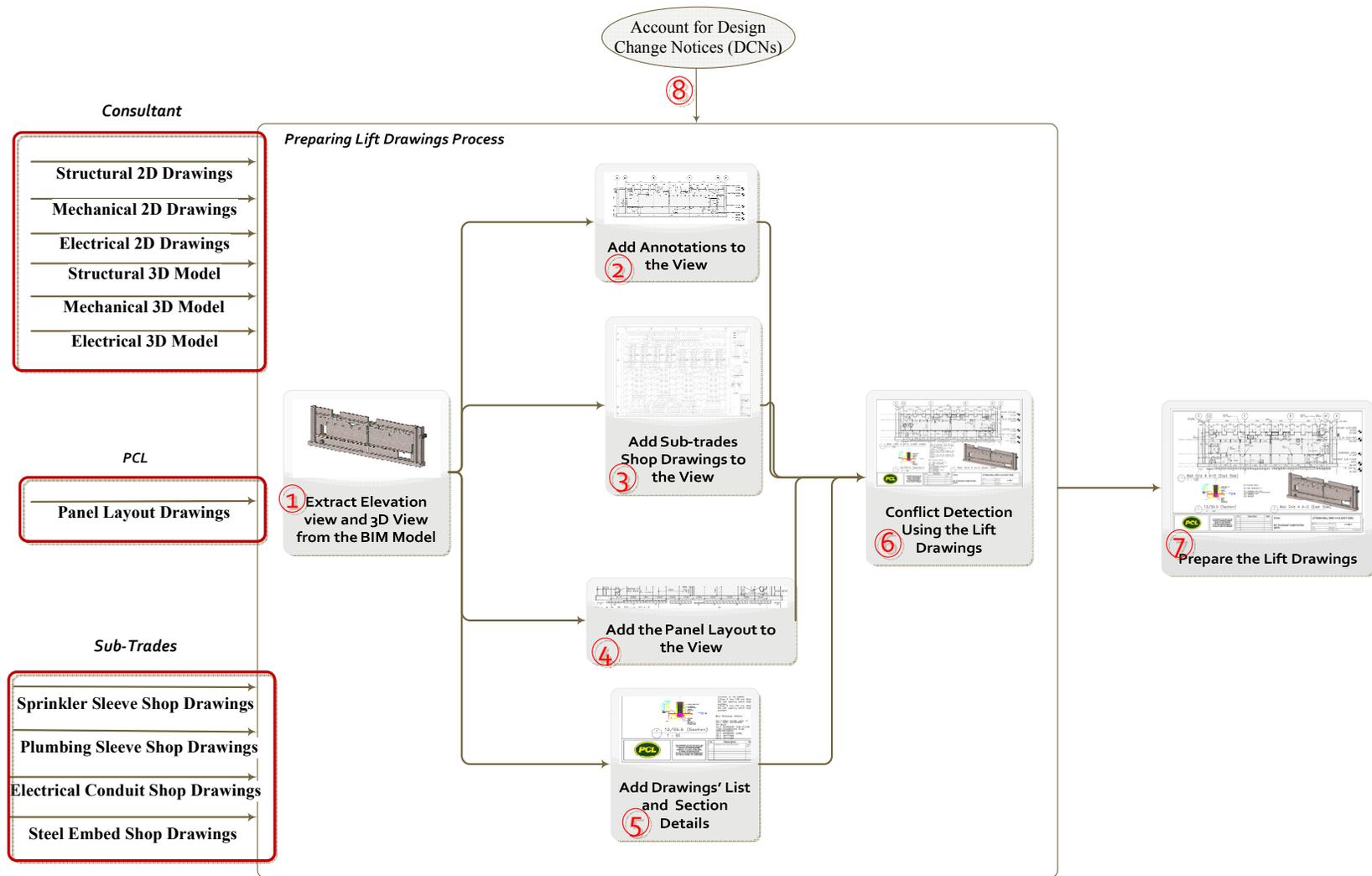
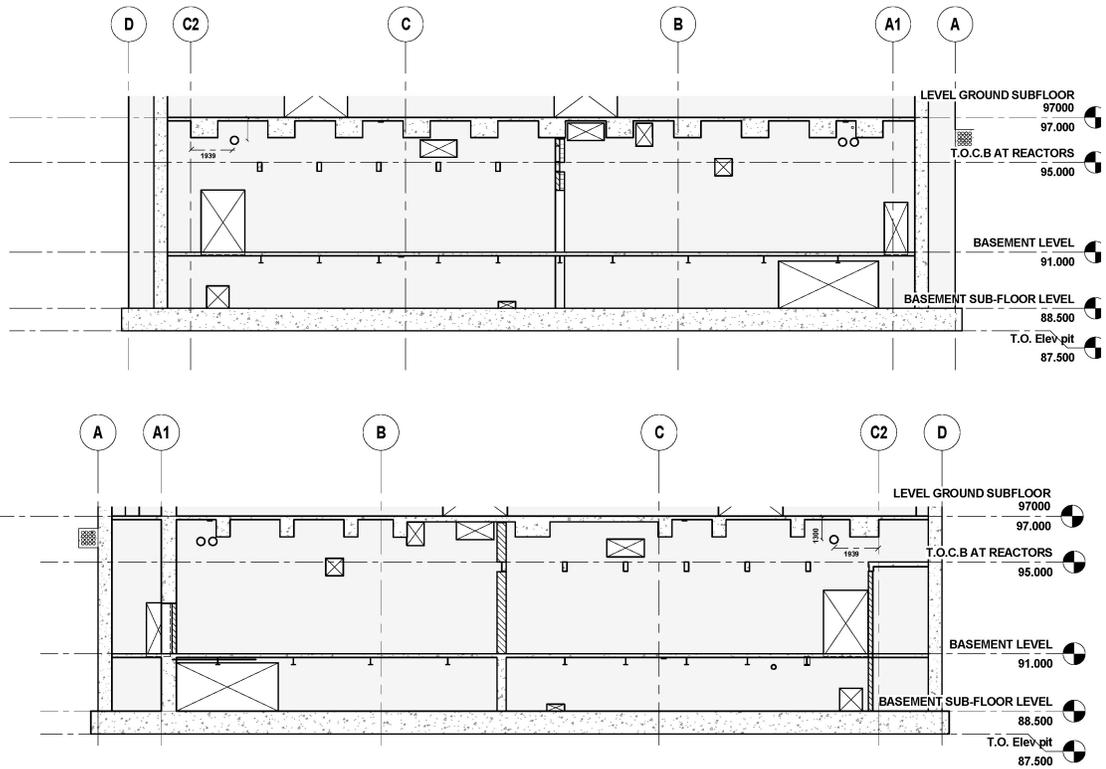


Figure 2.23 Process of preparing lift drawings from the 3D model

### **Step 1: Extract Elevation and 3D Views from the BIM Models**

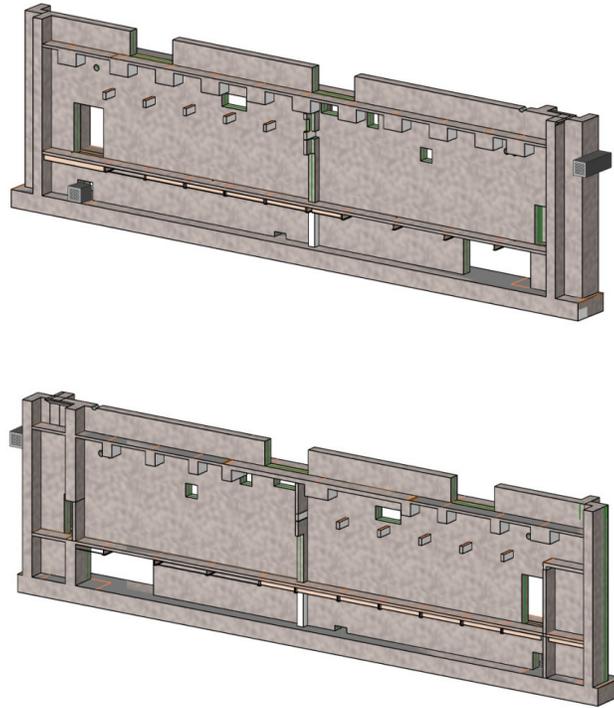
The BIM models created by designers are a rich source of information as they include the geometry, dimensions, material types, etc. A significant advantage of using BIM models for creating lift drawings is the accessibility to different 2D and 3D views of the component as well as any dimensions needed for casting it. In addition, the model helps the crew to visualize the components in 3D and avoid possible confusion resulting from the complexity of the component.

In step 1, a 2D elevation view of the wall was first extracted from the model. As discussed previously, the concrete walls in this project have a different geometry on each side. For instance, beams are not aligned or slabs are not on the same level. Showing the information about the two sides of the wall in the same elevation view makes the drawings too crowded and reading the required information really challenging. The BIM model makes it possible to provide both sides of the wall elevation view in separate drawings. In this case, to form either sides of the wall, the crew would just deal with the information regarding one particular side, which helps to improve efficiency and avoid any confusion. Figure 2.24 shows the elevation view on both sides for wall along gridline 4.



**Figure 2.24 Elevation view of the both side of the wall along gridline 4**

To help the crew visualize the surface of the wall and the geometry better, a 3D view of each side of the wall was extracted from the model. This gives the crew a better understanding of what each line in the 2D elevation view means. Figure 2.25 shows the 3D view of both sides of the wall along gridline 4 for the first lift.



**Figure 2.25 3D views of wall along gridline 4**

### **Step 2: Add Annotations to the View**

After providing the appropriate view of the component (Step1), it is necessary to put the required annotations for building the component on the view. For instance, the crew needs to know the exact size and location of the openings on the wall. The location of the openings is shown through their distance to gridlines and elevation lines. In this stage, the dimension of the components already included in the model, such as slabs and openings, are shown on the drawings. However, the dimensions of elements that are designed by the sub-trades, such as sleeves or embeds, are typically not specified because they are not included in the BIM models created by the consultants. Figure 2.26 shows the elevation view of the wall along gridline 4 with the required dimensions annotated.

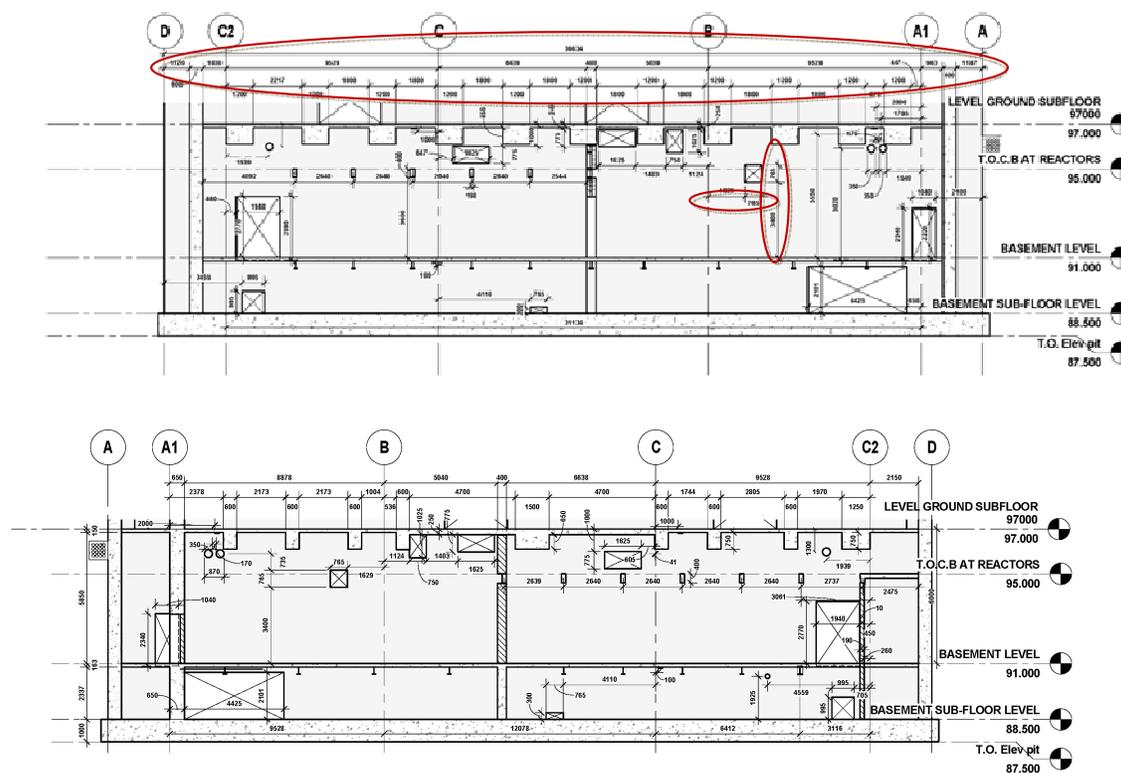


Figure 2.26. Elevation view along gridline 4 east and west view (First Lift)

### **Step 3: Add Sub-trades Shop Drawings to the View**

In the third step, the shop drawings of the sub-trades are reviewed to incorporate the various embeds and sleeves in the lift drawing.

#### ***Steel Embed Layout***

Steel embeds are one of the components that need to be shown on the drawings. Figure 2.29 shows one of the embed layout drawings. For instance, to show the steel embeds on the east side of the wall along gridline 4, the first embed is a Z3 type embed (detailed information such as its shape and size is provided in another sheet) which should be located 2444mm from gridline A1 towards gridline B and the next embed is 3284mm from the previous one.



**Figure 2.27. Steel embeds installed on the form ready for concrete to be poured**

In order to find the elevation of an embed, detail 1 at the right side of the picture should be explored. Based on this detail, the up side of the plate should be 50mm distant from the underside of the slab. Considering the slab depth of 153 mm and the elevation of the upper surface of the slab which is 91000, the elevation of the above side of the slab would be 90897 ( $91000 - 153 + 50$ ). There are some exceptions such as section 1 where embeds should use a different formula for the elevation.

As the location of each embed is specified via its distance to the previous embed, if the distance between two embeds is calculated wrong, all the steel embeds after the wrongly positioned embed will be located in the wrong place. The steel embeds are for installing steel beams; therefore, if the embed is in the wrong location, the beam can't be installed after pouring the concrete and the crew will have to demolish that part of the concrete wall, remove the embed, make a hole in the concrete wall, and install the embed again. All the wrongly located embeds would need to undergo this procedure. As a result, it is critical that the location of the embeds is accurate. Assuming the complex calculations necessary for locating the embeds, doing it on site would be a prone-to-error task. For this reason these embeds are included in the lift drawings.

Providing lift drawings and including the steel embeds on them helped to avoid any possible errors and omissions. By putting the steel embeds on the drawings, one could make sure that the embed layout is correct with no conflicts. For instance, if the embed plate wouldn't line up with the steel beams, or if it clashed with an opening, this could be seen on the drawings. Therefore, mistakes could be corrected prior to construction which would save time and cost.

### ***Sprinkler Sleeve Layout***

Another piece of information needed to be included in the drawings was the sprinkler sleeve designed by the sub-trades. Figure 2.30 shows the sprinkler design. For instance, for the wall along gridline 4, a sleeve should be considered between gridlines C and C2. The required information about the sleeve is written close to the sleeve where a cloud is drawn on the wall. It is a 200mm sleeve on elevation 90425 which is 1925 mm above the finished floor (AFF). The sprinkler sleeve is shown in Figure 2.30. As the sleeve is visible on both sides, it is modeled as a 3D object in the BIM model to avoid any mistakes.

### ***Plumbing Sleeve and Electrical Sleeve Layout***

No shop drawings were provided by plumbing and electrical sub-trades. A representative of the sub-trades is onsite during the forming process and locates the sleeves while the forming is done. As the main goal of providing lift drawings is to include all the information needed for casting the component, it was proposed that the sub-trades mark their sleeves on the lift drawings. The process is explained in detail in section 2.13.2. Figure 2.28 shows the view along gridline 4 with the sub-trades information on it.

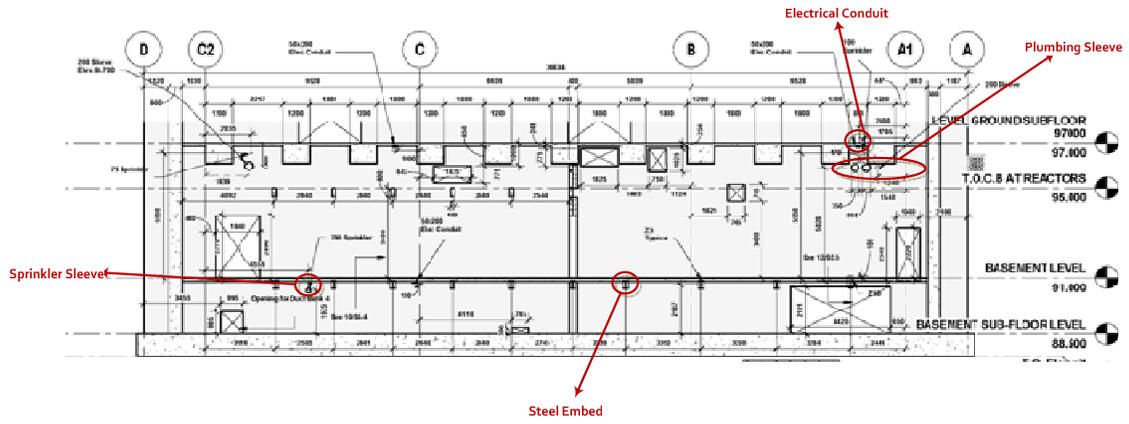


Figure 2.28 East side of the wall along gridline 4 including shop drawings information



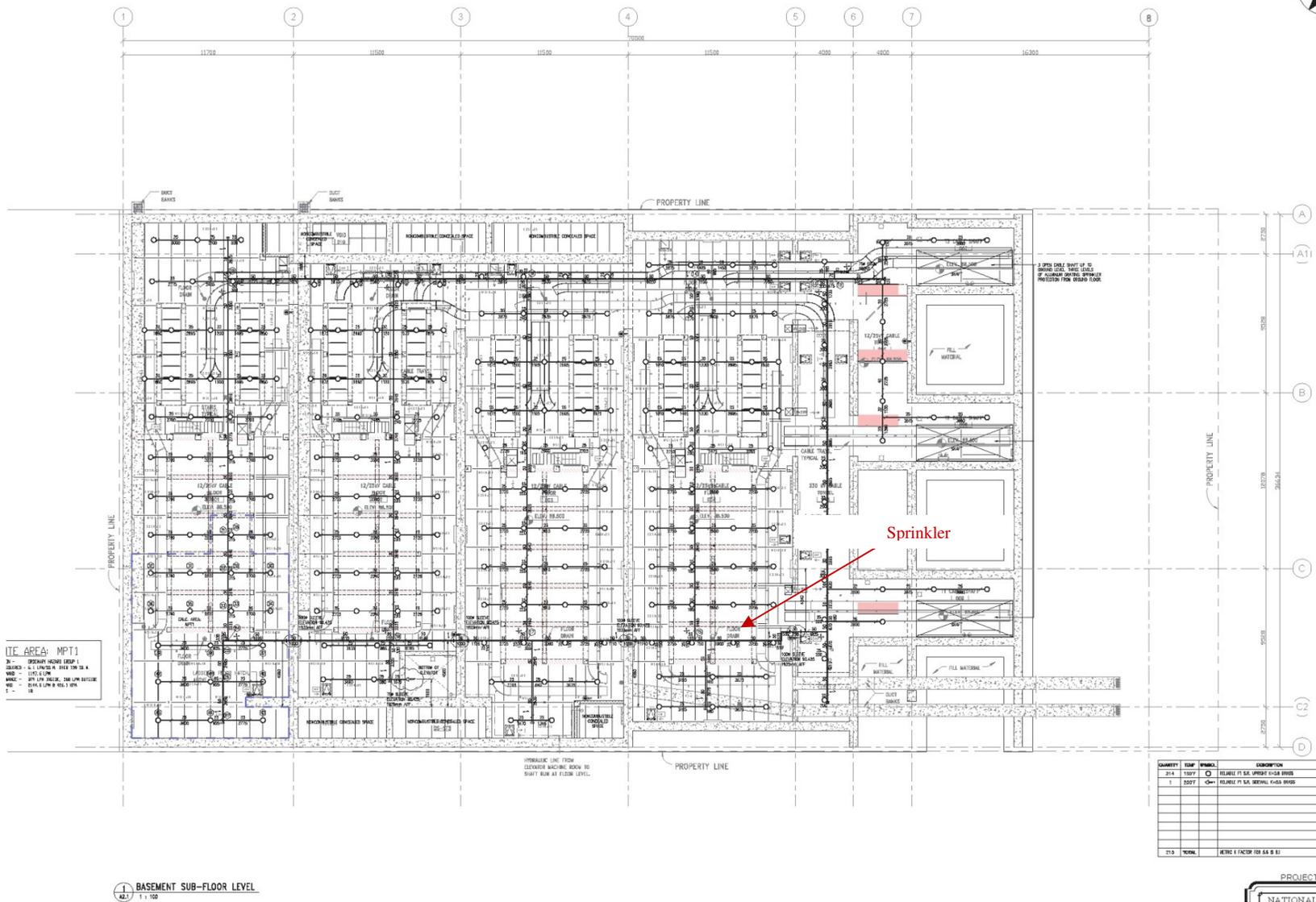


Figure 2.30 Sprinkler sleeve layout (basement sub-floor level)

#### **Step 4: Add the Panel Layout to the View**

In order to build the wall forms, PCL uses panels with different widths. The available widths are 6, 8, 10, 12, and 14 foot wide panels, and there is a certain number of each panel available on site. In order to cast a wall, the crew would install these panels close to each other and fill the gaps with plywood. Due to the limited numbers of each panel and considering the project schedule, the crew comes up with a panel layout schedule. This schedule allows them to identify which panel is being used in which wall at each time stage. The crew shows the panel sizes for each side of the wall using a plan view of structural drawings by drawing colorful lines on the wall by hand. Each color represents one panel size. Figure 2.31 shows the color-coded panel layout. For the west side of gridline 4 (left side), there are four yellow lines representing four 10 foot panels, two orange lines representing two 8 foot panels, one green line representing one 12 foot panel, one yellow line which shows one 10 foot panel, one red line representing a 14 foot panel, and two blue lines showing two 6 foot panels.

For casting a wall, the crew needs to know which panels should be used for each side of the wall; therefore, panel layout is one piece of information that needs to be on the lift drawings. To show the panels, rectangular on-scale icons are used in the drawings. By putting these icons beneath the elevation view, the crew can visualize the panels and make sure it is the right panel for that part of the wall. Figure 2.32 shows the panel layout for the west side of the wall along gridline 4. Figure 2.33 shows the same panels installed on the site. As can be seen, the gaps between panels are filled with plywood. The steel embeds and block outs can also be observed on the photo.

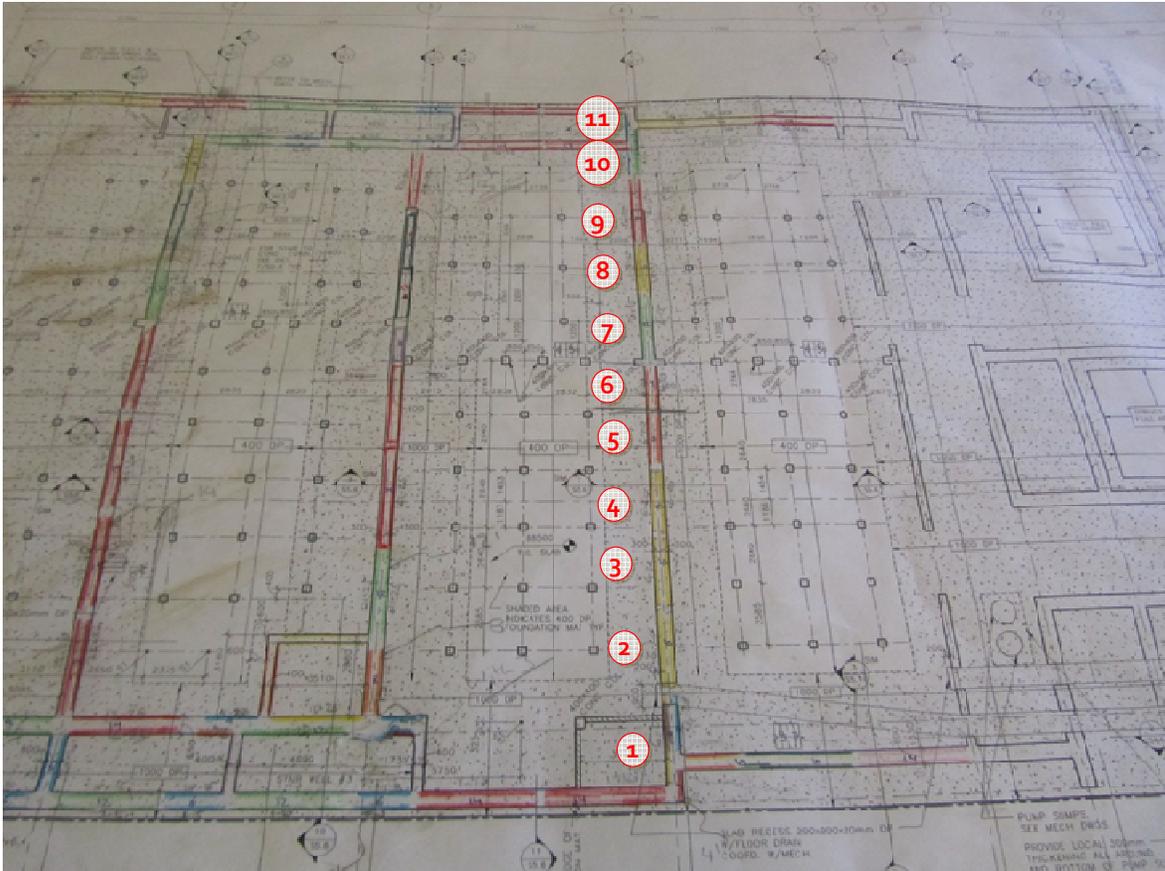


Figure 2.31 Panel layout color-coded by the crew

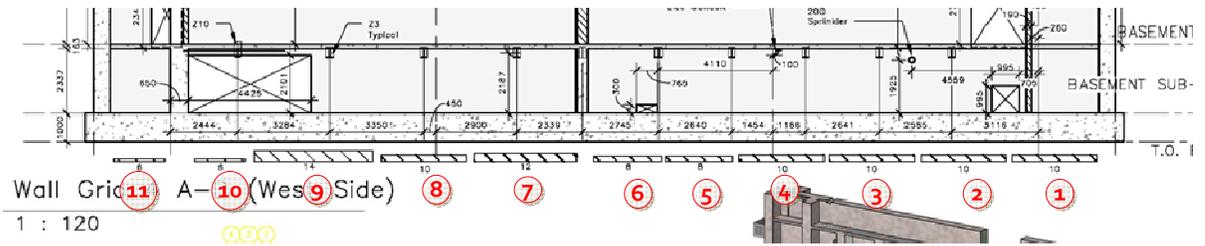
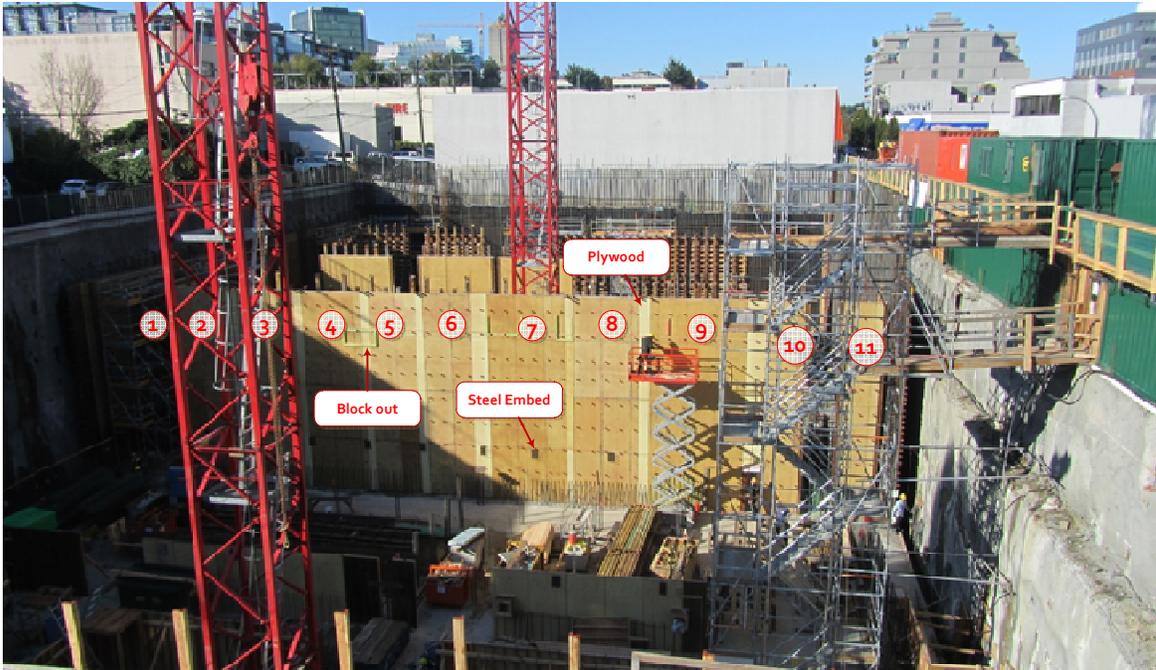


Figure 2.32 Panel layout along gridline 4 (West side)



**Figure 2.33 Panel layout for the west side of the wall along gridline 4**

### **Step 5: Add Drawing List and Section Details**

During construction of the component, there might be a need for the crew to refer to the structural drawing set for more information. A list of drawings related to that component is added to the lift drawing, including the relevant elevation views, section views and details. In this case, if any required information is not included on the drawings for some reason; the crew doesn't need to browse through all the drawing sets to find the desired information, which can help the crew save time.

In addition, if further space is available after putting all the previously mentioned types of information on the lift drawing sheet, section details can be added to the sheet to help the crew constructing the component.

## **Step 6: Conflict Detection Using the Lift Drawings**

When the sub-trades are designing and providing shop drawings for such components as sprinkler, plumbing and electrical systems, they check the plan view or elevation view to see whether their design clashes with any other component. However, in complex projects it is sometimes easy to miss elements like openings or beams, which may lead to these conflicts getting missed. Providing lift drawings helped the crews to visualize the walls with the steel embeds, sleeves, and ducts designed by other sub-trades and discover any conflicts between a sub-trades' design and a consultant design prior to construction. After all the information needed for casting the wall is entered in the elevation view of the wall, the view is checked to see if any conflicts between different disciplines can be found. For instance, by putting the embeds on the drawings, one might notice that one embed clashes with an opening. In that case, either the consultant should change the size or location of the opening or the sub-trade should change the size or location of the plate in order to resolve the conflict.

For example, at one point one of the sprinkler sleeves passed through a rebar zone. The sprinkler system designer was asked to change her design; however, each of her design options clashed with another element, such as rebar zone, electrical opening or an embed, when the options were put on the lift drawings. By looking at the lift drawings, it was evident that the sprinkler had the option to pass through an opening that was originally created for the electrical system. As a result, a request for information (RFI) was sent to the consultant asking for permission to do so. The consultant looked at the case and made sure there was enough room for the sprinkler to pass through the electrical opening. The process from finding the conflict to considering different options to receiving the RFI answer, took about one week. In this case, the conflict was noticed when the lift drawings were created and prior

to construction of that wall. If the conflict had been noticed on site at the time of construction, the project would have suffered delays. There was enough time available for the project team to come up with the best solution which saved time and cost.

Although using lift drawings to locate sleeves and ducts on the wall might increase the number of RFIs before the construction phase, it would definitely reduce the number of RFIs during construction and help to minimize delays and cost overruns.

In general, whenever a conflict is noticed when putting the elements of different disciplines on the drawings, it is clouded on the drawings and the sub-trades are asked to confirm that the information they provided is correct. If they confirm that it is what they intended and no mistakes were made in providing shop drawings, the conflict is mentioned and they are asked to redesign around it. Figure 2.34 shows a clouded drawing on which all the potential conflicts are clouded and listed on the drawing. The list is marked out by a red rectangle in Figure 2.34. Once the responsible parties go through the list, the clouds and the list will be removed from the drawing.

### **Step 7: Prepare the Lift Drawing Sheet**

In the end, all the gathered information is put on a single sheet. For instance, all the information needed for building one side of a specific wall in the first lift is put on a single sheet. Figure 2.37 and Figure 2.38 show the lift drawing prepared for both sides of the wall along gridline 4 for the first lift. In order to create wall and slab lift drawings the same process is repeated. Using this process, I provided 116 wall lift drawings and 16 slab lift drawings for the project.

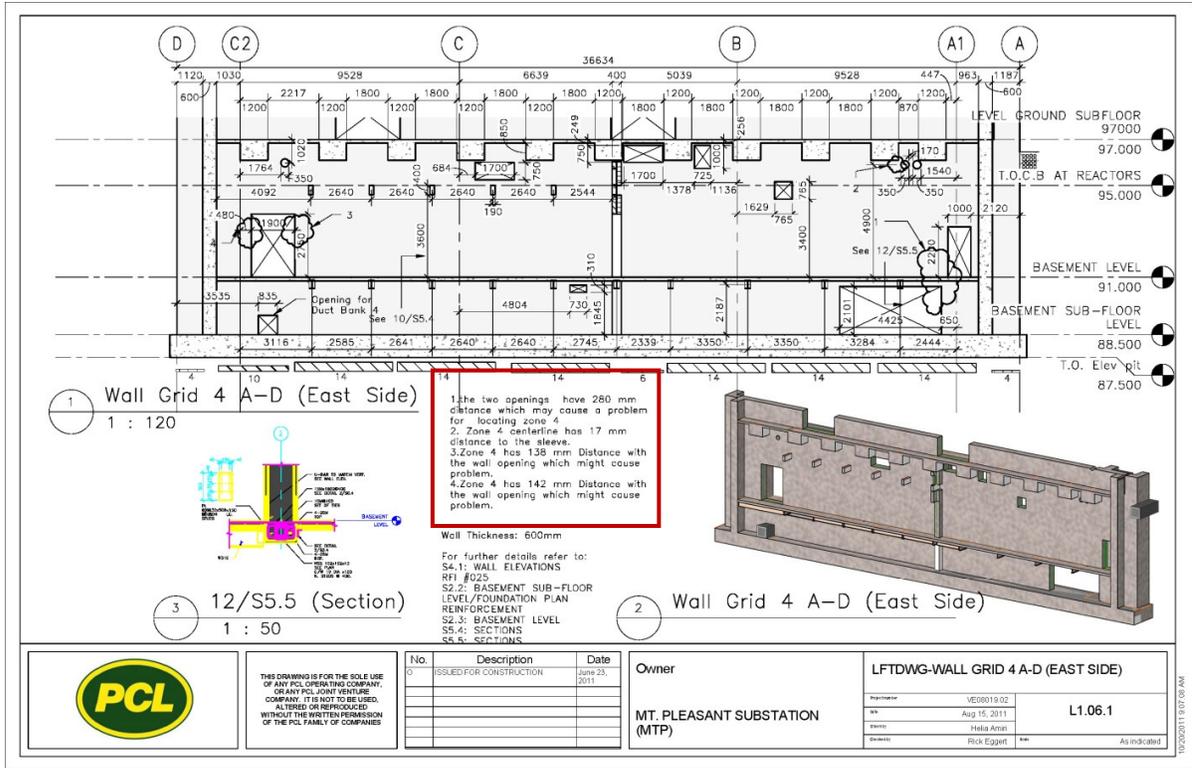


Figure 2.34. Clouded drawings showing potential conflicts

**Step 8: Account for Design Change Notices (DCN)**

Design change notices are the changes in design issued by the consultants during the construction phase. DCNs are usually issued at different stages of the construction phase and sometimes affect the components that are currently being constructed on site. Thus, they require quick action. Each DCN arrives on site as a set of 2D drawings that includes the changes that are highlighted with revision clouds; the modified BIM models usually arrive three to four weeks later. Figure 2.35 shows a change in the opening size for the wall along gridline 4. The main issue is that some of these changes need the sub-trades to alter their designs as well and if they are related to an upcoming activity on site, the redesign must be done quickly.

When a DCN is issued by consultants, changes on the walls have to be incorporated into the lift drawings. The main problem is that the updated BIM models always arrive three to four weeks later than DCN's 2D drawings. Even if updated BIM models arrive with the DCNs, they can't be used for the drawings that have already been prepared since the lift drawings can't be updated automatically. Therefore, for those drawings already provided, changes are made to the old 3D model; hence, the drawings are modified and for those drawings that haven't been provided until then, the up-to-date BIM models are used.

Sometimes changes to the design lead sub-trades to redesign their scope of work. Considering that DCNs might relate to concrete components and some of the changes will affect ongoing activities on site, the lift drawings should be modified as soon as possible. Figure 2.36 shows the process of changing the already-issued drawings when a DCN affects them.

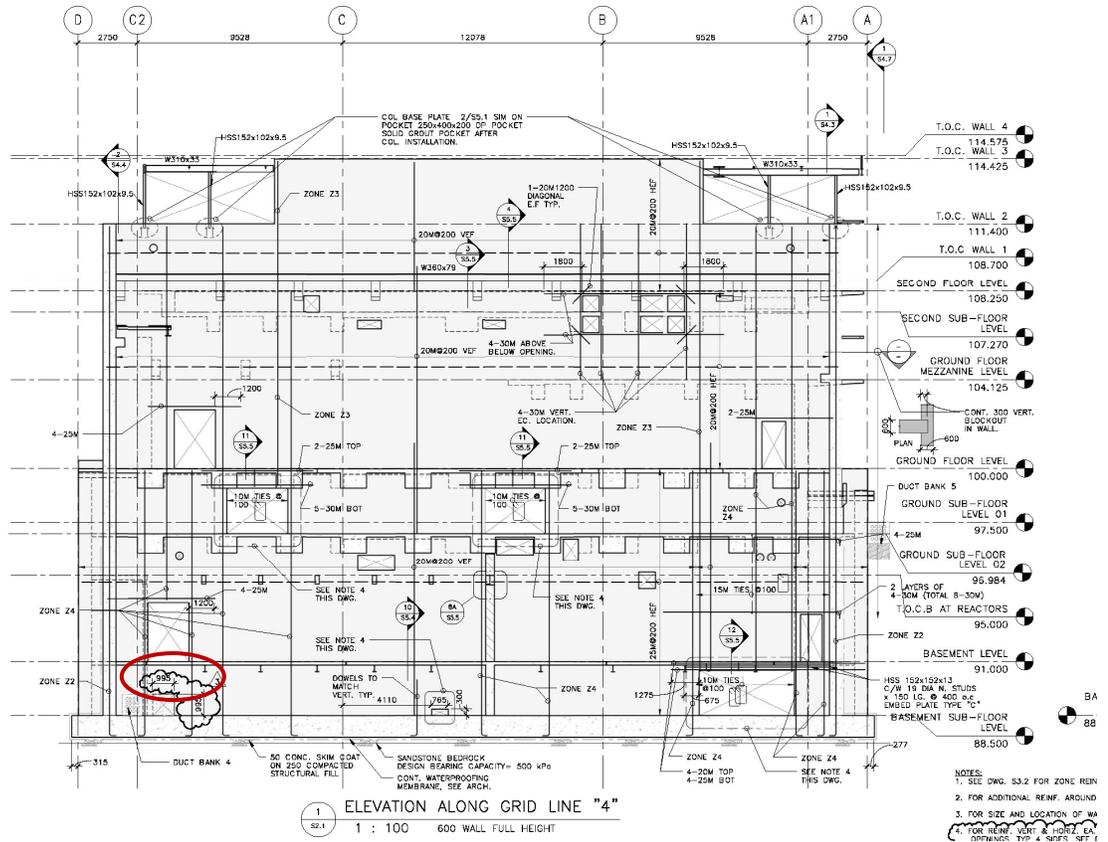


Figure 2.35 Design Change Notice (DCN) issued for changing the size of the opening

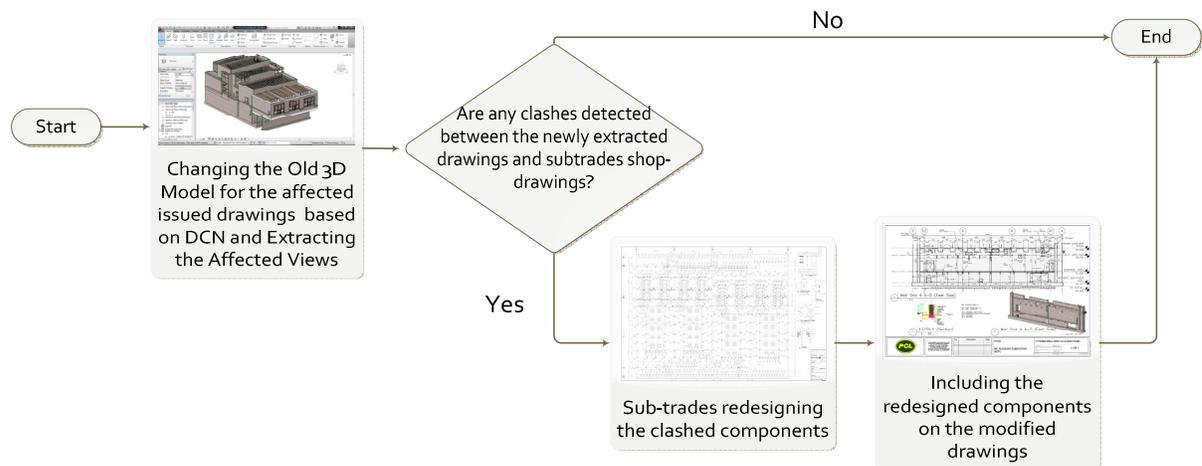


Figure 2.36 Changing the affected drawing process

To incorporate the changes to the already issued drawings which are affected by DCN, the old BIM model is changed based on the DCN and the related 3D view and elevation view are updated automatically. The view is checked to see if any of the sub-trades designs have conflict based on the change. If any conflict is noticed, the sub-trade responsible for that component is asked to redesign that part of his/her designs. For instance, a DCN includes an opening to be added to the wall. By adding the opening to the BIM model it is noticed that it clashes with a steel embed. Therefore, the steel embed sub-trade is asked to redesign that part of the drawing so that the new designed embed doesn't clash the opening. When the sub-trade redesigns his/ her design, the redesigned information is included in the lift drawing.

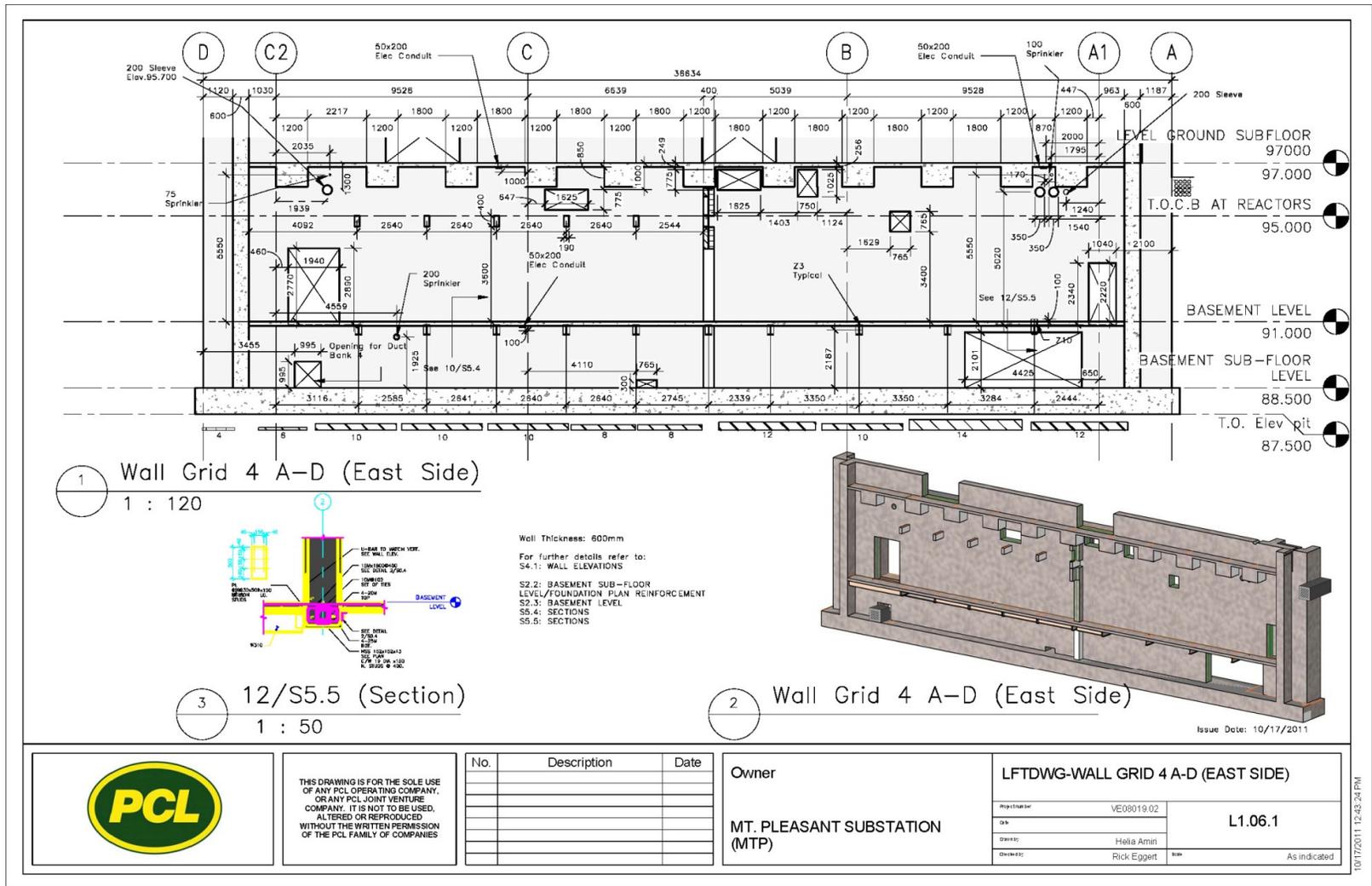


Figure 2.37 Sample of lift drawings east side of the wall along gridline 4 (First Lift)



## 2.11 Suspended Slab Lift Drawings

Suspended slab lift drawings are provided in the same way as wall lift drawings. All the information required to build formwork for a suspended slab is included in the lift drawings. Figure 2.39 is a photo taken when forming the slabs and Figure 2.40 shows a sample of the slab lift drawings.



**Figure 2.39. Forming the suspended slab on site**

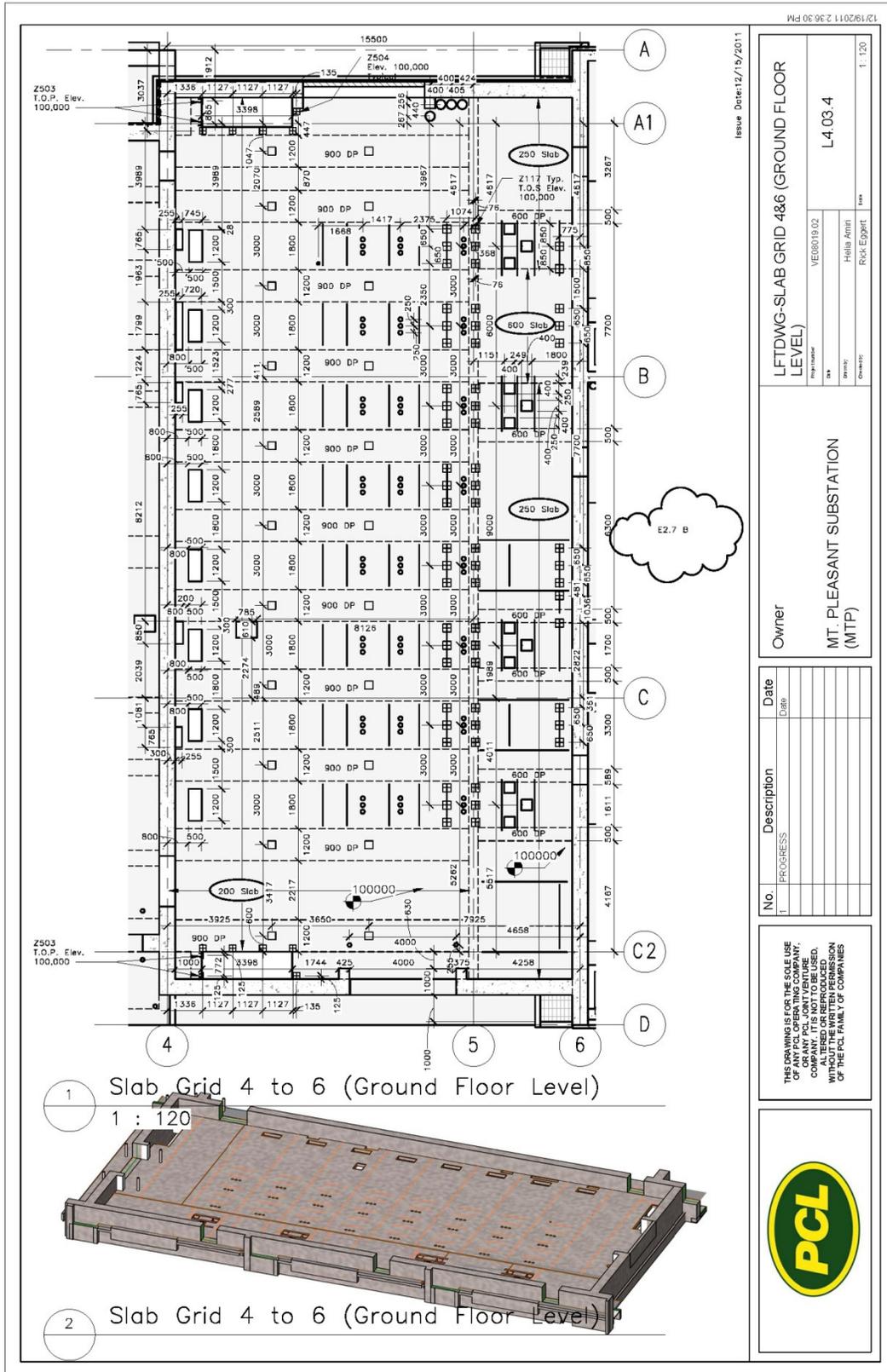


Figure 2.40 A sample of slab lift drawing

## **2.12 Benefits of BIM-based Concrete Lift Drawings**

In this section the benefits of using BIM-based concrete lift drawings by the crew is brought. These benefits are mostly stem from my observations and talking to field personnel on site.

### **2.12.1 Improve Productivity**

The main goal of creating lift drawings is to include all the information needed for the crew to build the concrete component. Having this source of information at hand eliminates the need to browse through various sources to find required information while they are working on site. This process is time consuming and prone to error, particularly considering the ongoing activities in progress and the tight schedule, which could potentially decrease the productivity on site.

I was able to contrast the process of using the BIM-based lift drawings with the traditional process for a small portion of the suspended slab construction. The crews did not realize that I had created BIM-based lift drawings and so were proceeding with the work using their traditional method. I observed that one of the field personnel had to come to the site office several times during the day in order to ask questions regarding the information in the shop drawings and consultant's drawings. Sometimes the numbers on the shop drawings were too small that they had to magnify a part of the shop drawings to be able to read it. Each time he came to the site office, he started browsing through different sets of drawings and asking the superintendent, field engineer and the responsible foreman about the drawings. Therefore, every time the crew encountered a problem, the process of building the forms was delayed, and the crew became idle. Additionally, the time of key personnel on site was also

diverted to answer questions. However, for those components constructed using the BIM-based lift drawings, I did not observe such situations. If the field personnel had any questions, it was usually to confirm the information that already existed on the drawings. The crew also mentioned that they preferred the BIM-based lift drawings because they were clear and comprehensive.

The site superintendent recognized many benefits in utilizing the BIM-based lift drawings. He felt that site productivity increased by 20% because the crew did not need to browse through different sources to find the required information. In addition, he believes that using the lift drawings saved 20% of the key site personnel time because the drawings were complete and clear enough that the crew did not need to clarify the information or answer questions. He also noted the importance of resolving RFI's prior to construction rather than during construction. As a result, he claimed that 50% of the crew's time was saved because they didn't need to wait for answers to RFI's.

### **2.12.2 Facilitate Communication**

The lift drawings facilitated communication between the different parties. Having each sub-trade represent their design on the lift drawings helped them to visualize their design in a more convenient way and in a way that was more understandable for the site personnel and crew. Sometimes, a sub-trades' design can be too vague and an RFI is needed to make it more clear; however, showing their design on the lift drawings leads to better understanding.

As the person responsible for coordinating the shop drawings, I found it more effective to provide the required information to the site crew using the lift drawings. I also

found that the sub-trades made fewer mistakes using the BIM-based lift drawings to show their design. For example, one of the sub-trades put a sleeve on the wall, and she did not notice that there was an opening in the same location for ductwork, which wasn't evident in the plan view. Once this information became part of the BIM-based lift drawings, I did not notice any more of these kinds of errors.

### **2.12.3 Facilitate Coordination**

When a DCN is issued and if the changes require the sub-trades to change their design and it is related to the ongoing or upcoming tasks, the redesign should be completed right away. Traditionally, sub-trades design their work and send it to the site and then their design is checked by the coordinator. If the proposed design has problems, it will be sent back to the sub-trades to be modified. This process is a time consuming process and sometimes it takes days. DCNs sometimes relate to the components that are being built or will be built pretty soon; therefore, accurate and rapid design is needed from the sub-trades. Using the traditional process cannot answer the project's needs; therefore we decided to use the Lift drawings to accelerate the process.

As a result, a set of updated lift drawings were sent to the sub-trades and they were asked to mark the required sleeves or openings on lift drawings and send it back. In this way, sub-trades could instantly see if their desired sleeve or opening location was clashing with any other elements. Instructions as to how to put the sleeves and openings on the lift drawings were also sent to the sub-trades as a guideline. In the instructions, the naming process of lift drawings was also described. The instructions are as follows:

## ***Instructions for Putting the Sleeves or Openings on Walls***

*To locate the sleeves on a concrete wall the following steps should be considered.*

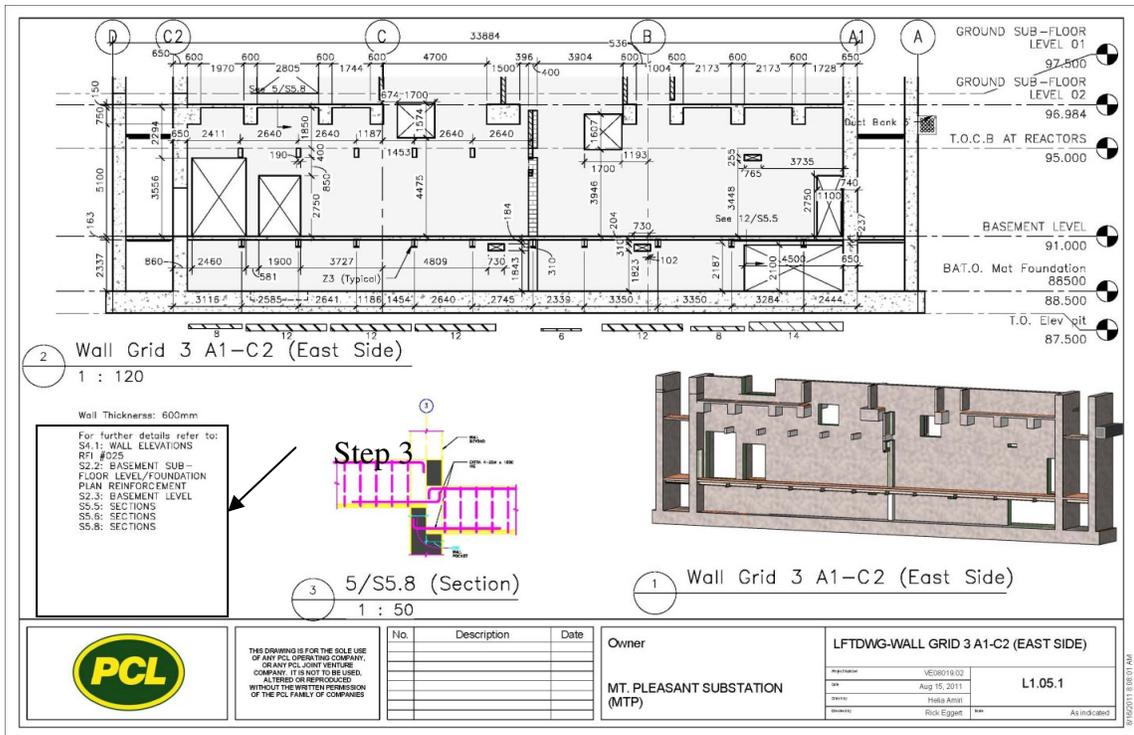
- 1. Go to the set of “Concrete Wall Lift Drawings” and find the related wall from the list of the drawings (L1.00.0 (Figure 2.41)).*

CONCRETE WALL LIFT DRAWINGS (BASEMENT LEVEL)		CONCRETE WALL LIFT DRAWINGS (BASEMENT LEVEL)	
Sheet Number	Sheet Name	Sheet Number	Sheet Name
L1.00.1	Plans (3D View)	L1.11.2	LFTDWG-WALL GRID 7.1 A-D (WEST SIDE)
L1.01.1	LFTDWG-WALL GRID A 1-4 (NORTH SIDE)	L1.12.1	LFTDWG-WALL GRID 6 A-D (EAST SIDE)
L1.01.2	LFTDWG-WALL GRID A 1-4 (SOUTH SIDE)	L1.12.2	LFTDWG-WALL GRID 6 A-D (WEST SIDE)
L1.02.1	LFTDWG-WALL GRID D 1-4 (NORTH SIDE)	L1.13.1	LFTDWG-WALL GRID A 4-6 (NORTH SIDE)
L1.03.1	LFTDWG-WALL GRID 1 A-D (EAST SIDE)	L1.13.2	LFTDWG-WALL GRID A 4-6 (SOUTH SIDE)
L1.04.1	LFTDWG-WALL GRID 2 A1-D (EAST SIDE)	L1.14.1	LFTDWG-WALL GRID C2+ 4-6 (NORTH SIDE)
L1.04.2	LFTDWG-WALL GRID 2 A1-D (WEST SIDE)	L1.14.2	LFTDWG-WALL GRID C2+ 4-6 (SOUTH SIDE)
L1.05.1	LFTDWG-WALL GRID 3 A1-C2 (EAST SIDE)	L1.15.1	LFTDWG-WALL GRID A+ 6-7.1 (NORTH SIDE)
L1.05.2	LFTDWG-WALL GRID 3 A1-C2 (WEST SIDE)	L1.15.2	LFTDWG-WALL GRID A+ 6-7.1 (SOUTH SIDE)
L1.06.1	LFTDWG-WALL GRID 4 A-D (EAST SIDE)	L1.16.1	LFTDWG-WALL GRID A1+ 6-7.1 (NORTH SIDE)
L1.06.2	LFTDWG-WALL GRID 4 A-D (WEST SIDE)	L1.16.2	LFTDWG-WALL GRID A1+ 6-7.1 (SOUTH SIDE)
L1.07.1	LFTDWG-WALL GRID C2 1-4 (NORTH SIDE)	L1.17.1	LFTDWG-WALL GRID B+ 6-7.1 (NORTH SIDE)
L1.07.2	LFTDWG-WALL GRID C2 1-4 (SOUTH SIDE)	L1.17.2	LFTDWG-WALL GRID B+ 6-7.1 (SOUTH SIDE)
L1.08.1	LFTDWG-WALL GRID A1 1-4 (NORTH SIDE)	L1.18.1	LFTDWG-WALL GRID C- 6-7.1 (NORTH SIDE)
L1.08.2	LFTDWG-WALL GRID A1 1-4 (SOUTH SIDE)	L1.18.2	LFTDWG-WALL GRID C- 6-7.1 (SOUTH SIDE)
L1.09.1	LFTDWG-WALL GRID 5 A-D (EAST SIDE)	L1.19.1	LFTDWG-WALL GRID C+ 6-7.1 (NORTH SIDE)
L1.09.2	LFTDWG-WALL GRID 5 A-D (WEST SIDE)	L1.19.2	LFTDWG-WALL GRID C+ 6-7.1 (SOUTH SIDE)
L1.10.1	LFTDWG-WALL GRID 7 A-D (EAST SIDE)	L1.20.1	LFTDWG-WALL GRID C2- 6-7.1 (NORTH SIDE)
L1.10.2	LFTDWG-WALL GRID 7 A-D (WEST SIDE)	L1.20.2	LFTDWG-WALL GRID C2- 6-7.1 (SOUTH SIDE)
L1.11.1	LFTDWG-WALL GRID 7.1 A-D (EAST SIDE)		

**Figure 2.41** List of the lift drawings

*Each sheet has a code with 3 parts. The first part is for the number of the lift so “1” means that it is the first lift. The second one is the number that is assigned to the wall for that lift and the third part is to show which side of the wall is shown. So each side of the wall has a sheet (except some exterior walls where showing two sides seems to be unnecessary). For instance, North or East side of the wall is indicated with digit 1 and South or West side of the wall is indicated with number “2”.*

*Let’s assume that you want to see the wall that is located on grid line 3, it shows on L1.00.0 that you should look at L1.05.1 for the east side and L1.05.2 for the west side.*



**Figure 2.42** Wall lift drawing along gridline 3

- After finding the related Lift Drawings check that where you want to put the sleeves doesn't clash with other sleeves, openings, beams, etc. Note that because sometimes slabs have different elevations on both sides it is better to check both sides.
- The list of the related structural drawings is put on the sheets as well. Find on which structural drawing the wall elevation is located. Now you need to check if your sleeve clashes with the rebar zones. The zones are shown on the drawings with lines called "Z" and a digit (For example Z4). You also can see the zones on S3.2 (Structural Drawings). No dimension is shown; therefore, you need to measure it with a ruler. The line indicates the centerline of the zone. The edge of the sleeve or the opening that you want to locate, must have 300mm distance from the centerline of the zone.

4. Check if there are any openings on the slab that can be blocked.
5. If you find no clashes you can locate the sleeve or the opening in your desired location.

Three out of four sub-trades used the instructions and placed their design by hand on the lift drawings and sent it back. One of the sub-trades mentioned that he is quite happy about designing using the shop drawings as he can visualize both sides of the wall and locate the required sleeves on the face of the wall instead of locating it on the plan view and try to visualize the face of the wall in his mind. He mentioned that using the lift drawings, he can design easier and faster. Figure 2.43 shows his design using lift drawings for locating the sleeves. The site superintendent also believed that in this way the sub-trades' time was reduced by 20%.

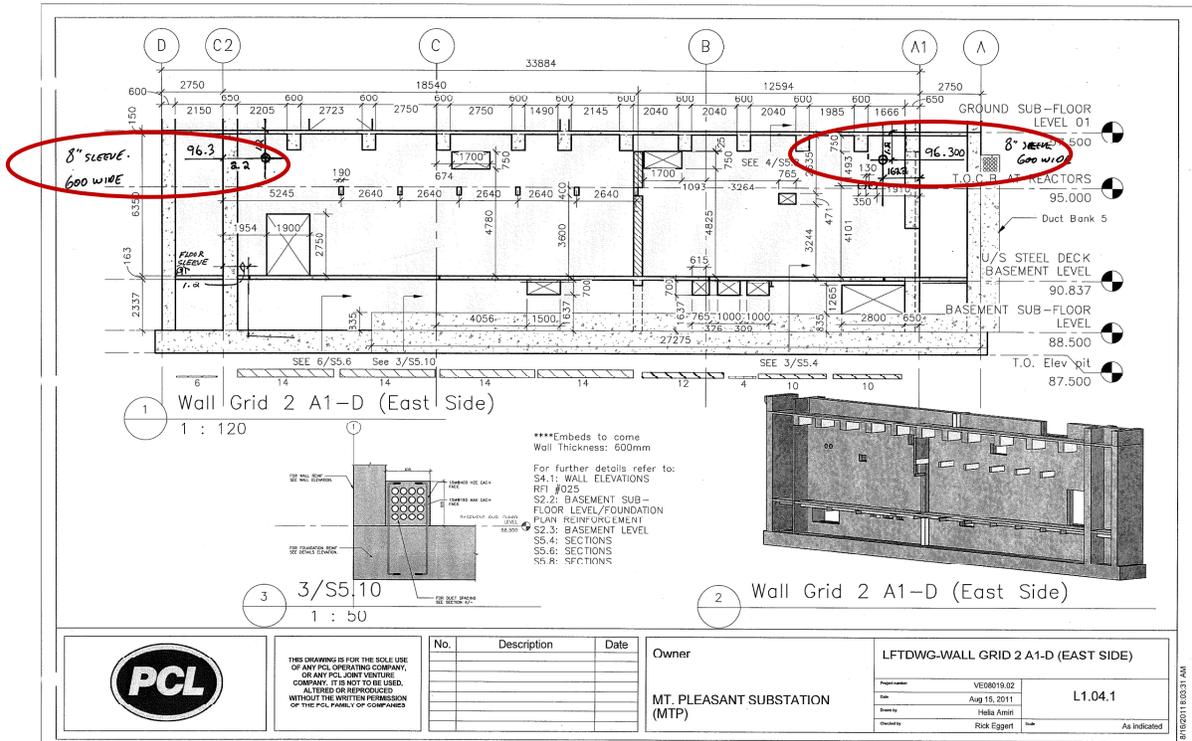


Figure 2.43. Plumbing sleeves design using lift drawings

#### **2.12.4 Detect Conflicts Prior to Construction**

As the lift drawings are provided prior to the construction of a particular component, clashes between components are revealed by showing all the consultants and sub-trades' designs on the drawing. For instance, by putting a steel embed on the elevation view of the lift drawings, it became clear that part of the embed blocked the opening. Discovering this type of conflict prior to construction saves a huge amount of time and money as either the embed and the related beam need to be redesigned or the opening needs to be relocated. Resolving these issues prior to construction also leads to increased productivity.

#### **2.12.5 Decrease in Errors and Mistakes on Site**

Some of the information included in the different sources, such as the embeds layout drawing, is hard to read and needs calculations. The crowded worksite and tight schedule makes undergoing the process of locating a steel embed on site prone to error. Lack of time on site can make it impossible to double check with other drawings such as the steel beams layout shop drawings, which adds to the possibility of error. One of the purposes of creating lift drawings is to convey the information to the site crew clearly and help them avoid mistakes on site. For example, I noticed that the crew had problems with locating the embeds on site without the BIM-based lift drawings. For the embeds on the slab forms, they made mistakes in calculating their location. Fortunately when the field personnel came to the site office to clarify some information, the mistakes were found prior to construction. However, if this mistake had not been found, it would have caused delays and additional costs to the project.

As a person who was responsible for creating the lift drawings and coordinating the various sub-trades' design, I identified many conflicts and errors w. Some of these conflicts took days to be resolved and some of the errors were hardly noticeable before I put them on the lift drawings. Without the lift drawings, these errors and conflicts would have occurred during construction, causing additional costs and delays to the project. The site superintendent estimated that 50% of the mistakes were identified prior to construction by creating the BIM-based lift drawings.

#### **2.12.6 Use of the Lift Drawings**

Using the lift drawings to cast concrete components raised some doubts about the validity of the information included on the drawings; however, after building some concrete walls and checking the data with the source, the crew found it a useful tool and began to rely on the drawings without needing to double check the sources of the information. Figure 2.44 shows the lift drawings being used on site. The crews trusted this information and ultimately preferred it over traditional methods.



**Figure 2.44** The lift drawings are being used on site and being relied on by the crew

## **2.13 Challenges of BIM for Creating Lift Drawings**

In this section the challenges for creating the lift drawings are discussed.

### **2.13.1 Modeling Sub-Trade's Design**

In order to create the lift drawings, the shop drawings should be included in the BIM model first. Some of the components are not included in the Revit library such as forming panels and steel embeds; therefore, creating them in BIM model will take extra time and energy. The challenge was that if it is necessary to provide all the components as a 3D (BIM)

component considering the time and energy needed for creating them. In other words, which components should be modeled as 3D objects and which can be modeled as 2D objects?

I found that there is no need to provide all the components in the BIM model as BIM objects. For instance, for components such as forming panels and embed layout that is different for each side of the wall, I provided them as 2D objects in the BIM model. However, for some components such as openings, sleeves, and conduits creating it as a BIM component is useful because it affects both sides of the wall. Therefore, if an opening is put as a 3D objects this opening can be seen on the other side of the wall as well. However, by putting a 2D object such as a rectangle on the face of the wall, It is necessary to locate the opening on the other side of the wall as well, which takes more time and increases possibility for errors.

### **2.13.2 Coordinating Design Change Notices (DCN) and Lift Drawings**

There were two challenges in coordinating DCN's with the BIM-based lift drawings.

#### ***Challenge 1: Several Semi-updated BIM models***

As it is discussed in section 0, when a DCN arrives two scenarios will happen. If the changes affect the already issued drawings, the model that these drawings were extracted from should be updated. This will incorporate the changes to the already issued drawings. However, when a DCN doesn't affect the already issued drawings, it is better to extract the drawings from the updated model issued with DCN. These two scenarios will cause two problems:

**Scenario 1:** If a DCN has an impact on the already provided drawings, the old model has to be updated according to consultants' 2D DCN drawings to incorporate the changes. The user who is responsible for changing the BIM model based on the 2D drawings might

make a mistake. As the error is made in the BIM model it can affect various lift drawings. For instance, the height of a wall is shortened on the DCN drawings. If the person who is changing the wall height in the BIM model makes a mistake, not only s/he provided the wrong information in the lift drawing sheet related to that wall, but also wrong information will be provided on the lift drawings for the walls that have a junction with this wall.

**Scenario 2:** Lots of DCNs are arriving on site during the project and for each DCN an updated model will be created by the consultants and sent to the contractor. For each DCN some changes have to be done in the old BIM models to update the already issued drawings and for the drawings that have not been issued yet the updated model will be used. By increasing the number of DCNs, the number of BIM models increase from each of which some of the drawings were extracted. In the end, there are numbers of BIM models that each of them includes some of the lift drawings. These BIM models are updated based on the changes that affect their drawings; however, the other changes are not included in them. Therefore, several semi updated model will exist and the user cannot make sure if the information in each model is the most recent one.

To solve this problem, I tried to document the changes. For each BIM model, I documented the date it was arrived on site, the number of DCN that the BIM model was issued for, and the number of DCNs that I updated the model based on that. Therefore by looking at the BIM model and the DCN's the user can find out which changes are included in the model, however, this is a tedious task.

### ***Challenge 2: Coordination with the Crew***

Changes in design require changes to the lift drawings. Usually several DCNs arrive on site in a short time which causes the lift drawings to change constantly. Sometimes it includes lots of minor changes such as an opening is moved 50cm; therefore, it is hard for the

crew to easily notice if the drawing they are working with incorporated these changes. As a result the crew was confused if the drawings they are building the components based on, are the most updated one. When the crew is working with the old drawings and is not aware of it, they will build the component based on the old information. Therefore, they have to demolish the component and build it again based on the updated information which will cause extra costs and delays.

To deal with this challenge, all the sheets were dated and the date of the most updated drawings were put in a table and included with the drawing set. Even the sheet containing the table of drawings was itself dated so that the crew can make sure that the table shows the most updated drawings.

Each time a change was made, the related drawings were changed and dated and the table of drawings is modified based on the new dates. Figure 2.45 shows the table of drawing sheets. The date of the issuance of the drawing sheet is the same as the date of that drawing sheet in the table; therefore the drawing list is up-to-date. Figure 2.46 shows the lift drawing for the wall along gridline 4 with the issue date of October 17<sup>th</sup>, 2011. As can be seen in Figure 2.45 the wall along gridline 4 has the same issue date; therefore the drawing is the most up-to-date one.

CONCRETE WALL LIFT DRAWINGS (BASEMENT LEVEL)			CONCRETE WALL LIFT DRAWINGS (BASEMENT LEVEL)		
Sheet Number	Sheet Name	Sheet Issue Date	Sheet Number	Sheet Name	Sheet Issue Date
L1.00.0	LFTDWG-DRAWING LIST	12/08/11	L1.12.1	LFTDWG-WALL GRID 6 A-D (EAST SIDE)	11/08/11
L1.00.1	LFTDWG-PLANS (3D VIEW)	08/15/11	L1.12.2	LFTDWG-WALL GRID 6 A-D (WEST SIDE)	11/08/11
L1.01.1	LFTDWG-WALL GRID A 1-4 (NORTH SIDE)	10/17/11	L1.13.1	LFTDWG-WALL GRID A 4-6 (NORTH SIDE)	12/02/11
L1.01.2	LFTDWG-WALL GRID A 1-4 (SOUTH SIDE)	10/18/11	L1.13.2	LFTDWG-WALL GRID A 4-6 (SOUTH SIDE)	12/08/11
L1.02.1	LFTDWG-WALL GRID D 1-4 (NORTH SIDE)	10/18/11	L1.14.1	LFTDWG-WALL GRID C2+ 4-6 (NORTH SIDE)	12/08/11
L1.03.1	LFTDWG-WALL GRID 1 A-D (EAST SIDE)	10/21/11	L1.14.2	LFTDWG-WALL GRID C2+ 4-6 (SOUTH SIDE)	12/01/11
L1.04.1	LFTDWG-WALL GRID 2 A1-D (EAST SIDE)	11/15/11	L1.15.1	LFTDWG-WALL GRID A+ 6-7.1 (NORTH SIDE)	09/30/11
L1.04.2	LFTDWG-WALL GRID 2 A1-D (WEST SIDE)	11/15/11	L1.15.2	LFTDWG-WALL GRID A+ 6-7.1 (SOUTH SIDE)	11/03/11
L1.05.1	LFTDWG-WALL GRID 3 A1-C2 (EAST SIDE)	11/17/11	L1.16.1	LFTDWG-WALL GRID A1+ 6-7.1 (NORTH SIDE)	11/03/11
L1.05.2	LFTDWG-WALL GRID 3 A1-C2 (WEST SIDE)	11/17/11	L1.16.2	LFTDWG-WALL GRID A1+ 6-7.1 (SOUTH SIDE)	11/03/11
L1.06.3	LFTDWG-SUSPENDED SLAB AT MECHANICAL SHAFT	10/25/11	L1.17.1	LFTDWG-WALL GRID B+ 6-7.1 (NORTH SIDE)	09/30/11
L1.06.1	LFTDWG-WALL GRID 4 A-D (EAST SIDE)	10/17/11	L1.17.2	LFTDWG-WALL GRID B+ 6-7.1 (SOUTH SIDE)	11/03/11
L1.06.2	LFTDWG-WALL GRID 4 A-D (WEST SIDE)	10/18/11	L1.18.1	LFTDWG-WALL GRID C- 6-7.1 (NORTH SIDE)	11/03/11
L1.07.1	LFTDWG-WALL GRID C2 1-4 (NORTH SIDE)	11/28/11	L1.18.2	LFTDWG-WALL GRID C- 6-7.1 (SOUTH SIDE)	10/21/11
L1.07.2	LFTDWG-WALL GRID C2 1-4 (SOUTH SIDE)	11/10/11	L1.19.1	LFTDWG-WALL GRID C+ 6-7.1 (NORTH SIDE)	09/30/11
L1.08.1	LFTDWG-WALL GRID A1 1-4 (NORTH SIDE)	10/18/11	L1.19.2	LFTDWG-WALL GRID C+ 6-7.1 (SOUTH SIDE)	11/03/11
L1.08.2	LFTDWG-WALL GRID A1 1-4 (SOUTH SIDE)	10/18/11	L1.20.1	LFTDWG-WALL GRID C2- 6-7.1 (NORTH SIDE)	11/03/11
L1.09.1	LFTDWG-WALL GRID 5 A-D (EAST SIDE)	11/24/11	L1.20.2	LFTDWG-WALL GRID C2- 6-7.1 (SOUTH SIDE)	10/21/11
L1.09.2	LFTDWG-WALL GRID 5 A-D (WEST SIDE)	11/24/11	L1.21.1	LFTDWG-WALL GRID 2&3 A&A1	11/07/11
L1.10.1	LFTDWG-WALL GRID 7 A-D (EAST SIDE)	10/13/11	L1.22.1	LFTDWG-WALL GRID 3&4 A&A1	11/21/11
L1.10.2	LFTDWG-WALL GRID 7 A-D (WEST SIDE)	10/12/11	L1.23.1	LFTDWG-WALL GRID 2&3 C&2D	11/07/11
L1.11.1	LFTDWG-WALL GRID 7.1 A-D (EAST SIDE)	10/13/11	L1.24.1	LFTDWG-WALL GRID 3&4 C&2D	11/09/11
L1.11.2	LFTDWG-WALL GRID 7.1 A-D (WEST SIDE)	10/21/11	L1.25.1	LFTDWG-ELEVATOR WALL BTW GRID 2&3	11/18/11
			L1.26.1	LFTDWG-ELEVATOR WALL BTW GRID C&C2	11/21/11

Issue Date: 12/08/2011

 <p>THIS DRAWING IS FOR THE SOLE USE OF ANY PCL ORIGINATING COMPANY, OR ANY PCL JOINT VENTURE COMPANY. IT IS NOT TO BE USED, ALTERED OR REPRODUCED WITHOUT THE WRITTEN PERMISSION OF THE PCL FAMILY OF COMPANIES.</p>	<table border="1"> <thead> <tr><th>No.</th><th>Description</th><th>Date</th></tr> </thead> <tbody> <tr><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td></tr> </tbody> </table>	No.	Description	Date										<p>Owner</p> <p>MT. PLEASANT SUBSTATION (MTP)</p>	<p>LFTDWG-DRAWING LIST</p> <table border="1"> <tr><td>Project</td><td>VE08019.02</td><td>Sheet</td><td>L1.00.0</td></tr> <tr><td>Drawn</td><td>Halla Amiri</td><td> </td><td> </td></tr> <tr><td>Checked</td><td>Rock Eggert</td><td> </td><td> </td></tr> </table>	Project	VE08019.02	Sheet	L1.00.0	Drawn	Halla Amiri			Checked	Rock Eggert		
		No.	Description	Date																							
Project	VE08019.02	Sheet	L1.00.0																								
Drawn	Halla Amiri																										
Checked	Rock Eggert																										

Figure 2.45 Drawing list with their latest modification date

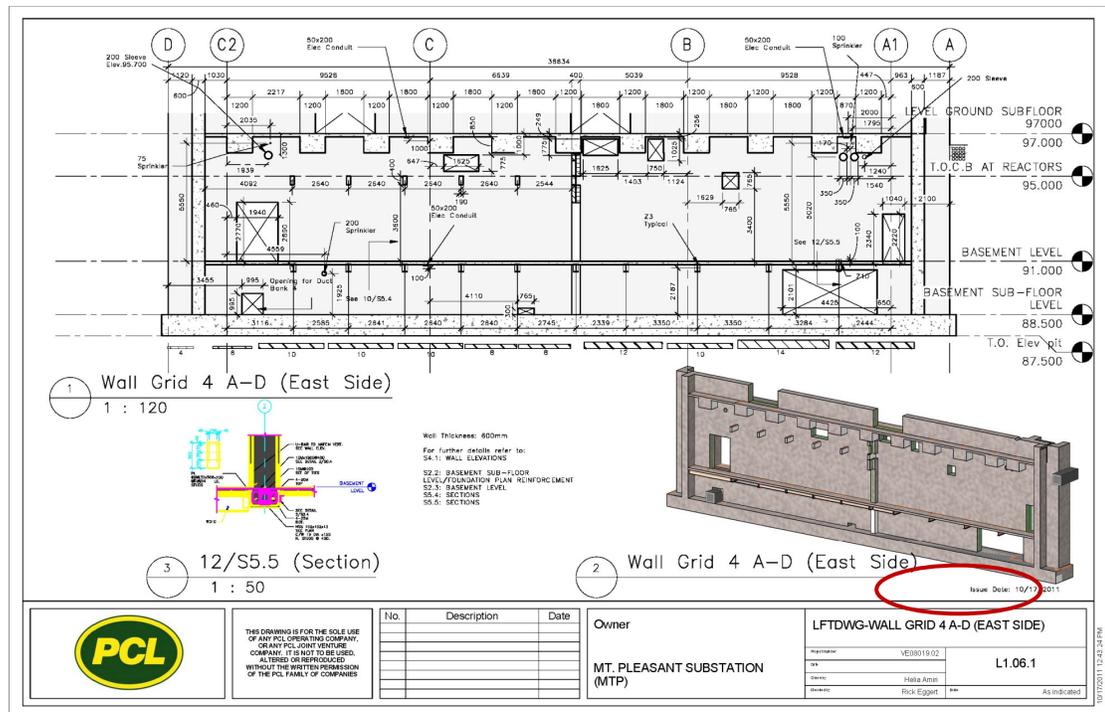


Figure 2.46 Issue date marked on wall lift drawing along gridline 4

## **2.14 Clash Detection Using BIM Models**

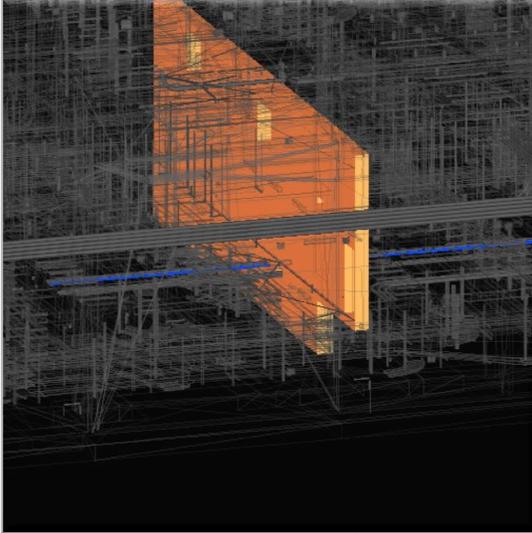
Due to the complexity of the project and considering the provided BIM models were from different disciplines such as structural, electrical, and mechanical, clash detection tests between each two of the BIM models are done to find any possible conflict between structural, electrical and mechanical designs. The conflicts found at this stage are related to the consultants` designs as only their designs were modeled in 3D. Therefore, the conflict detection at this stage doesn`t include the sub-trades` designs. However, as was mentioned in previous sections, creating lift drawings is a way of detecting conflict between sub-trades` and consultant designs.

Having structural, mechanical, and electrical BIM models, a clash detection test was done between each two of them using Autodesk Navisworks Manage. The results were reviewed and the clashes were divided into two categories, major and minor clashes. Minor clashes are those clashes that can be fixed on site where fixing them during construction doesn`t cause any delays or cost. Major clashes are those clashes that should be resolved prior construction because fixing them on site can cause delays and cost. For instance clashing a lighting fixture with a wall, or passing a conduit sleeve through a slab are considered minor clashes, whereas a duct passing through a concrete beam is a major clash that should be resolved prior to construction because it involves redesigning part of the job.

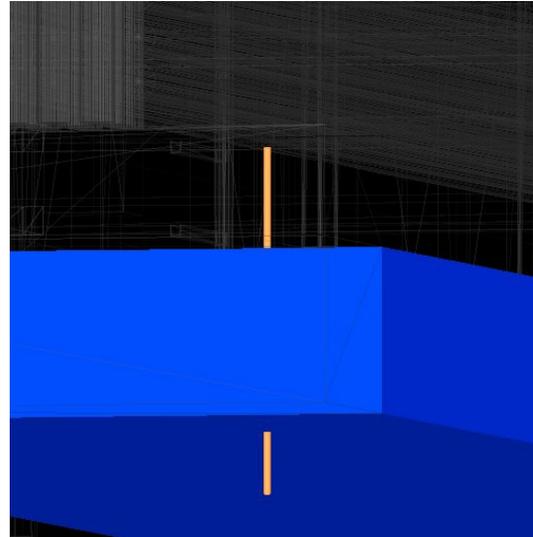
### **2.14.1 Clash Detection Between Structural and Electrical Models**

In total, 126 minor clashes were found between the structural and electrical models. The team decided that these would be resolved during construction. An example of such

clashes was when conduit sleeves were passing through a slab or a wall (Figure 2.47 and Figure 2.48).



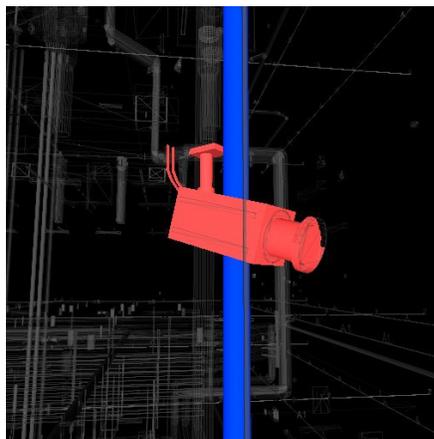
**Figure 2.47 Conduit sleeve passes through the wall (minor clash)**



**Figure 2.48 Conduit sleeve passes through the slab (minor clash)**

## **2.14.2 Mechanical and Electrical Models**

A total of 71 clashes were found between the mechanical and electrical models, and all of which were considered minor. Figure 2.49 shows a minor clash between a surveillance camera and a water pipe .



**Figure 2.49 Pipe passes through surveillance camera (minor clash)**

	<i>No.</i>	<i>Examples</i>
<i>Minor Clashes</i>	71	Clash 22 (Surveillance Camera clashes the Domestic Cold Water Pipe)
<i>Major Clashes</i>	0	
<i>Total</i>	71	

### 2.14.3 Mechanical and Structural Models

In total, 244 clashes between mechanical and structural models were found. 240 of these clashes were minor clashes, while four were viewed as ‘major’ clashes that had to be resolved prior to construction. Figure 2.50 shows one of these minor clashes

	<i>No.</i>	<i>Examples</i>
<i>Minor Clashes</i>	240	Clash 5 (Pipe goes through the S.O.G)
<i>Major Clashes</i>	4	Clash 19 (Duct passes through the beam at 107.35m elevation)
<i>Total</i>	244	

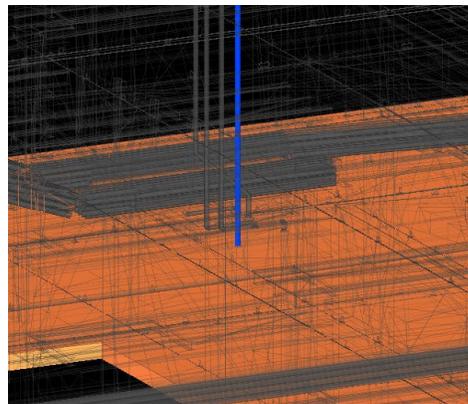


Figure 2.50 Pipe passes through the slab (minor clash)

#### Major Clash 1.

The table below shows that at the elevation 107.35 between gridlines B & C and 2 & 3 a mechanical duct passes through a concrete beam and to verify that they can look at drawing S4.1 which is a structural drawing. This clash is considered as a major clash because

it cannot be solved on site and requires either the structural design or the mechanical design to change. Figure 2.51 shows this clash.

<i>Clash 19</i>			
<i>Structural Element</i>	<i>Mechanical Element</i>	<i>Position</i>	<i>References</i>
Concrete Beam	Duct	Grids B&C 2&3 at 107.35 el.	S4.1

**Major Clash 2.**

The table below shows that at the same level and position as major clash, major clash 2 happened. Looking at both clashes, it seems that both of them indicate one clash; however, by checking the model it showed that the duct passes through two beams which are parallel to each other. Figure 2.52 shows major clash 2.

<i>Clash 50</i>			
<i>Structural Element</i>	<i>Mechanical Element</i>	<i>Position</i>	<i>References</i>
Concrete Beam	Duct	Grids B&C 2&3 at 107.35 el.	S4.1

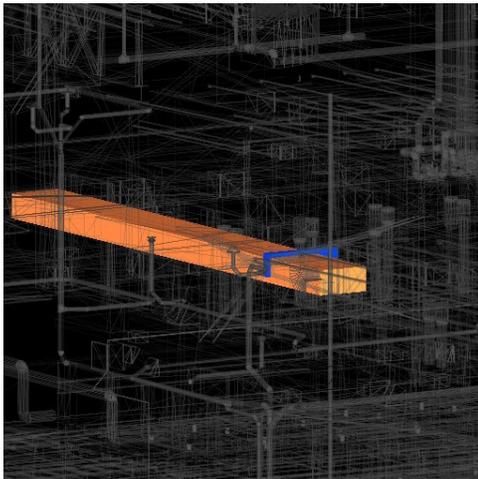


Figure 2.51 Major clash 1

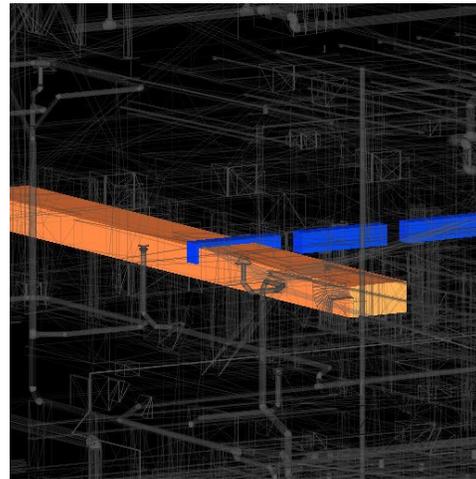


Figure 2.52 Major clash 2

### Major Clash 3.

Figure 2.53 shows major clash 3. A duct passes through a concrete wall at gridlines D&C and 5&6 at the elevation of 97.74. As it can be seen from the Figure 1.54 the duct was supposed to pass through the opening above the duct so there must be a mistake in the elevation of either the duct or the opening.

<i>Clash 53</i>			
<i>Structural Element</i>	<i>Mechanical Element</i>	<i>Position</i>	<i>References</i>
Concrete Wall	Duct	Grids D&C2 5&6 at 97.74 el.	S4.4

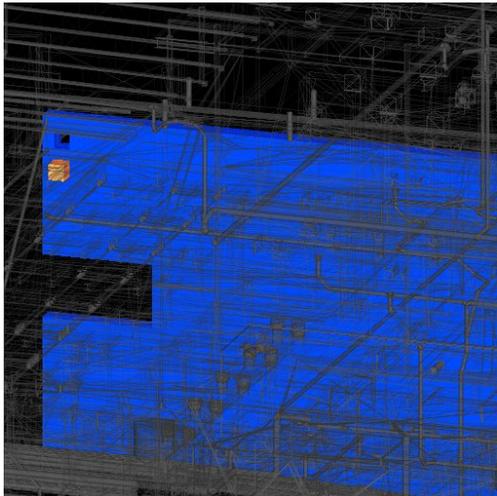


Figure 2.53 Major clash 3

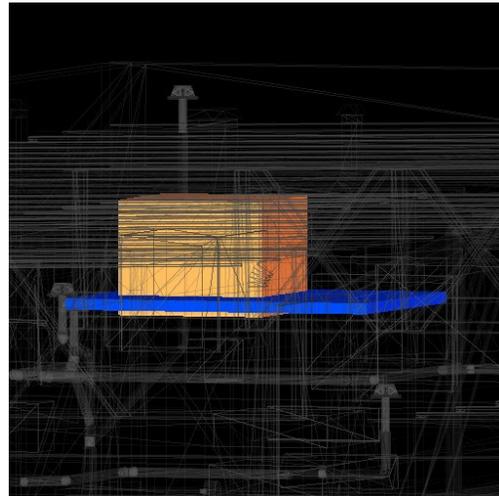


Figure 2.54 Major clash 4

### Major Clash 4.

Figure 2.54 shows major clash 4 in which a duct elbow passes through the roof of the elevator shaft. The position is indicated in the table below. This clash is a major clash as either the mechanical design or the structural design should change to solve the conflict.

<i>Clash 67</i>			
<i>Structural Element</i>	<i>Mechanical Element</i>	<i>Position</i>	<i>References</i>
Roof of Elevator Shaft	Duct Elbow	Grids C&C2 2&3 at 114.20 el.	S4.2, M1.6

Existence of Major and Minor clashes indicates that the consultant does not perform the clash detection test to highlight the conflicts between their different disciplines' designs.

## **2.15 Impacts of BIM on Clash Detection**

The benefits of using Navisworks for clash detection included: avoiding delays and extra costs, and improving communication.

### **2.15.1 Avoiding Delays and Extra Costs**

Navisworks Manage is an efficient tool for identifying clashes between different disciplines if their models are available. In this case, conflicts between different disciplines' designs could be highlighted in a timely manner and mistakes could be avoided prior to construction. In such a way, they were able to avoid delays and extra costs regarding to fixing these conflicts on site.

### **2.15.2 Improving Communications and Transferring Knowledge**

PCL asked for a meeting with all the sub-trades at the consultant's office. In the meeting which was held in August 2011, the major conflicts were mentioned and the responsible parties were asked to modify their designs. A full report of all clashes was given to the sub-trades and consultants and they were asked to go through all the clashes to see if there were any other clashes that should be taken care of.

After the meeting, most of the attendees declared that they had never used nor were they aware of any clash detection software. The attendees mentioned that to find clashes they just did a walk-through in the model. By simply doing a walk-through in the model, they would definitely miss some clashes. Having this meeting helped the project participants to come together in one room and talk through the different issues arising on the project.

## **2.16 Challenges of BIM on Clash Detection**

There were many challenges with using Navisworks for conflict detection which are described below.

### **2.16.1 Locating the Conflict**

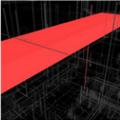
Navisworks Manage is a great tool for highlighting the clashes between different designs. The main problem is that after finding the clashes it is hard to locate each clash as the gridlines are not exported to Navisworks with the model. The clashes are specified based on coordinates, which is not that useful. For solving this problem a 3D gridline is imported to Navisworks as another model. In this way, the location of the conflict is determined better and is added to the report as a comment; however, this is a time-consuming task. Figure 2.55 shows a clash in the clash report provided by Navisworks Manage and the location based on gridlines which is added to the report as comments.

### **2.16.2 Vague Names for the Components**

Looking at the clash report produced by Navisworks, sometimes it is hard to identify the clashing component. For instance, looking at the clashing components in Figure 2.55, it is

hard to distinguish what “Solid” is from the electrical model or what “Solid\_Mitered Elbow/Tees” is in the mechanical model. In order to determine if it is a major clash or a minor clash, the types of components clashing with each other should be known.

As a result, the components were found in the BIM model in Revit and were specified according to category. In this way it could be seen if it was a major or minor clash. Figure 2.56 shows the list of components in Revit and to which category the components belong.

	<b>Name</b>	Clash1
	<b>Distance</b>	-0.50m
	<b>Description</b>	Hard
	<b>Status</b>	New
	<b>Clash Point</b>	4083.06m, -4366.39m, 107.11m
	<b>Date Created</b>	2011/7/15 14:50:05
<b>Item 1</b>		
<b>Layer</b>	<No level>	
<b>Path</b>	File ->File ->PCL_Electrical Revit Model.nwc -><No level> ->Type F1-F1N-MH 5097.6 AFF ->Type F1-F1N-MH 5097.6 AFF -	
<b>Item Name</b>	Type F1-F1N-MH 5097.6 AFF	
<b>Item Type</b>	Solid	
<b>Item 2</b>		
<b>Layer</b>	<No level>	
<b>Path</b>	File ->File ->MPT_Mech PCL Contractor Version.nwc -><No level> ->_Return_Mitered Elbows / Tees ->Solid	
<b>Item Name</b>	<u>_Return_Mitered Elbows / Tees</u>	
<b>Item Type</b>	Solid	
<b>Comment 1</b>		
<b>Status</b>	New	
<b>User</b>	hamiri	
<b>Text</b>	GRID C 2&3 GRND LVL	
	2011/7/18 22:08:37	

**Figure 2.55** Clash report and the added comments



## **2.17 4D Visualization**

I also performed 4D visualization of the structural BIM model. The procedure, impacts, and challenges are discussed in the following sections.

### **2.17.1 Breaking Down the 3D Model**

Considering the complexity of the project and the tight schedule, it was decided to create a 4D visualization from the BIM model and the schedule. To create the 4D visualization, the BIM model should be broken down based on the tasks on the schedule. For instance, if a slab is going to be poured in three steps, the component should be broken down into the three parts that are going to be placed. In this case, by attaching the components to their tasks in the schedule, the 4D visualization will be created.

Figure 2.57 shows a part of schedule for placing the suspended slab for the ground sub-floor level. As shown, the slab is placed in different steps. Figure 2.58 shows the same slab broken down to be compatible with the schedule.



### **2.17.2 Impact of Using 4D Visualization**

According to the Project Manager, the 4D visualization provided a useful way to visualize the construction of the structure. Specifically, the 4D visualizations allowed the contractor to visualize the sequencing of the walls, identify optimal pour break locations, and maintain a continuous flow of work. The 4D model was particularly useful in identifying and resolving sequencing issues. For instance, it became clear that the whole wall on gridline 6 should be completed before the corbels for the crane rail was placed. It also helped to avoid sequencing problems where completion of work had to be delayed, such as waiting for materials or other works to be completed, allowing production to be as high as possible and work to flow. In addition, the 4D visualizations also helped to manage the congested site. Space constraints were easier to identify in 4D, and the critical resources, such as the tower crane, could be allocated in a more logical way. For instance, it became clear that the walls on grid C2 needed to be placed before wall A1 was poured due to the reach required over the top.

### **2.17.3 Challenges for Creating 4D Visualization**

In order to create the 4D visualization, the whole BIM model had to be broken down based on the different tasks in the schedule. For instance, a slab should be broken down to four or five pieces which is a time-consuming activity as it can't be divided by using a "split" command. The slab had to be copied five times and each copy had to be edited using the "edit boundary" command to create each piece of the slab. As a result, breaking down the components sometimes means recreating that part of the model which is very tedious with existing tools.

## 2.18 Conclusion

The purpose of this part of the research was to evaluate the use of BIM in the construction phase of a project with a particular emphasis on the field personnel. Due to the complexities in the structure of the BC Hydro Mount Pleasant Substation and the availability of the consultants' BIM models, PCL decided to utilize the BIM models in the construction phase.

I created lift drawings from the BIM models for the walls and slabs to facilitate the process of forming and casting the components. I observed that using the lift drawings increased the productivity of the crew since they didn't have to browse through different sources of information on site, and helped to avoid mistakes and errors by coordinating the different sources of information and making it available in an easy to understand format.

In addition, these lift drawings also helped to detect conflicts between different sub-trades' designs and consultants' designs. Encouraging all the sub-trades to show their designs on the lift drawings instead of preparing shop drawings had several benefits. This method provided sub-trades with a way of checking if there are any conflicts between their design and another trade's design and increased efficiency by saving the time spent while the drawings go back and forth. Using this method also provided a single format for all the trades to show their design rather than each trade showing their design in their own format. Having the single format helped the field personnel and coordinator extract the information more easily which increased productivity. The table below shows the site superintendent claims about the benefits of using lift drawings on site.

**Table 2.1 Benefits of using BIM-based lift drawings based on the superintendent's claims**

Estimated percentage increase in crew's productivity due to the use of BIM-based lift drawings	20
Estimated percentage savings in key site personnel's time due to the clarity and comprehensiveness of the BIM-based lift drawings	50
Estimated percentage of RFI's issued prior to construction rather than during construction due to the enhanced coordination enabled by BIM-based lift drawings	100
Estimated percentage reduction in crew's wait time as a result of early resolution of RFI's	50
Percentage reduction in errors on site through the use of BIM-based lift drawings rather than making the necessary calculations during construction	50
Percentage savings of sub-trades time by using their design on the lift drawings	20

Conflict detection using the BIM model was the other way of leveraging BIM in this stage. The clash detection helped the contractor become aware of the clashes between three different designs that were modeled in BIM. Finding the major conflicts prior to construction helped the project avoid delays and extra costs.

In addition, a 4D visualization was created to help the project team visualize the construction process. As a result, in theory any mistakes or inefficiencies in the scheduling could be identified prior to construction; it also could help when allocating critical resources to different tasks.

Design change notices (DCNs) were a significant challenge in this project. With the issuance of each DCN, the BIM model should be updated in order to incorporate the changes

on the drawings. They also raise the challenge of coordination between sub-trades, as their changes to the design should be incorporated in the drawings in a timely manner. To deal with these challenges, it is recommended that the project team hold regular meetings in subsequent projects. Face to face communication will help the stakeholders solve the project's problems in a more convenient and faster manner.

## **Chapter 3:**

### **BIM for Quantity Takeoff**

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This chapter investigates BIM for quantity takeoff (QTO) to support construction cost estimating and life-cycle analysis (LCA). Efficient and accurate QTO is essential to provide cost and environmental impact feedback for decision-making throughout the project delivery process. In this chapter, I evaluate BIM-based QTO tools in comparison with 2D-based approaches using a case study of the Pharmaceutical Sciences Building project (Pharmacy) located at the UBC campus in Vancouver. The scale and complexity of this building made it an ideal project to study the use of BIM for QTO.

The specific research objectives for this case study were to:

1. Identify the requirements of QTO tools to support construction cost estimation and life cycle assessment.
2. Evaluate and compare 2D and BIM- based QTO tools.
3. Identify the benefits and shortcomings of these tools to support QTO for different types of construction components in meeting the requirements identified in (1).

The next sections describe the case study project in more detail and the functionality of the specific software analyzed in this research. Subsequent sections describe the evaluation of the software tools to support QTO for construction cost estimating and LCA.



**Figure 3.1** Rendered 3D view of UBC Pharmaceutical Sciences Building (Source: Saucier+Perotte Architects| Hughes Condon Marler Architects)

### **3.1 UBC Pharmaceutical Sciences Building (Case Study)**

In this chapter the UBC Pharmaceutical Sciences building will be studied in order to evaluate BIM-based QTO versus 2D-based QTO software.

#### **3.1.1 About the Project**

The UBC Faculty of Pharmaceutical Sciences and Centre for Drug Research and Development is located at the corner of Wesbrook Mall and Agronomy Road on the UBC Point Grey Campus. The Pharmaceutical Building, with a gross area of 300,000 square feet, houses for the first time under one roof all the teaching, learning, research and community

outreach activities of the Faculty of Pharmaceutical Sciences. The six-storey building provides teaching and learning spaces including lecture halls, classrooms and seminar rooms, as well as study spaces for students. The building also includes a pharmacist clinic, three floors of research spaces and a data center.

It is a 155 million dollar project designed to achieve a Leadership in Energy and Environmental Design (LEED) Gold certificate. The project started in mid-2010 and will be finished in September 2012. Some of the key building systems are outlined in Table 3.1.



**Figure 3.2 UBC Pharmacy Building**

**Table 3.1 Building characteristics of Pharmaceutical Building**

<i>Structure</i>	Concrete columns supporting concrete suspended slab
<i>Floors</i>	Basement: Concrete SOG, Level -1 interstitial: Steel joist floor, Other levels: Concrete suspended slab
<i>Exterior walls</i>	Curtain wall
<i>Interior walls</i>	Concrete cast in place walls, gypsum on steel stud walls, Metal clad wall, Masonry partition wall, and Curtain wall
<i>Roof</i>	Concrete suspended slab with two SBS sheet membrane, protection board and two layers of rigid insulation
<i>Mechanical</i>	Heat Exchange System

### **3.1.2 BIM Models**

The consultants provided architectural, structural, mechanical, and electrical BIM models in addition to the traditional drawing sets. The structural model contains all the structural components such as foundation system, concrete columns, concrete walls and slabs, while the architectural model contains components such as curtain wall system, partition walls, including masonry walls and metal stud walls, and ceilings. The components considered in this research are foundation systems, concrete walls (shear walls), and partition walls. Therefore, the structural and architectural BIM models were of particular importance in this research. Figure 3.3 and Figure 3.4 show snapshots of these two models.

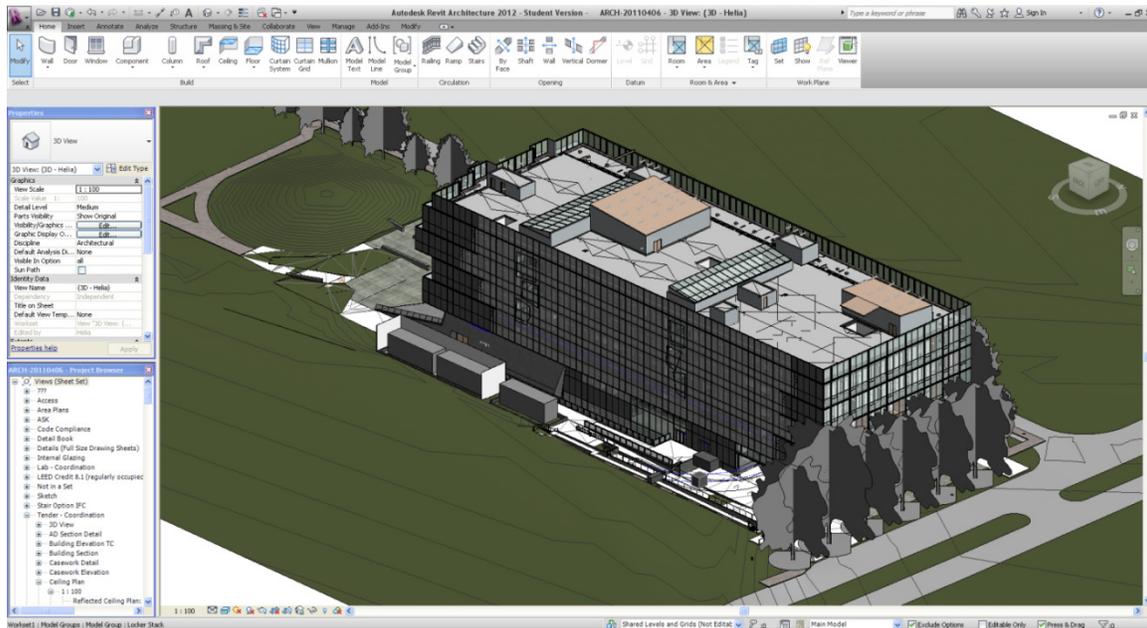


Figure 3.3 Snapshot of Pharmacy Building architectural BIM model

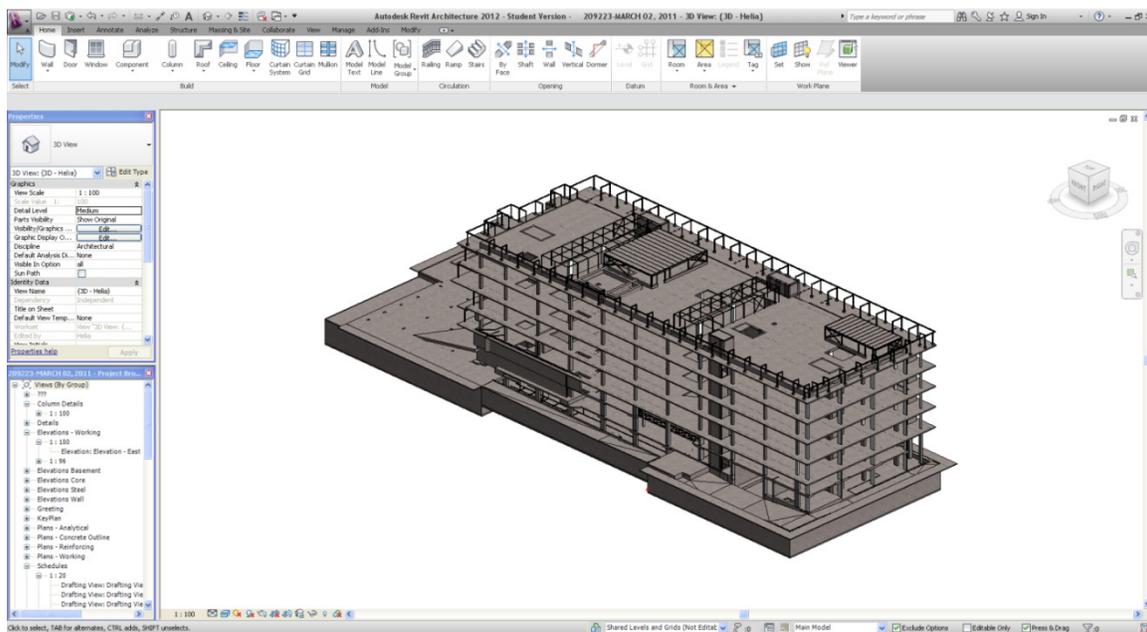


Figure 3.4 Snapshot of Pharmacy Building structural BIM model

### **3.2 Quantity Takeoff for Cost Estimating and LCA Purposes**

Currently, construction cost and environmental impacts are two of the most important factors guiding decision-making about different design alternatives, particularly during the early stages of projects. The first step towards creating an accurate cost estimate is to calculate the QTO with reasonable accuracy. In addition, with the increasing interest in sustainability, environmental impacts of the building have become another key factor for consideration. In order to evaluate the environmental impacts of the building, the types of materials being used and their quantities must be identified. For this reason, QTO will be the first step towards an environmental assessment as well. Considering the complexity and dynamic nature of today's projects, rapid feedback on the construction cost and environmental impact of different alternatives are needed. Therefore, it is essential that QTO be performed accurately and in a timely manner.

QTO is an activity performed by contractors, subcontractors, and cost consultants in order to determine the number of items or material quantities associated with the building components for a particular project. It is among the most time-consuming tasks on a construction project, and they are performed an average of seven times throughout the life of a project just for cost estimating purposes (Laitinen, 1998). This information can be used for different stages of the work such as cost estimating, bidding, material procurement, decision-making and LCA. In this research, the focus is on using QTO for construction cost estimating and LCA purposes.

### **3.2.1 Background on Construction Cost Estimating**

Cost is an important factor in the early phases of the project, often dictating whether a project is feasible or not. It is critically important to get rapid cost feedback to support design decision-making and the evaluation of different design alternative (Tiwari, Odelson, & Khanzode, 2009). Considering the current fast track nature of projects, rapid cost feedback is also needed when changes are made during the construction phase. Cost estimating is therefore the backbone of success for any construction project (Alder, 2006) and precision is a vital factor in the cost estimating process. The first step towards having an accurate cost estimate is having a precise QTO.

The level of detail included in cost estimates varies at different stages of the project. For instance, the level of detail in the conceptual design phase is less than in the construction phase of the project. In order to create a cost estimate, an estimator needs to obtain information including the project's scope and schedule details and data. Based on the obtained information, s/he starts performing the QTO of the project and assigns the related cost for constructing the component, considering factors such as different design features, resources, and labor, using the firm's cost database. The next step involves determining the risks and setting contingencies (Del Pico 2012).

One of the major tasks in the cost estimating process is performing QTO. The process of extracting quantities from 2D drawings can take up to 50%-80% of the estimator's time in any project (Bylund & Magnusson, 2011). Considering the ability of the BIM-based software to calculate the quantities efficiently and with great precision, using a 3D model of the project can help the estimator to save considerable time.

### **3.2.2 Background on Building Life Cycle Assessment**

Rebitzer (2004) describes LCA as a “methodological framework for estimating and assessing the environmental impacts attributable to the lifecycle of a product, such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use, land use, and noise and others”. Lifecycle analysis for a building is usually completed in the early stages of the project when different alternatives are evaluated to find the most environmentally friendly alternative.

LCA uses an available Life Cycle Inventory (LCI) database to provide the analysis. LCA software such as GaBi (PE International, 2011) and Athena Impact Estimator (Athena sustainable Material Institute, 2011) provide the building’s environmental impact results using these databases. In this research Athena Impact Estimator is studied as the software and its database is created for North America and is more compatible with the building systems in Canada. To date Athena has invested more than \$2 million on database development to provide an ever growing comprehensive lifecycle inventory database for building materials and product. Athena not only developed data for building materials but also considered transportation, construction and demolition process including on-site construction of a building’s assemblies, maintenance, repair and replacement affects through the operating life, and demolition and disposal (Athena sustainable Material Institute, 2011); Therefore makes it a good candidate to provide a cradle-to- grave LCA tool.

In Athena Impact Estimator, the user inputs the quantities of the materials being used in the project through dialog boxes and the software calculates the environmental impacts of the building based on the materials and their quantities, using Athena’s LCI database. The

software reports footprint data for environmental impact measures such as global warming potential, acidification potential, ozone depletion potential, etc.

Therefore, for calculating the environmental impact of the building some required information about the quantities of the materials should be input to the software. Some of the quantities should be manipulated to be accepted for the software. For instance, Athena doesn't accept thickness more than 500mm for spread footings; therefore, if the thickness of a footing is more than 500mm, the user should change the thickness of the footing to 500mm and change the length or width considering the volume to be constant. Figure 3.5 shows a snapshot of an Excel sheet created to consider the software limitations into calculations for Pharmacy building. As it can be seen there are nine F2 Spread footings with the thickness of 1025mm. In Impact Estimator, all of these footings are input as one footing with the thickness of 500mm considering the total volume to be constant. Therefore, the length is changed from 3.45m to 63.65m. For all types of components there are some limitations and assumptions that must be considered after the QTO is done.

I provided an Excel sheet for the Pharmacy Building (shown in Figure 3.5), input the quantities I took off and calculated the inputs based on the software limitations. The calculated quantities were then input to the Impact Estimator. Figure 3.5 shows the dialog box in which the quantities for footing F1 were input. The software also asks for the size of rebar and the strength of the concrete in addition to the dimensions.

Example\_Pharmacy\_Inputs&AssumptionsDocuments - Microsoft Excel

Page Layout Formulas Data Review View

Gridlines Formula Bar Headings

Zoom 100% Zoom to Selection

New Window Arrange All Freeze Panes Hide

View Side by Side Synchronous Scrolling Reset Window Position

Save Workspace Switch Windows

Macros

1 Foundation

## IE Inputs Document - Pharmacy

Assembly Name	Input Fields	Input Values	
		Known/Measured	IE Inputs
1.2.2 Footing_F2	Number	9.00	1.00
	Length (m)	3.45	63.65
	Width (m)	2.85	2.85
	Thickness (mm)	1,025.00	500.00
	Concrete (MPa)	25.00	30.00
	Concrete flyash %	-	average
1.2.3 Footing_F3	Number	25.00	20.00
	Length (m)	12.00	1.00
	Width (m)	3.60	37.20
	Thickness (mm)	3.15	3.15
	Concrete (MPa)	1,125.00	500.00
	Concrete (MPa)	25.00	30.00
1.2.4 Footing_F4	Concrete flyash %	-	average
	Rebar	30.00	20.00
	Number	4.00	1.00
	Length (m)	3.75	35.25
	Width (m)	3.45	3.45
	Thickness (mm)	1,175.00	500.00
1.2.5 Footing_F5	Concrete (MPa)	25.00	30.00
	Concrete flyash %	-	average
	Rebar	30.00	20.00
	Number	3.00	1.00
	Length (m)	4.20	34.65
	Width (m)	3.75	3.75
	Thickness (mm)	1,375.00	500.00

Figure 3.5 Snapshot of spread footing quantities and the inputs to Impact Estimator

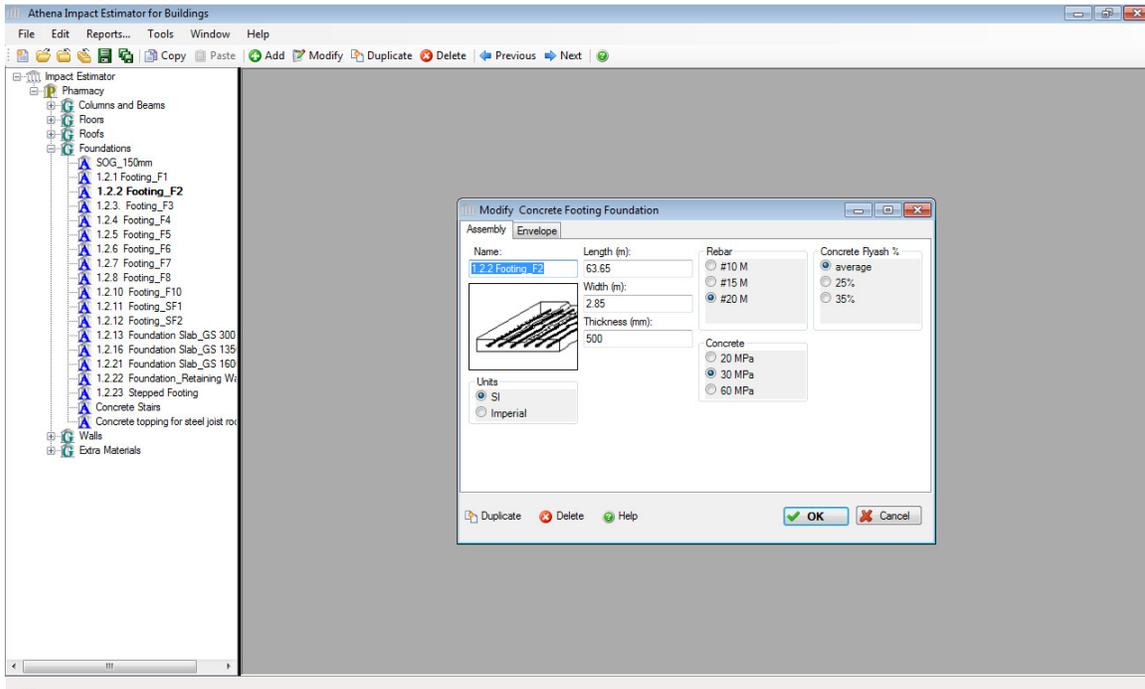
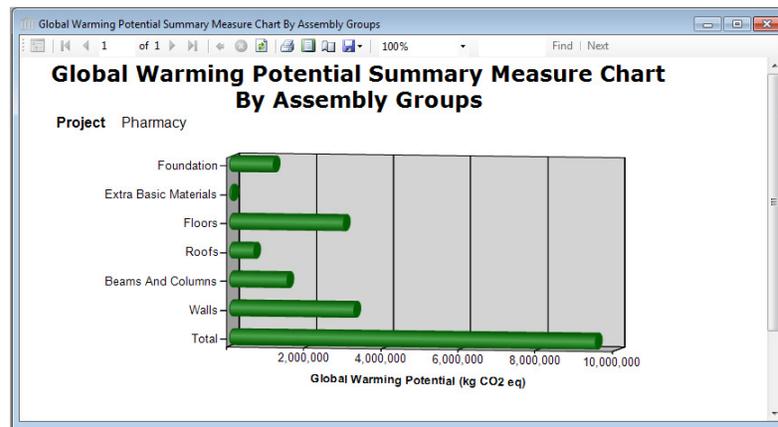


Figure 3.6 Snapshot of Inputting spread footing data to Athena Impact Estimator

After inputting all the quantities and required information for different components in the building, the software calculates the environmental impacts of the building using its database and gives the results. Figure 3.7 shows the global warming potential for pharmacy building. It can be observed that walls and floors have more impact on global warming than the other components; therefore, in order to minimize the global warming potential of the building, the decision maker should focus on changing walls and floors types.



**Figure 3.7 Global warming potential for Pharmacy building**

Looking at the process of LCA shows that the first critical step is performing the QTO of the building and providing the information in a format required for the software input.

### 3.2.3 Summary

Looking at the previous sections, it is obvious that a precise QTO completed in a timely manner plays an important role for cost estimating and LCA purposes. Traditionally, QTO has been accomplished using the drawing sheets; however, it is a tedious, and time-consuming task. Many tools, such as On-Screen Takeoff and BIM-based software, have been developed to help estimators perform more accurate QTO in a more efficient manner. Two-

dimensional drawings lack the rich three-dimensional (3D) context that estimators need to identify important cost-sensitive design features. In addition, extracting quantities from 2D drawings can take up to 50%-80% of the estimator's time; however, with the 3D model, the time usage is expected to decrease (Bylund & Magnusson, 2011).

In this chapter, I evaluate BIM-based QTO compared with 2D-based QTO using the Pharmacy Building as a case study. I studied the available software and chose two applications of BIM-based software (Revit and Tocoman) and one 2D-based software (On-Screen Takeoff) based on their popularity, ease of use, and their compatibility with different cost estimating software. I developed a criteria for evaluating the software based on the requirements of construction cost estimators and consultants performing LCA. I compared the QTO process for three types of components: foundations, shear walls and partition walls, using the developed criteria. I then assessed the benefits and shortcomings of each piece of software.

The next sections describe the software utilized in this case study and the criteria developed to evaluate these tools as a basis for LCA and construction cost estimating. Subsequent sections describe the QTO process using these tools on the Pharmacy Project, and the evaluation of these tools against the established criteria.

### **3.3 Software**

I evaluated and compared the efficiency of BIM-based and 2D-based QTO tools. I reviewed several software and selected one popular 2D-based software and two types of BIM-based software to complete this analysis. On-Screen Takeoff is a 2D-based QTO

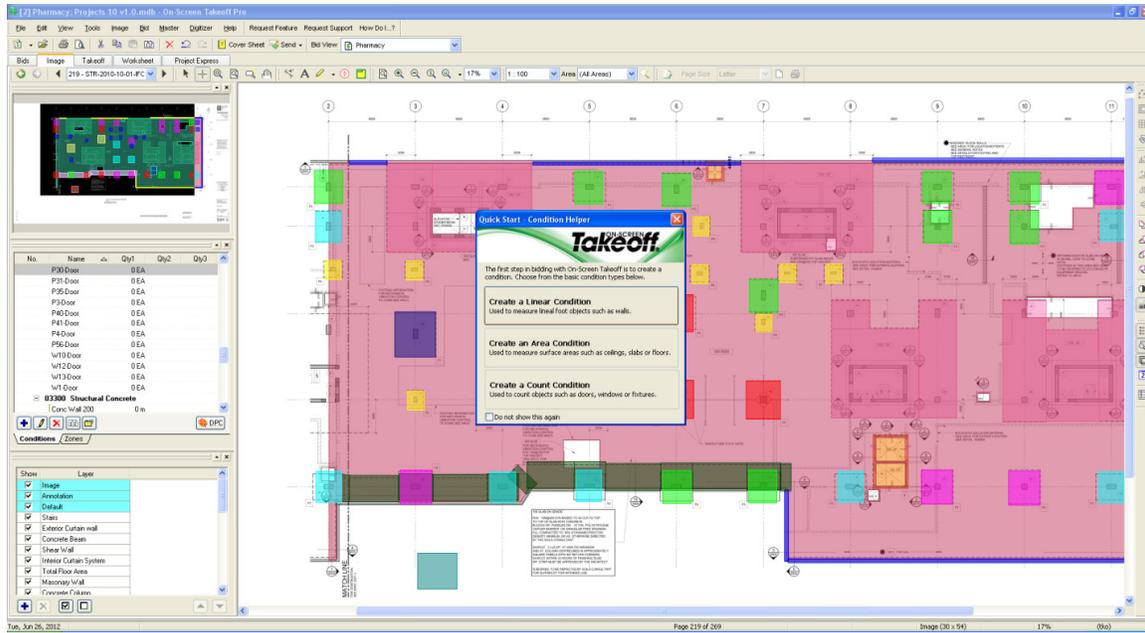
software used for this research because of its popularity among estimators, ease of use, and its capabilities in providing the required information for cost estimating purposes.

Revit was selected as one of the BIM-based QTO software because it is commonly used for modeling and design and supports numerous purposes including the creation of 2D drawings, visualizing the project, and creating bills of materials. Tocoman iLink is another BIM-based software studied in this chapter because of its popularity in the industry, its ability to export information to Navisworks, and to support multiple estimating application like Excel, Timberline, Map, and BidCon.

### **3.3.1 On-Screen Takeoff**

On-Screen Takeoff is 2D-based QTO software that uses electronic plans to do the QTO. It allows the user to view a variety of drawing files and to measure items electronically using the mouse. The software offers a choice of colors, line styles, count symbols, and area fill patterns for the item measured (Alder, 2006).

For this project, both architectural and structural drawings were used. In order to measure the quantities of a component a condition is applied. Conditions allow the user to identify what is being measured. In other words, each condition is a task for measuring a component. For instance, if we want to measure foundation type F, we create a condition for that. There are three conditions that can be used based on the type of component. Figure 3.8 shows these three conditions in the software: Count, Linear, and Area conditions, which are described next.



**Figure 3.8 Different conditions available for QTO**

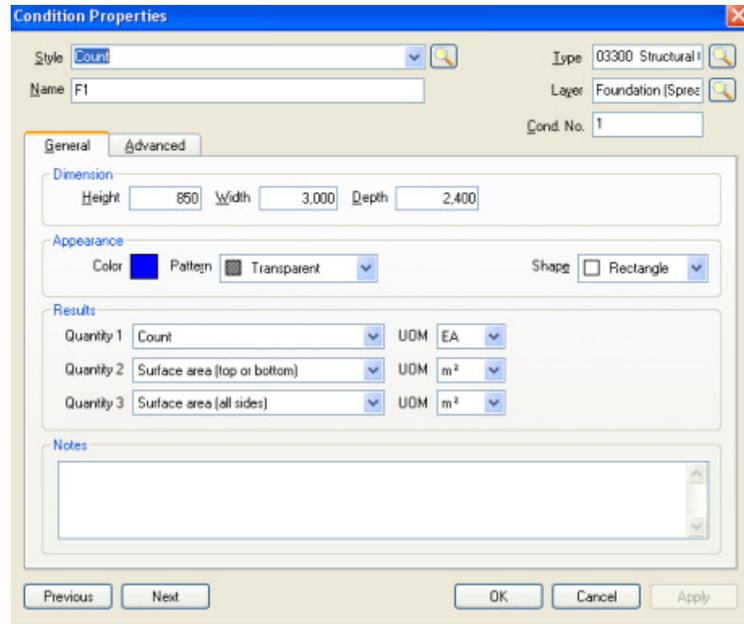
### 3.3.1.1 Count Condition

The count condition is used when the estimator wants to count the number of components; for example, counting the number of doors or spread footings. By giving the dimensions of a specific component such as spread footings or doors, the existing number of this component can be counted. After selecting the count condition, a window will open asking for the dimensions and quantities needed (Figure 3.9).

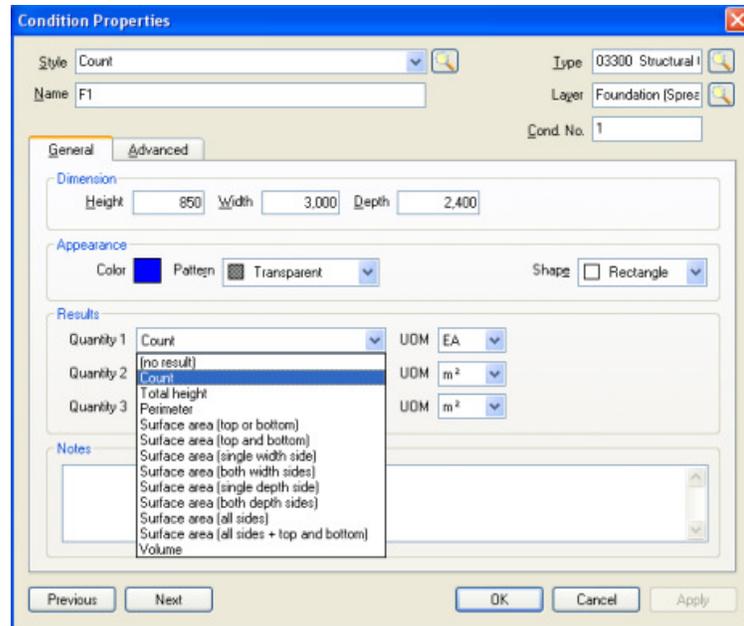
In the properties window, it asks for a name, type and layer of the component. For example, to provide quantities for a foundation called F1, the name would be typed as F1, the type would be chosen from a list (“structural concrete” in this example) and the layer would be set as “foundation”. The layers can be turned on or off to make navigation through the drawings more convenient. For instance, if the walls and foundations are measured using the same drawing, the measurement for walls can be made invisible by turning off the related layer. The next part asks for the dimensions. For the count condition, the height, width, and

depth of the component are requested. To differentiate between different types of footings such as F1, F2, etc., it is better to assign them different colors. The color can be chosen in this window as well. In the results part, there are three different quantities that the model can be asked to calculate. Based on the type chosen, the available quantities are different. For instance, for the spread footing, the following quantities can be asked for (Figure 3.10):

- Count
- Total height
- Perimeter
- Surface area (top or bottom)
- Surface area (single width side)
- Surface area (both width sides)
- Surface area (single depth side)
- Surface area (both depth sides)
- Surface area (all sides)
- Surface area (all sides + top and bottom)
- Volume

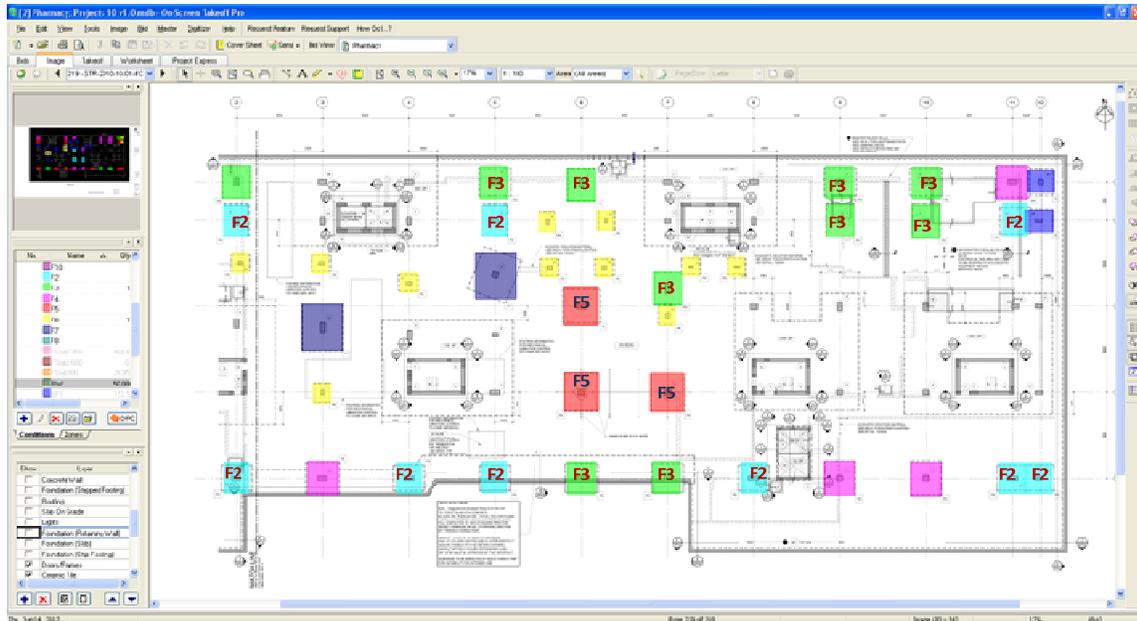


**Figure 3.9 Condition properties window for count condition**



**Figure 3.10 Available results for spread footing using count condition**

Figure 3.11 shows the QTO of spread footings in the Pharmacy Building using the count condition. The user should supply the software with the length, width, and height for each category of spread footing. Different colors indicate different kinds of spread footings.



**Figure 3.11 QTO of spread footings using the counting condition**

### 3.3.1.2 Linear Condition

This condition is usually used to count the linear foot measurement of objects such as walls or strip footings. The same requirements apply as for the count condition; however, the user should also input the height and thickness of the component to the software. If the surface is sloped, the slope ratio can be specified in the dimension part as well. Figure 3.12 shows the condition property window and the calculated results. Figure 3.15 is a snapshot of the QTO of strip and retaining wall foundations using the linear condition.

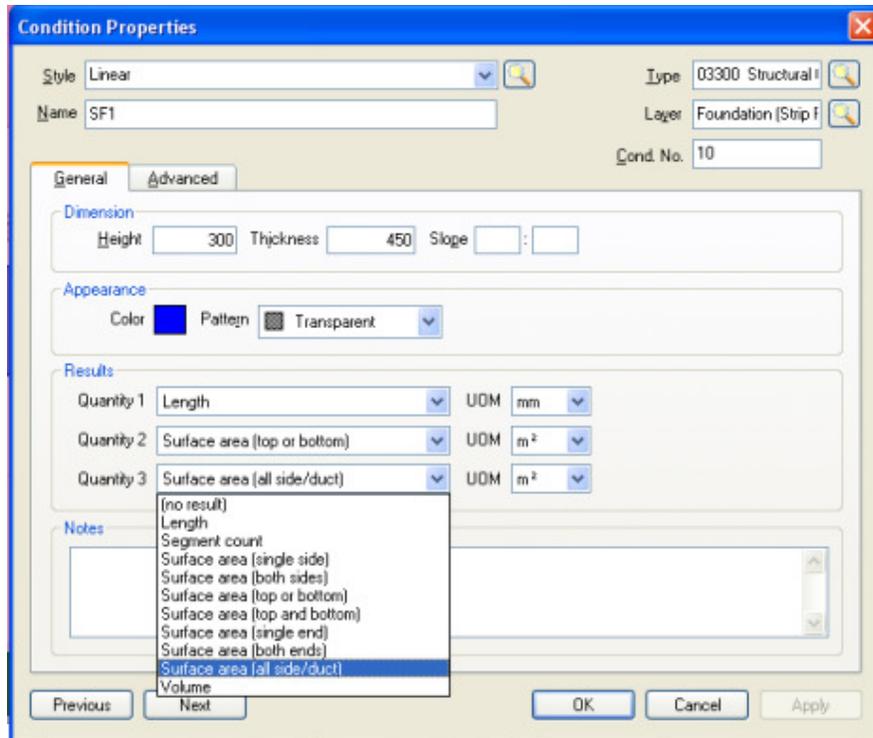


Figure 3.12 Available results for spread footing using linear condition

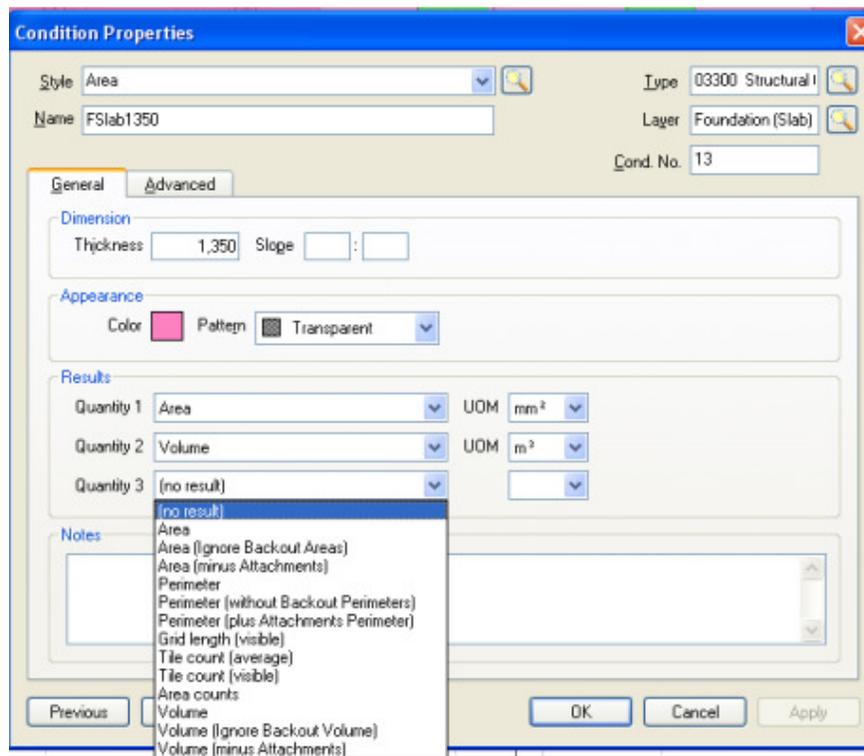
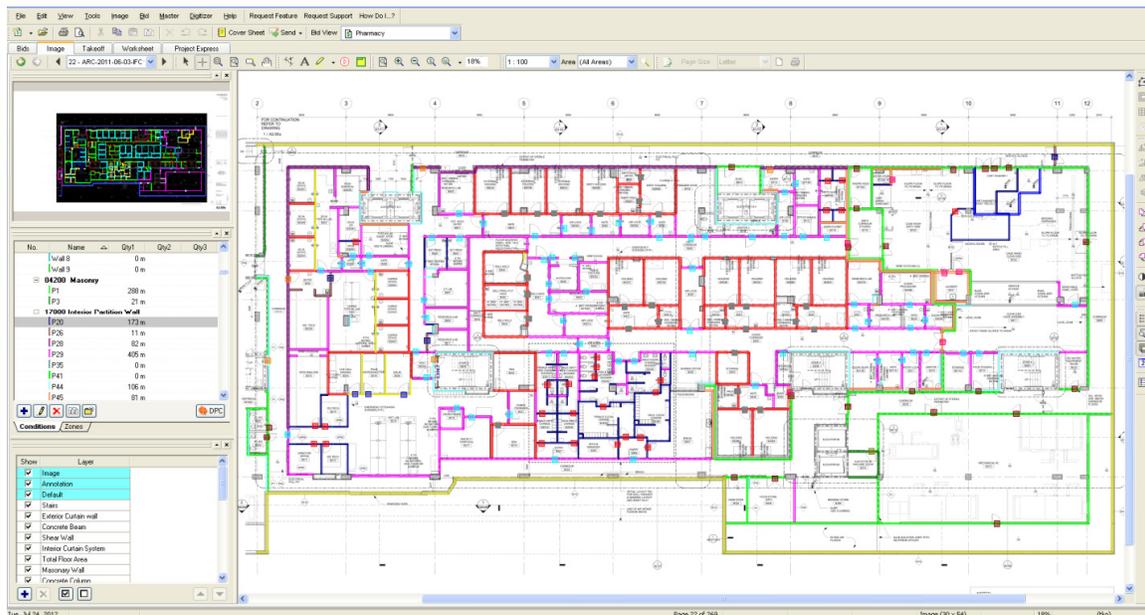


Figure 3.13 Available results for spread footing using area condition

This condition is also used for calculating the quantities of different walls. For shear walls, the type is set up as structural concrete and the layer is indicated as shear wall; however, for partition walls, the type is interior partition wall and the layer is set as interior walls. The software has the ability to add new layers and types in order to organize the QTO in the desired way. For walls, the height and the thickness of the walls should be input and calculations of different quantities such as length can be requested. The user should make sure to input the information from the drawings correctly. For instance, if a wall is not attached to the ceiling and the estimator put the height of the walls based on the height of the ceiling level, the calculations will be wrong. When calculating the shear walls if he or she forgets to consider the openings, there will be mistakes in calculating the concrete volume. Figure 3.14 shows a snapshot of the partition walls measured in On-Screen Takeoff.



**Figure 3.14 Snapshot of the partition walls measured in On-Screen Takeoff**

### 3.3.1.3 Area Condition

This condition is used to measure the surface area of components such as floors, ceilings, etc. This condition requires the same information as the other conditions; however, for the dimension part it asks for thickness and slope. Figure 3.16 shows the QTO of the foundation slab using the area condition. In this case, the user inputs the thickness, the area will be measured using the mouse, and the quantities will be calculated by the software. Figure 3.13 shows the condition property window and the results that the software calculates for this condition. Different colors indicate different types of foundation slabs.

Figure 3.17 shows a snapshot of QTO done by On-Screen Takeoff. The grouping in this software is based on how the operator inputs the information. For instance, if the operator wants to place spread, strip and slab footings in different groups, s/he can put each category in a separate folder when completing the QTO.

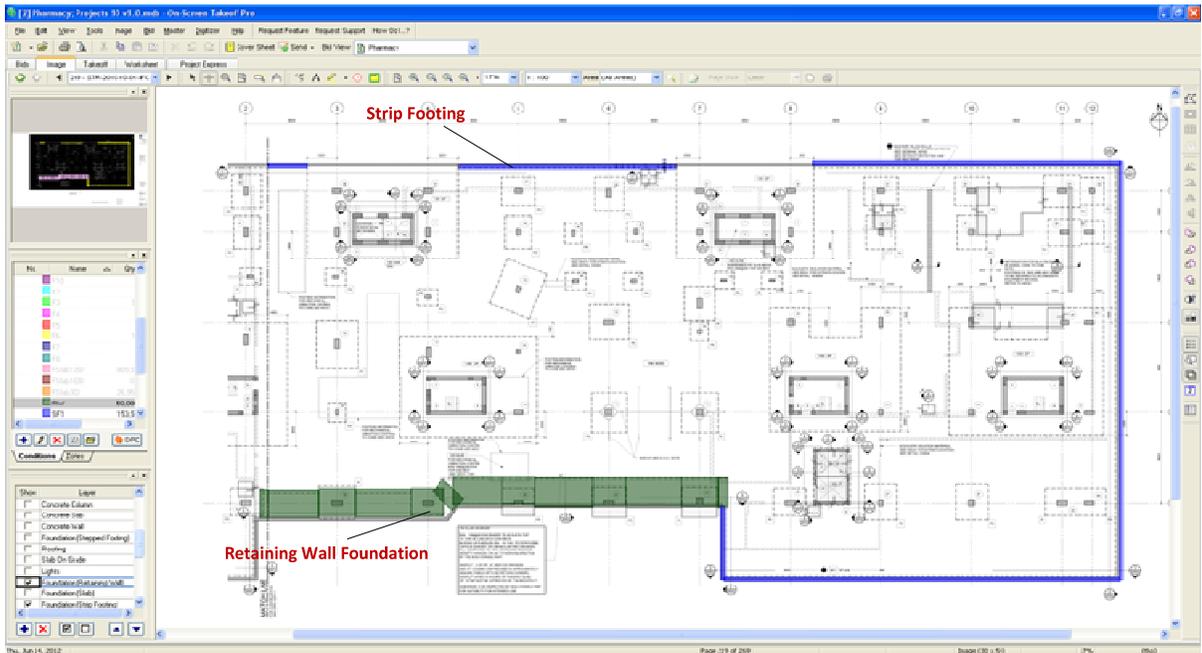


Figure 3.15 QTO of strip footings and retaining wall foundations using the linear condition

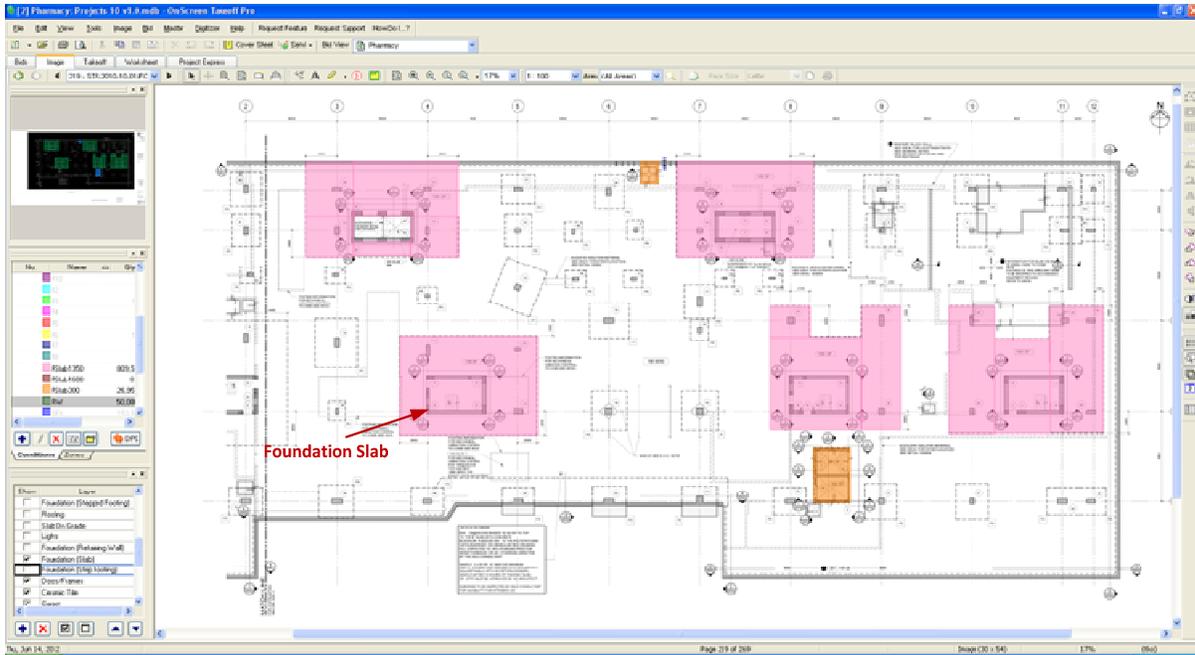


Figure 3.16 QTO of foundation slabs using the area condition

[2] Pharmacy; Projects 10 v1.0.mdb - On-Screen Takeoff Pro

File Edit View Tools Image Bid Master Digitizer Help Request Feature Request Support How Do I...?

Bids Image Takeoff Worksheet Project Express

Takeoff Totals Takeoff + Typical Group/Area Totals Individual Typical Group Totals

No.	Name	Height	Area	Quantity 1	UOM1	Quantity 2	UOM2	Quantity 3	UOM3	Notes
Wall										
Foundation										
03300 Structural Concrete										
16	SteppedF	0 mm	(unassigned)	2,707,745	mm <sup>2</sup>	10	EA	0		
15	Rw	400 mm	(unassigned)	50,080	mm	148	m <sup>2</sup>	336	m <sup>2</sup>	
14	FSlab1600	0 mm	(unassigned)	193,084,496	mm <sup>2</sup>	19	m <sup>3</sup>	0		
13	FSlab1350	0 mm	(unassigned)	809,532,761	mm <sup>2</sup>	1,093	m <sup>3</sup>	0		
12	FSlab300	0 mm	(unassigned)	36,838,371	mm <sup>2</sup>	11	m <sup>3</sup>	0		
11	SF2	300 mm	(unassigned)	92,030	mm	41	m <sup>2</sup>	138	m <sup>2</sup>	
10	SF1	300 mm	(unassigned)	296,510	mm	133	m <sup>2</sup>	445	m <sup>2</sup>	
9	F10	900 mm	(unassigned)	8	EA	12	m <sup>2</sup>	35	m <sup>2</sup>	
8	F8	1,400 mm	(unassigned)	2	EA	34	m <sup>2</sup>	46	m <sup>2</sup>	
7	F7	1,525 mm	(unassigned)	2	EA	46	m <sup>2</sup>	59	m <sup>2</sup>	
6	F6	650 mm	(unassigned)	37	EA	140	m <sup>2</sup>	188	m <sup>2</sup>	
5	F5	1,375 mm	(unassigned)	3	EA	47	m <sup>2</sup>	66	m <sup>2</sup>	
4	F4	1,175 mm	(unassigned)	4	EA	52	m <sup>2</sup>	68	m <sup>2</sup>	
3	F3	1,125 mm	(unassigned)	12	EA	136	m <sup>2</sup>	182	m <sup>2</sup>	
2	F2	1,025 mm	(unassigned)	9	EA	88	m <sup>2</sup>	116	m <sup>2</sup>	
1	F1	850 mm	(unassigned)	2	EA	14	m <sup>2</sup>	18	m <sup>2</sup>	
SDG										
Floor										
Level 01										
03300 Structural Concrete										
8	300 Slab	0 mm	(unassigned)	2,764	m <sup>2</sup>	0		0		
8	250 Slab	0 mm	(unassigned)	2,047	m <sup>2</sup>	0		0		
8	200Slab	0 mm	(unassigned)	839	m <sup>2</sup>	0		0		
8	250 Slopped Slab	0 mm	(unassigned)	534	m <sup>2</sup>	0		0		slope is assu...
9	300 Slopped Slab	0 mm	(unassigned)	175	m <sup>2</sup>	0		0		slope is assu...
9	175 Apron Slab	0 mm	(unassigned)	605	m <sup>2</sup>	0		0		Rebar 15M ...
3	4.8kpa live load	0 mm	(unassigned)	3,646	m <sup>2</sup>	0		0		
3	12kpa live load	0 mm	(unassigned)	1,955	m <sup>2</sup>	0		0		

Figure 3.17 Snapshot of QTO done by On-Screen Takeoff



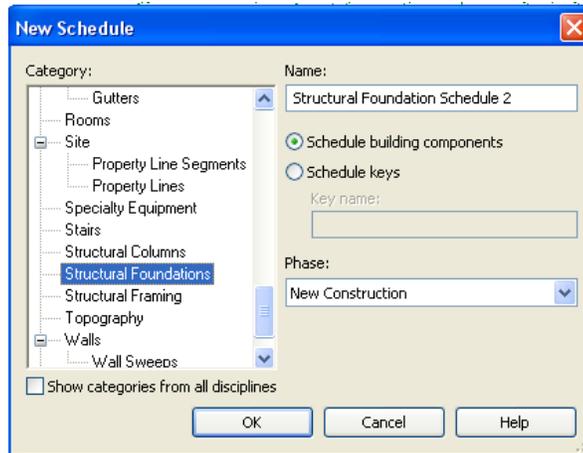


Figure 3.19 Snapshot of Revit for creating new schedule for foundation

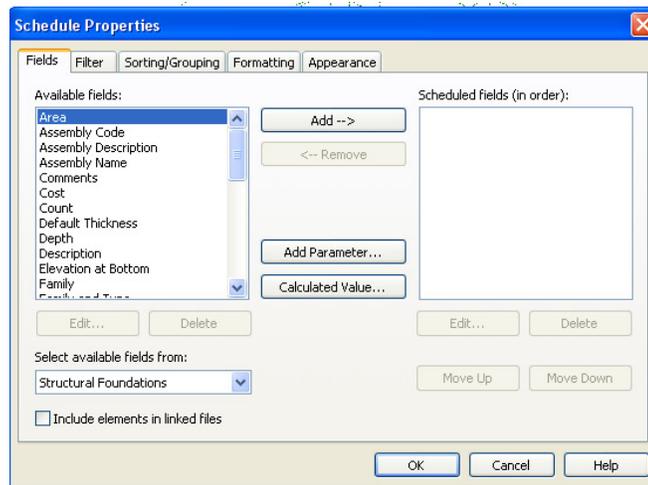


Figure 3.20 Selecting the desired properties for foundation QTO in Revit

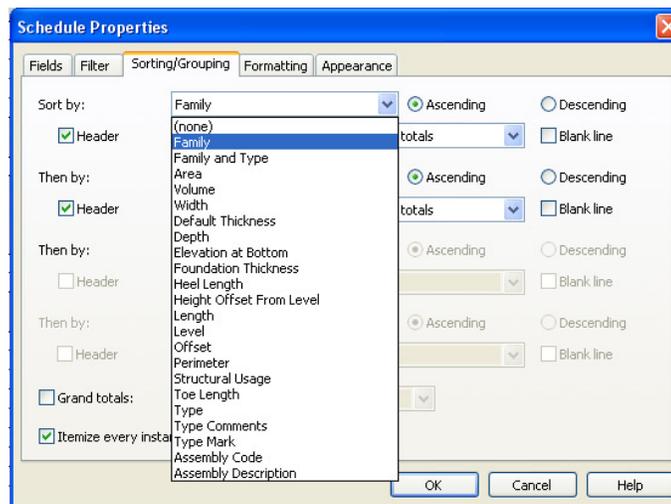


Figure 3.21 Schedule properties window in Revit showing the categories in which foundation can be grouped

Revit has the ability to group the components based on different attributes. Figure 3.21 shows the available attributes by which foundations can be grouped. Different types of components have different attributes by which they can be grouped. Figure 3.22 shows the Pharmaceutical Building foundation QTO in Revit Architecture which are grouped by the “family” field.

Family	Family and Type	Area	Count	Volume	Width	Default Thick	Depth	Elevation at B	Foundation
GS Rectangular Footing	GS Rectangular Footing: F6	6315000 mm²	1	2457000000	1800		650	-7850	
GS Rectangular Footing	GS Rectangular Footing: F6	6315000 mm²	1	2457000000	1800		650	-7850	
GS Rectangular Footing	GS Rectangular Footing: F6	6315000 mm²	1	2457000000	1800		650	-7850	
GS Rectangular Footing	GS Rectangular Footing: F6	6311269 mm²	1	2454574897	1800		650	-7850	
GS Rectangular Footing	GS Rectangular Footing: F6	6315000 mm²	1	2457000000	1800		650	-7850	
GS Rectangular Footing: F6: 37									
GS Rectangular Footing: F7									
GS Rectangular Footing	GS Rectangular Footing: F7	37590000 mm²	1	34998750000	4500		1525	-8725	
GS Rectangular Footing	GS Rectangular Footing: F7	37590000 mm²	1	34998750000	4500		1525	-8725	
GS Rectangular Footing: F7: 2									
GS Rectangular Footing: F8									
GS Rectangular Footing	GS Rectangular Footing: F8	28515000 mm²	1	23751000000	3900		1400	-8600	
GS Rectangular Footing: F8: 1									
GS Rectangular Footing: F10									
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing	GS Rectangular Footing: F10	3600000 mm²	1	1296000000	1200		900	-5626	
GS Rectangular Footing: F10: 11									
GS Rectangular Footing: 81									
GS Stepped Footing									
GS Stepped Footing: GS Stepped Footing									
GS Stepped Footing	GS Stepped Footing: GS Stepped Footing	1836249 mm²	1	348843151.2	450			-7500	
GS Stepped Footing	GS Stepped Footing: GS Stepped Footing	2699853 mm²	1	512005278.5	450			-8600	
GS Stepped Footing	GS Stepped Footing: GS Stepped Footing	2206866 mm²	1	395240397.5	450			-8600	
GS Stepped Footing: GS Stepped Footing: 3									
GS Stepped Footing: 3									
Wall Foundation									
Wall Foundation: Retaining Wall - Offset - 250 Wall									
Wall Foundation	Wall Foundation: Retaining Wall - Offset - 2		1	27090420656	2950			Varies	400
Wall Foundation	Wall Foundation: Retaining Wall - Offset - 2		1	475728529.0	2950			Varies	400
Wall Foundation	Wall Foundation: Retaining Wall - Offset - 2		1	15634748049	2950			Varies	400
Wall Foundation: Retaining Wall - Offset - 250 Wall: 3									
Wall Foundation: SF1 - Offset - 250 Wall									
Wall Foundation	Wall Foundation: SF1 - Offset - 250 Wall		1	1656138876	450			Varies	300

Figure 3.22 Foundation QTO in Revit Architecture

### 3.3.3 Tocoman iLink

Tocoman iLink is an add-on to BIM applications (e.g., Revit, ArchiCAD and Tekla). Tocoman iLink is able to calculate quantities; therefore, only the quantity of the modeled components can be calculated. For instance, if the goal is doing the QTO of the foundation system, the required categories—continuous wall foundation and isolated footing—are selected in the model browser and it is determined in which category they should be grouped. (Figure 3.23)

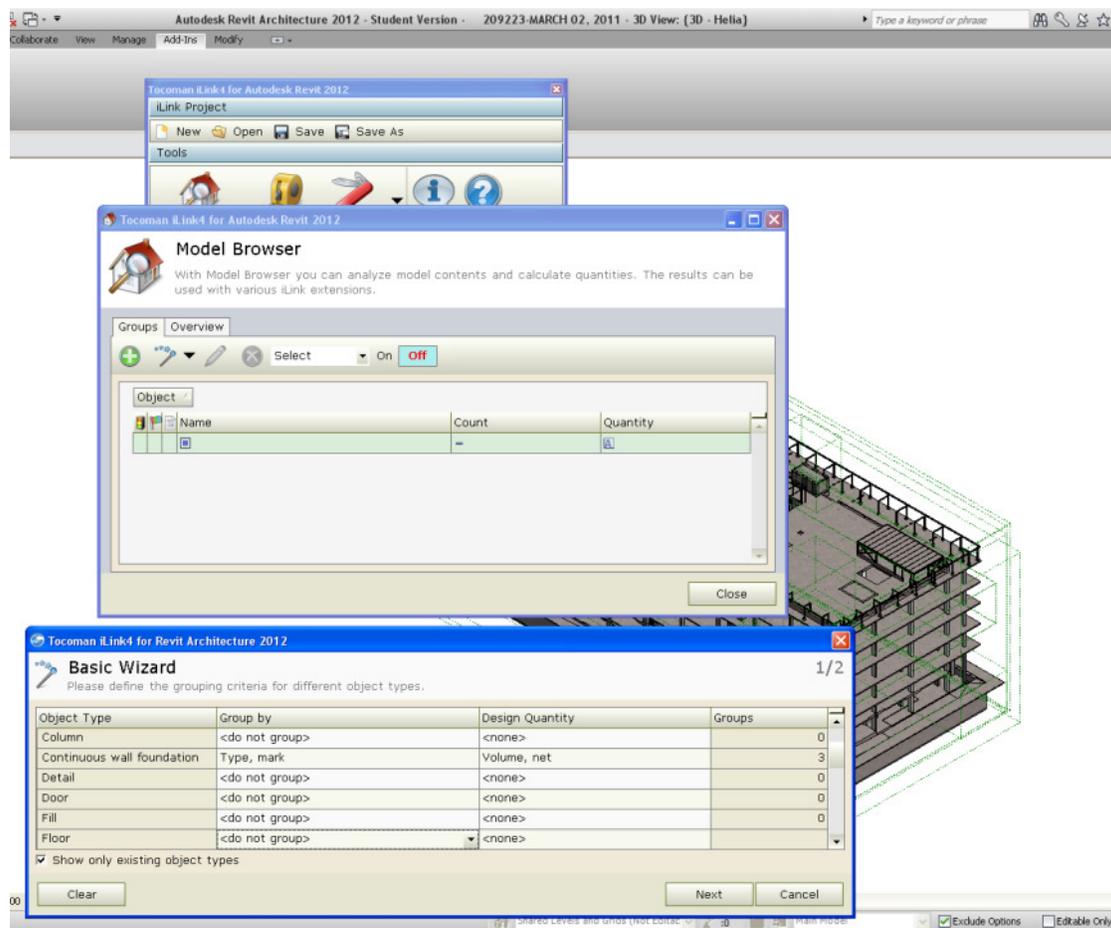


Figure 3.23 Choosing object type, grouping criteria, and the desired quantity in Tocoman iLink

Object	Name	Count	Quantity
Object : Continuous wall foundation (3 items)			
	SF1	18	38.363 m3
	SF2	2	11.809 m3
	<no value>	3	43.191 m3
Object : Isolated footing (10 items)			
	F10	11	11
	F5	3	3
	F1	2	2
	F4	4	4

**Figure 3.24 Results for foundation QTO done by Tocoman for foundation**

Tocoman iLink is not a modeling software; however, it tries to analyze the content of models created by Revit, ArchiCAD, and Tekla. The functions that Tocoman has beyond the QTO part of Revit are as follows:

1. Create an Excel report useful for the estimators.
2. Publish the information (Figure 3.25) and visualize the results as Navisworks models (Figure 3.26).
3. Connect the BIM-based quantities with existing cost estimating and scheduling application when used together with Tocoman Express.
4. Provide the quantities for each level of the building.

As mentioned, the results can be exported to an Excel sheet. The exported quantities include quantities other than the selected one. For instance, if the selected quantity for concrete walls is volume, the Excel sheet file also includes area, count, and approximate weight which might also be useful. Figure 3.27 shows the QTO of foundations done by Tocoman and exported to Microsoft Excel.

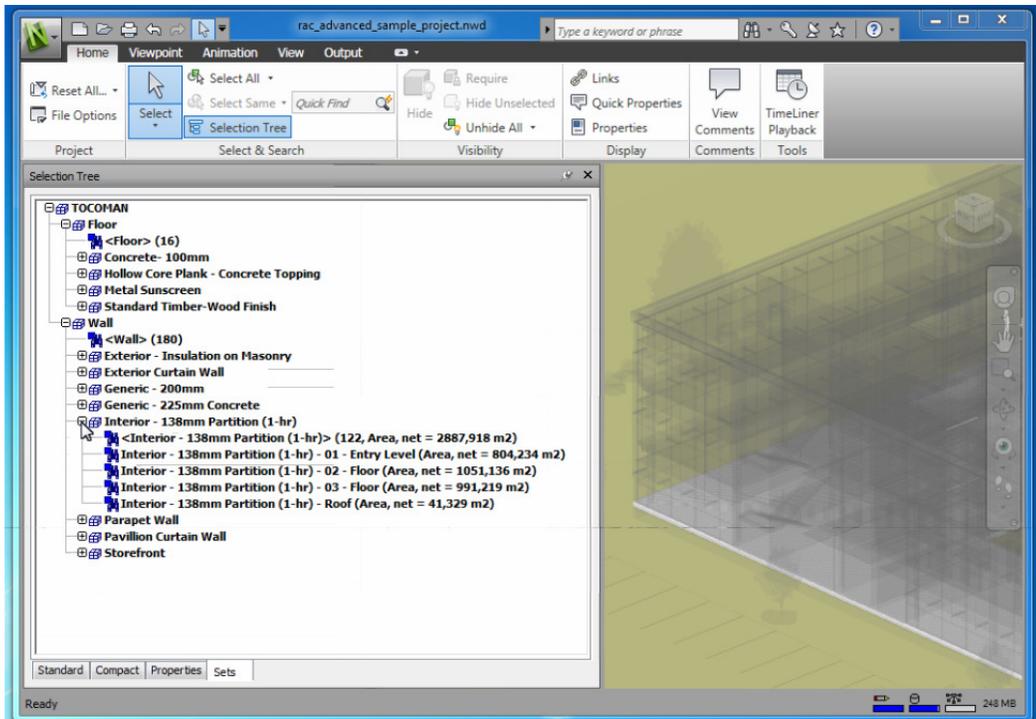


Figure 3.25 Information published in Navisworks by Tocoman iLink (Source: Tocoman website)

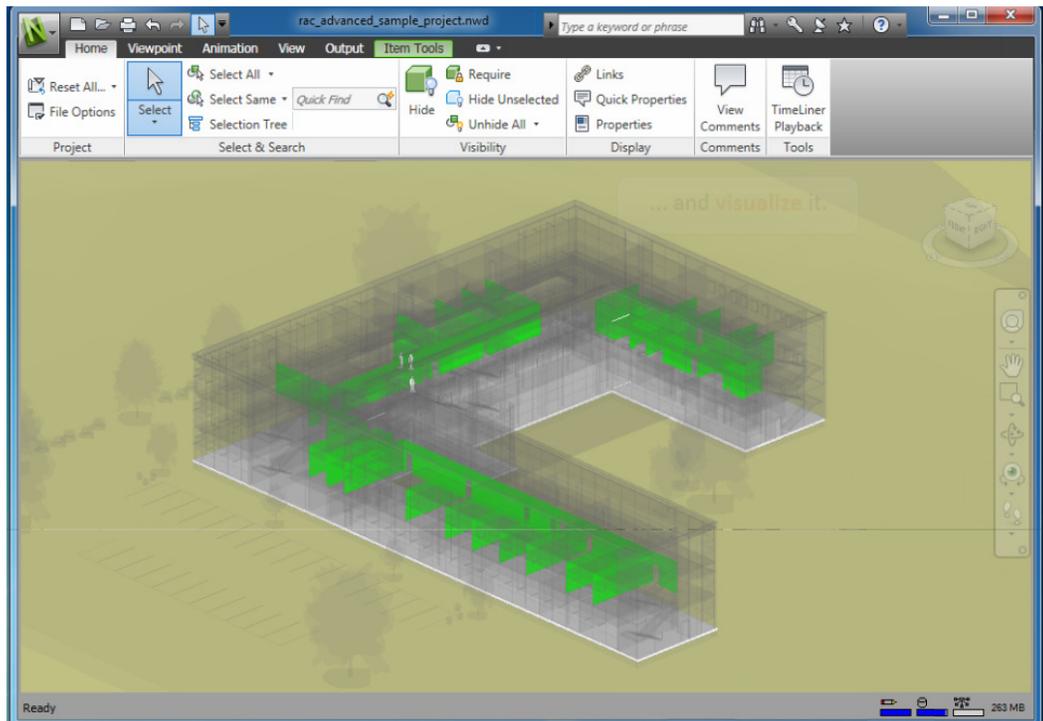


Figure 3.26 Results are visualized in Navisworks by Tocoman iLink (Source: Tocoman Website)

Flag	Name	Type	Property	Unit	Total
<no value>		Continuous wall foundation	Volume, net	m3	43
<no value>		Isolated footing	Count		3
			Volume, net	m3	1
	F10	Isolated footing	Count		11
			Volume, net	m3	14
	F1	Isolated footing	Count		2
			Volume, net	m3	11
	F2	Isolated footing	Count		9
			Volume, net	m3	89
	F3	Isolated footing	Count		12
			Volume, net	m3	153
	F4	Isolated footing	Count		4
			Volume, net	m3	61
	F5	Isolated footing	Count		3
			Volume, net	m3	65
	F6	Isolated footing	Count		37
			Volume, net	m3	91
	F7	Isolated footing	Count		2
			Volume, net	m3	70
	F8	Isolated footing	Count		1
			Volume, net	m3	24
	GS 1350 Foundation	Floor	Area, net	m2	814
	GS 1600 Foundation	Floor	Area, net	m2	192
	GS 300 Foundation	Floor	Area, net	m2	38
	SF1	Continuous wall foundation	Volume, net	m3	38
					38
	SF2	Continuous wall foundation	Volume, net	m3	12

Figure 3.27 QTO of foundations using Tocoman (Exported to Excel Sheet)

The next section describes the criteria I developed to evaluate the 2D and BIM-based software tools based on the requirements of construction cost estimators and consultants performing LCA.

### 3.4 Evaluation Criteria

Looking at the process of QTO and its use in cost estimating and LCA, I developed a criteria to assist with the evaluation of the different software. These criteria are the factors required by the user to analyze data and provide the results. Take, for instance, an estimator who needs to know the volume of concrete used for constructing shear walls in a certain level. By using QTO software with good “grouping” capabilities, he or she will be able to

group the walls by levels and extract the data needed from that. Or, in order to estimate the cost of project, the estimator needs to have certain dimensions and quantities of a component. By checking the “Availability”, we determined whether the required information is provided by the software or not.

These criteria are as follows:

- 1 Availability: assesses whether the software provides the required quantities for each purpose. For instance, an estimator needs to know the surface area of a spread foundation to calculate the forming. I assessed whether the software provides surface area for spread footing by using the availability criteria.
- 2 Consistency/Variability: assesses the consistency of the quantity results across the different software applications.
- 3 Grouping: assesses the ability of the software to group components based on different attributes. For instance, the estimator needs to know the quantity of a specific type of component in a zone or on a certain level in the building.
- 4 Visual verification: assesses how powerful the software is in terms of visualizing the components for the quantities calculated. For instance, Tocoman highlights the calculated components by isolating them in BIM model.
- 5 Reporting: assesses the ability of the software to provide useful QTO reports. For example, the estimator needs to provide these information in an excel sheet.

### **3.5 Evaluating BIM-based Quantity Takeoff Tools on the UBC Pharmaceutical Sciences Building**

In this section, I evaluate the three pieces of software using the criteria mentioned in the previous section. I evaluated the QTO software for three kinds of components in the building: (1) Foundation System, (2) Shear Walls, and (3) Partition Walls. I selected these components because they each have unique requirements in terms of the kinds of quantities needed for LCA and construction cost estimating.

#### **3.5.1 Foundation System**

There are five types of foundations in this building: spread footings, strip footings, retaining walls, stepped footings and foundation slabs. My approach involved extracting quantities with the different software and evaluating the results against the established criteria.

##### **3.5.1.1 Availability**

The quantities needed for cost estimating and LCA and the ability of each piece of software to provide them are shown in Table 3.2. Three icons are used to show the capability of the software in providing the required information:

- ☺ The software provides the required information directly.
- ☹ The quantities can be extracted from the software indirectly. For instance, the software provides the length and thickness but not the surrounding area; however, the user can do the calculation using the provided length and thickness.
- ⊖ The software does not provide the information nor can it be calculated indirectly.

Based on Table 3.2, On-Screen Takeoff provides all the information required for cost estimating and LCA purposes. Revit provides most of the information needed and some quantities can be calculated from the information extracted from the model. Tocoman only provides the total volume of all the foundations from each type and there is no access to the volume of each single foundation.

**Table 3.2 Availability of the required quantities for footings in each software**

		Revit		Tocoman		On-Screen Takeoff	
		Availability	Comments	Availability	Comments	Availability	Comments
<b>Cost Estimating</b>	<b>Volume</b>	☺	-	☺	The total Value of each type of foundation is given. No access to each individual foundation quantity.	☺	It needs some dimensions as an input. For example for the spread or strip footings it should at least have the thickness as input. However, the thickness can be measured in the software if any views are available.
	<b>Surface Area</b>	☺	Surrounding + Surface Area are given in material takeoff	☹	-	☺	
	<b>Surrounding Area</b>	☺	Length and Thickness are given. Area can be calculated.	☹	-	☺	
<b>LCA</b>	<b>Length</b>	☺	-	☹	-	☺	
	<b>Width</b>	☺	-	☹	-	☺	
	<b>Thickness</b>	☺	-	☹	-	☺	

- ☺ The quantities can be extracted from the software directly.
- ☹ The quantities can be extracted from the software indirectly, for instance surrounding area can be calculated by having length and thickness.
- ☹ The quantities cannot be extracted from the software.

### 3.5.1.2 Consistency/ Variability

The QTO results from the three pieces of software for costs estimating purposes are shown in Table 3.3. It can be seen that for most of the listed parameters all the pieces of software provide the required quantities and the results are almost the same. However, for the

“area”, only On-Screen Takeoff provides the amount. For LCA purpose (Table 3.4), Tocoman doesn’t provide any data for any types of foundation. As the foundation slabs don’t have a specific shape such as a rectangle, there is no specific length or width associated with them and neither Revit nor On-Screen Takeoff provides any data for that. The same thing happens with stepped footing. For the other data provided, Revit and On-Screen Takeoff provide the same quantities.

**Table 3.3 Comparison of QTO results for foundations**

	Length (m)			Width (m)			Thickness (m)			Comments
	Revit	Tocoman	On-Screen Takeoff	Revit	Tocoman	On-Screen Takeoff	Revit	Tocoman	On-Screen Takeoff	
Foundation Slab: GS 300 Foundation	*_	-	*_	*_	-	*_	0.3	-	0.3	* The foundation slab doesn’t have specific shape such as rectangle or square; therefore, a certain length or width cannot be measured. ** because of the unique shape of stepped footings, it cannot be defined as length, width, and thickness.
Foundation Slab: GS 1350 Foundation	*_	-	*_	*_	-	*_	1.35	-	1.35	
Foundation Slab: GS 1600 Foundation	*_	-	*_	*_	-	*_	1.6	-	1.6	
F1	3.00	-	3.00	2.4	-	2.4	0.85	-	0.85	
F2	3.45	-	3.45	2.85	-	2.85	1.025	-	1.03	
F3	3.60	-	3.60	3.15	-	3.15	1.125	-	1.13	
F4	3.75	-	3.75	3.45	-	3.45	1.175	-	1.18	
F5	4.20	-	4.20	3.75	-	3.75	1.375	-	1.38	
F6	2.10	-	2.10	1.8	-	1.80	0.65	-	0.65	
F7	5.10	-	5.10	4.5	-	4.50	1.52	-	1.52	
F8	4.35	-	4.35	3.9	-	3.90	1.4	-	1.40	
F10	1.20	-	1.20	1.2	-	1.20	0.9	-	0.90	
GS Stepped Footing	**_	-	**_	**_	-	**_	**_	-	**_	
Retaining Wall - Offset - 250 Wall	51.24	-	50.08	2.95	-	2.95	0.4	-	0.40	
SF1	316.18		296.51	0.45	-	45.00	0.3	-	0.30	
SF2	100.73		92.03	0.45	-	0.45	0.3	-	0.30	

**Table 3.4 Comparison of QTO results for foundations (continued)**

	Volume (m3)			Surface area(m2)			Surrounding area(m2)			Comments
	Revit	Tocoman	On-Screen Takeoff	Revit	Tocoman	On-Screen Takeoff	Revit	Tocoman	On-Screen Takeoff	
Foundation Slab: GS 300 Foundation	11.42	11.41	11.05	-	-	36.84	-	-	*_	*The foundation slabs don't have a simple rectangular shape; therefore, it is not possible for the software to calculate the surrounding area. ** Because of the unique shape of the stepped footing, the On-Screen takeoff is not providing the areas.
Foundation Slab: GS 1350 Foundation	1098.65	1098.65	1092.87	-	-	809.53	-	-	*_	
Foundation Slab: GS 1600 Foundation	307.40	307.40	308.94	-	-	193.08	-	-	*_	
F1	11.04	11.04	12.24	-	-	14.40	-	-	18.00	
F2	89.17	89.17	90.70	-	-	88.49	-	-	116.00	
F3	153.09	153.09	153.09	-	-	136.08	-	-	182.00	
F4	60.81	60.81	60.81	-	-	51.75	-	-	68.00	
F5	64.97	64.97	64.97	-	-	47.25	-	-	66.00	
F6	90.91	90.91	90.91	-	-	139.86	-	-	188.00	
F7	70.00	70.00	70.00	-	-	45.90	-	-	59.00	
F8	23.75	23.75	23.75	-	-	33.93	-	-	46.00	
F10	14.26	14.26	14.26	-	-	11.52	-	-	35.00	
GS Stepped Footing	1.26	1.26	1.36	-	-	**_	-	-	**_	
Retaining Wall - Offset - 250 Wall	43.19	43.19	59.09	-	-	147.74	-	-	336.00	
SF1	38.36	38.36	40.03	-	-	133.43	-	-	445.00	
SF2	11.81	11.81	12.42	-	-	41.41	-	-	138.00	

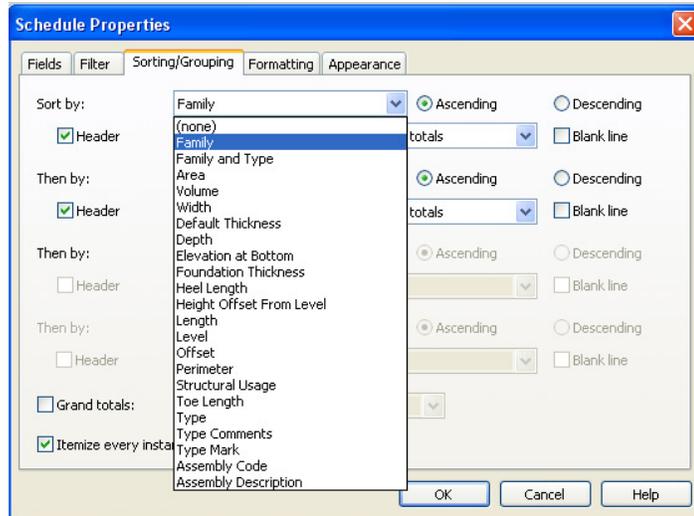
### 3.5.1.3 Grouping

In terms of grouping capabilities, Revit has the ability to group components based on each field from which the estimator wants information (Figure 3.20). Figure 3.28 shows a sample of the categories that the estimator can choose to group foundations. Obviously, these are the fields from which the estimator needs the quantities for each foundation. Revit also

gives the user the opportunity to group foundations based on three different categories simultaneously. For instance, foundations can be grouped based on “Family and Type” then “Width” and then “Level”.

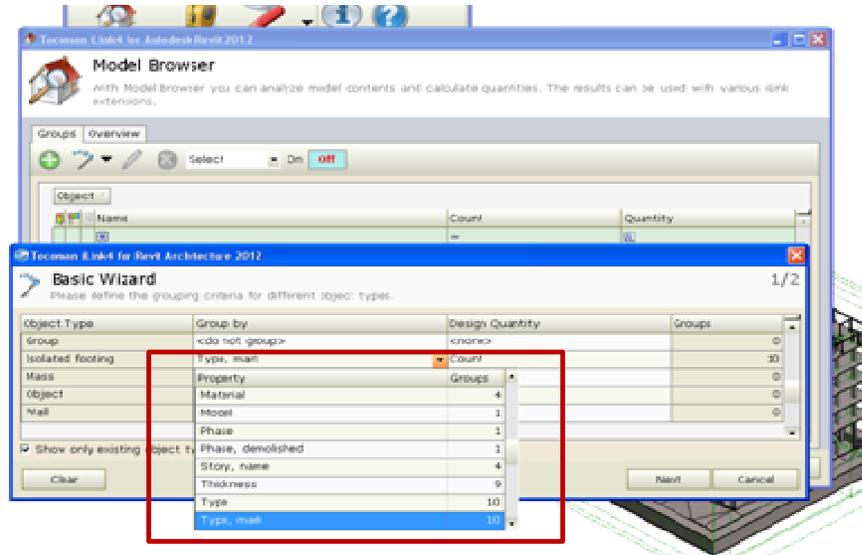
However, there are some criteria based on which an estimator might be interested in grouping the components that are not included in Revit, such as zoning. Sometimes the foundations are divided into different zones for different concrete pours and the estimator needs to have quantities based on each zone. There are some ways to include it in the model, such as adding the zone number as a comment and trying to group them by comments; however, this is a time-consuming task.

Figure 3.29 shows the grouping options in Tocoman. Tocoman is able to group the foundation based on assembly code, comment, depth, description, family, group ID, group level, group name, has weight, keynote, material, model, phase and phase demolished. When the components are grouped based on a category in Tocoman, the accumulated results for each group are shown. However, sometimes the estimator needs the information itemized (separate information about each item in that group), which Revit provides. For instance, if she or he needs to know the volume of a specific strip footing, Revit will be the better option to look at.



**Figure 3.28 Categories in which foundations can be grouped based on in Revit**

In On-Screen Takeoff, grouping is done by making different folders and assigning the components to each folder. In this case, it can be said that grouping is a manual process. For instance, the estimator might make a folder called “Foundation” and within that folder would create different categories, such as spread footing, strip footing, foundation slab, zones, etc. Then each foundation would be assigned to its related folder. When compared to Revit, this is a time-consuming task, especially if the estimator wants to change the grouping criteria.

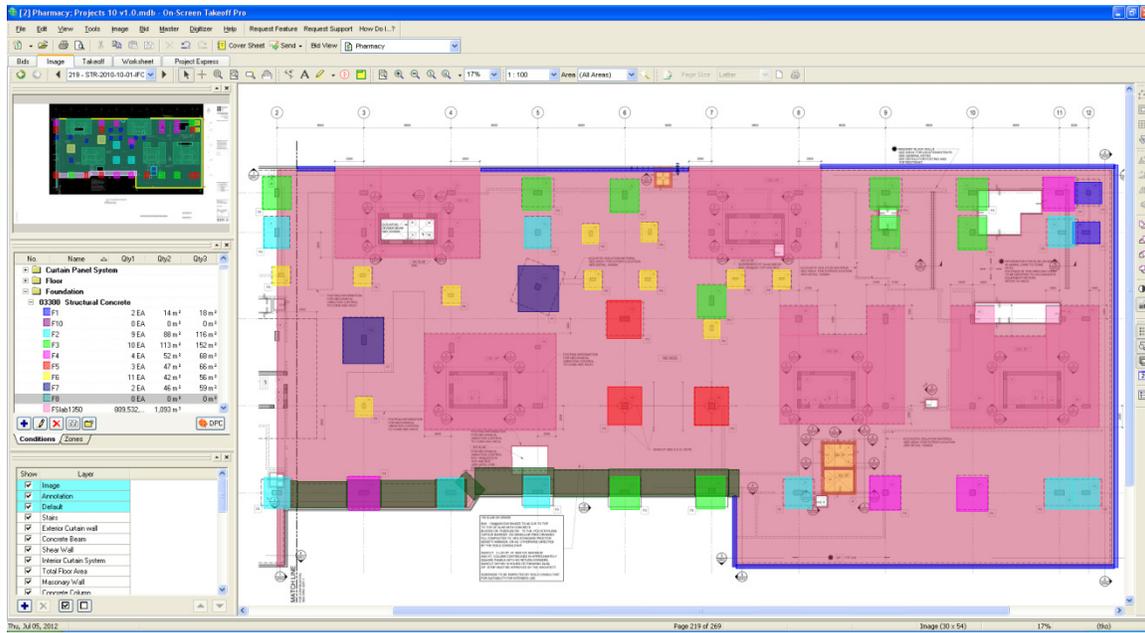


**Figure 3.29** Different categories for grouping the results for foundation in Tocoman

The main problem with On-Screen Takeoff and Tocoman is that only the accumulated quantity of a parameter is shown for each group; however, in Revit there is a useful option of having the quantities of each item in a group (itemized quantities) as well.

### 3.5.1.4 Visual Verification

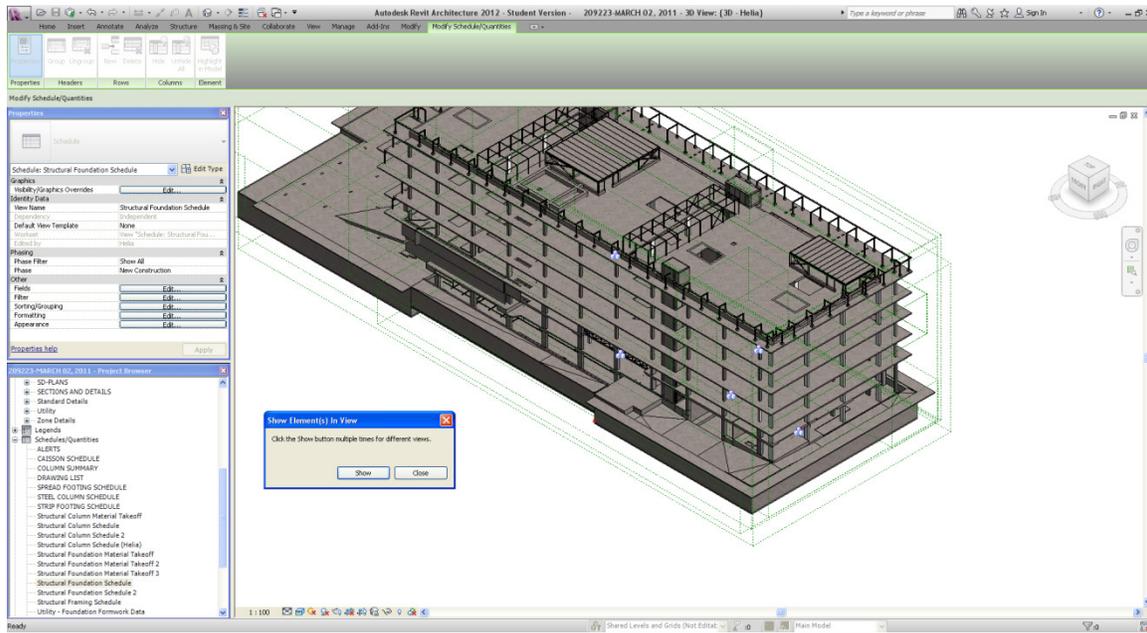
In On-Screen Takeoff, the quantities for the foundation are calculated using the foundation outline drawing. Using this drawing and identifying different foundation types with different colors helps to avoid missing any foundations. Figure 3.30 shows the foundation outline on which the QTO of the foundations is done using different colors. Foundations that are missing from the QTO can be identified easily by looking at the drawing.



**Figure 3.30 Visual verification in On-Screen Takeoff for foundations**

In order to visualize the components from which quantities are taken in Revit, one may select the component and use the “show” command. Revit will start opening each view in which the component is included; however, the component cannot always be seen clearly in those views and opening different windows in Revit takes time, especially when the model is large.

In addition, Revit is not able to highlight all the foundations at the same time as not all the components can be selected in the schedule sheet at the same time. Only the foundations in the same group can be selected at the same time. As a result the viewer cannot have a general overview of all the foundations and check if there is any foundation missing in the QTO. Figure 3.31 shows one of the views Revit opens to show foundation F3. The chosen components cannot be visualized through this view.



**Figure 3.31 Visual verification for foundations in Revit**

In Tocoman, it is possible to choose all the foundations and try to highlight them in the model. The main problem is that Tocoman tries to highlight the components on the active view in Revit; therefore, if the view is totally irrelevant nothing is shown. However, when dealing with a relevant view like the whole model 3D view, Tocoman does a good job of cutting the model and highlighting the selected components. Figure 3.32 shows how Tocoman cuts the model to show the foundations. As all the foundations can be chosen and highlighted, it is easy to visually verify whether any foundation is missing from the QTO.

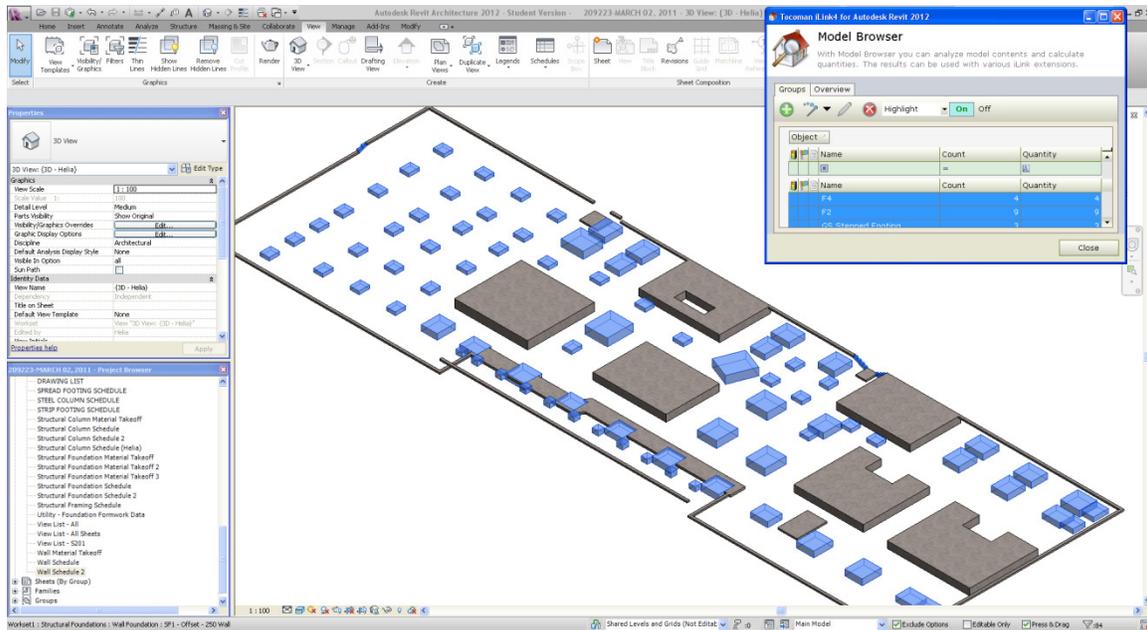


Figure 3.32 Visual verification for foundation in Tocoman

### 3.5.1.5 Reporting

In On-Screen Takeoff, the output is a worksheet that is organized based on the folders and the type of component specified when making a new condition. In this worksheet, in front of each component the three desired quantities are calculated with their unit of measurement; however, there is no specification of what the quantities are. For instance, if the surrounding area is the user's first choice for calculation and surface area is their second choice, they are both shown in the report as a number with the unit measurement of "m<sup>2</sup>", without identifying which one is surrounding area and which one is surface area. The user has to open the condition to figure out what the numbers mean unless the user remembers it or has specified a rule. Figure 3.33 shows a snapshot of the project's output in a worksheet.

There are two ways of exporting data to spreadsheets, copy and paste information to spreadsheet or save it as a CSV file. Looking at the results of the two options, I found that copy and paste option leads to a better organized information. However, still organizing

pasted data in an Excel sheet is a time-consuming task. Figure 3.34 shows copied data from an On-Screen worksheet. No headers are copied and different layers such as folders and types are copied in the same format.

No.	Name	Qty1	UOM1	Qty2	UOM2	Qty3	UOM3	Mat (\$)	Labor (\$)	Sub (\$)	Total (\$)
1	F1	2	EA	14	m <sup>2</sup>	18	m <sup>2</sup>	0.00	0.00	0.00	0.00
2	F2	9	EA	88	m <sup>2</sup>	116	m <sup>2</sup>	0.00	0.00	0.00	0.00
3	F3	12	EA	136	m <sup>2</sup>	182	m <sup>2</sup>	0.00	0.00	0.00	0.00
4	F4	4	EA	52	m <sup>2</sup>	68	m <sup>2</sup>	0.00	0.00	0.00	0.00
5	F5	3	EA	47	m <sup>2</sup>	66	m <sup>2</sup>	0.00	0.00	0.00	0.00
6	F6	37	EA	140	m <sup>2</sup>	188	m <sup>2</sup>	0.00	0.00	0.00	0.00
7	F7	2	EA	46	m <sup>2</sup>	59	m <sup>2</sup>	0.00	0.00	0.00	0.00
8	F8	1	EA	17	m <sup>2</sup>	23	m <sup>2</sup>	0.00	0.00	0.00	0.00
9	F10	8	EA	12	m <sup>2</sup>	35	m <sup>2</sup>	0.00	0.00	0.00	0.00
10	SF1	296,510	mm	133	m <sup>2</sup>	445	m <sup>2</sup>	0.00	0.00	0.00	0.00
11	SF2	92,030	mm	41	m <sup>2</sup>	138	m <sup>2</sup>	0.00	0.00	0.00	0.00
12	FSlab-300	36,838,371	mm <sup>2</sup>	11	m <sup>3</sup>			0.00	0.00	0.00	0.00
13	FSlab-1350	809,532,761	mm <sup>2</sup>	1,093	m <sup>3</sup>			0.00	0.00	0.00	0.00
14	FSlab-1600	193,084,496	mm <sup>2</sup>	19	m <sup>3</sup>			0.00	0.00	0.00	0.00
15	RW	50,080	mm	148	m <sup>2</sup>	336	m <sup>2</sup>	0.00	0.00	0.00	0.00
16	SteppedF	2,707,745	mm <sup>2</sup>	10	EA			0.00	0.00	0.00	0.00
SOG											
03300 Structural Concrete											
17	SOG 150	5,520,041,964	mm <sup>2</sup>					0.00	0.00	0.00	0.00
Wall											
Level -1											
(unassigned)											
P1-Door		29	EA					0.00	0.00	0.00	0.00

Figure 3.33 On-Screen Takeoff output for foundation

The screenshot shows an Excel spreadsheet with the following data table:

Folder??	Type??																
Foundation																	
03300 Structural Concrete																	
	1 F1		2 EA		14 m <sup>2</sup>		18 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	2 F2		9 EA		88 m <sup>2</sup>		116 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	3 F3		12 EA		136 m <sup>2</sup>		182 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	4 F4		4 EA		52 m <sup>2</sup>		68 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	5 F5		3 EA		47 m <sup>2</sup>		66 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	6 F6		37 EA		140 m <sup>2</sup>		188 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	7 F7		2 EA		46 m <sup>2</sup>		59 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	8 F8		1 EA		17 m <sup>2</sup>		23 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	9 F10		8 EA		12 m <sup>2</sup>		35 m <sup>2</sup>		0	0	0	0	0	0	0	0	0
	10 SF1			296,510 mm		133 m <sup>2</sup>		445 m <sup>2</sup>		0	0	0	0	0	0	0	0
	11 SF2			92,030 mm		41 m <sup>2</sup>		138 m <sup>2</sup>		0	0	0	0	0	0	0	0
	12 FSlab300			36,838,371 mm <sup>2</sup>		11 m <sup>3</sup>				0	0	0	0	0	0	0	0
	13 FSlab1350			809,532,761 mm <sup>2</sup>		1,093 m <sup>3</sup>				0	0	0	0	0	0	0	0
	14 FSlab1600			193,084,496 mm <sup>2</sup>		19 m <sup>3</sup>				0	0	0	0	0	0	0	0
	15 RW			50,080 mm		148 m <sup>2</sup>		336 m <sup>2</sup>		0	0	0	0	0	0	0	0
	16 SteppedF			2,707,745 mm <sup>2</sup>		10 EA				0	0	0	0	0	0	0	0
SOG																	

Figure 3.34 On-Screen Takeoff output copied to Excel

In Revit, the outputs are shown in a table; the components are grouped based on the specified criteria. In contrast to Tocoman and On-Screen Takeoff, the itemized information about each component in each group is available; however, the accumulated quantities are not. For instance, if there are three foundations of type “F1”, the quantities such as area, volume, etc. for each of the three are shown separately; however, the total volume, total area, etc. are not. In order to obtain the accumulated information the schedule should be exported to Excel and the summation can be calculated there.

It is worth mentioning that in Revit there is an option to show the quantities in a group, item by item (itemized quantities) or just by grand total. As Revit doesn’t provide the accumulated information for quantities such as area and volume, when the grand total option

is selected and the itemized information is not selected, nothing is shown in the table and the Revit user might consider that the information is not provided. Figure 3.35 shows the results from Revit when only the grand total option is selected. It can be seen that nothing is shown in “Area” and “Volume” for most of the foundations. If the area and volume are shown for some groups, it is either the only item in that group or the area and volume of the items in that group are equal.

Family	Family and Type	Area	Count	Volume	Width	Default Thick	Depth	Elevation at B
Foundation Slab	Foundation Slab: GS 300 Foundation		3		0.300			
Foundation Slab	Foundation Slab: GS 300 Foundation: 3							
Foundation Slab	Foundation Slab: GS 1350 Foundation		5		1.350		-8.550	
Foundation Slab	Foundation Slab: GS 1350 Foundation: 5							
Foundation Slab	Foundation Slab: GS 1600 Foundation	192 m²	1	307.40 m³	14.500	1.600	-8.800	
Foundation Slab	Foundation Slab: GS 1600 Foundation: 1							
GS Rectangular Footing	GS Rectangular Footing: F1		2		2.400		0.850	-8.050
GS Rectangular Footing	GS Rectangular Footing: F1: 2							
GS Rectangular Footing	GS Rectangular Footing: F2		9		2.850		1.025	-8.225
GS Rectangular Footing	GS Rectangular Footing: F2: 9							
GS Rectangular Footing	GS Rectangular Footing: F3	19 m²	12		3.150		1.125	-8.325
GS Rectangular Footing	GS Rectangular Footing: F3: 12							
GS Rectangular Footing	GS Rectangular Footing: F4	21 m²	4	15.20 m³	3.450		1.175	-8.375
GS Rectangular Footing	GS Rectangular Footing: F4: 4							
GS Rectangular Footing	GS Rectangular Footing: F5	27 m²	3	21.66 m³	3.750		1.375	-8.575
GS Rectangular Footing	GS Rectangular Footing: F5: 3							
GS Rectangular Footing	GS Rectangular Footing: F6		37		1.800		0.650	
GS Rectangular Footing	GS Rectangular Footing: F6: 37							
GS Rectangular Footing	GS Rectangular Footing: F7	38 m²	2	35.00 m³	4.500		1.525	-8.725
GS Rectangular Footing	GS Rectangular Footing: F7: 2							

Figure 3.35 Snapshot of Revit showing the grand total quantities

The schedule can be exported as a “txt” file and then imported into an Excel file. This file still needs to be organized before it is used (e.g., some of the parameters don’t include the unit of measurement). Figure 3.36 shows the quantities from Revit in the Excel sheet.



Flag	Name	Type	Property	Unit	Total	
	1350 Foundation	Floor	Volume, net	m3	1,098.65	1099
	1600 Foundation	Floor	Volume, net	m3	307.40	307
	300 Foundation	Floor	Volume, net	m3	11.41	11
	F10	Isolated footing	Volume, net	m3	14.26	14
			Count		11.00	11
	F1	Isolated footing	Volume, net	m3	11.04	11
			Count		2.00	2
	F2	Isolated footing	Volume, net	m3	89.17	89
			Count		9.00	9
	F3	Isolated footing	Volume, net	m3	153.09	153
			Count		12.00	12
	F4	Isolated footing	Volume, net	m3	60.81	61
			Count		4.00	4
	F5	Isolated footing	Volume, net	m3	64.97	65
			Count		3.00	3
	F6	Isolated footing	Volume, net	m3	90.91	91
			Count		37.00	37
	F7	Isolated footing	Volume, net	m3	70.00	70
			Count		2.00	2
	F8	Isolated footing	Volume, net	m3	23.75	24
			Count		1.00	1
	Retaining Wall	Continuous wall foundation	Volume, net	m3	43.19	43
	SF1	Continuous wall foundation	Volume, net	m3	38.36	38
	SF2	Continuous wall foundation	Volume, net	m3	11.81	12
	Stepped Footing	Isolated footing	Volume, net	m3	1.26	1
			Count		3	3

Figure 3.37 Tocoman output as an Excel spreadsheet

In this section we tried to evaluate the capabilities of the software based on the specified criteria for performing a QTO of a building foundation system. As discussed each of software has some strength and some weaknesses. For instance On-Screen takeoff provides the information that is needed by an estimator; however, providing the quantity take off using this software is a time-consuming task. Tocoman is a great tool for visualizing the calculated components but it doesn't provide all information that is needed. In contrast, Revit almost provides the necessary information but is not capable in visual verification. The next section evaluates the three types of software for concrete walls in Pharmacy building.

### **3.5.2 Concrete Wall (Shear Walls)**

Based on the structural 2D drawings, there are ten types of shear walls in the building: Walls 1 to 10. Figure 3.38 and Figure 3.39 show the shear wall keyplan and the shear wall schedule for the Pharmaceutical Building.

#### **3.5.2.1 Availability**

Looking at the ability of each type of software to provide the required information, none of the software provides the height of the walls. The total height of the wall can be calculated manually using the shear wall schedule (Figure 3.39) and elevations which is a time-consuming, error prone task. Furthermore, if the estimator needs to know the height of the wall level by level, it needs to be calculated manually as well. Among the software, Revit is the only software that provides wall thickness which is an important parameter for both cost estimation and LCA purposes. The information required for cost estimating and LCA purposes and the assessment of software are shown in Table 3.5.

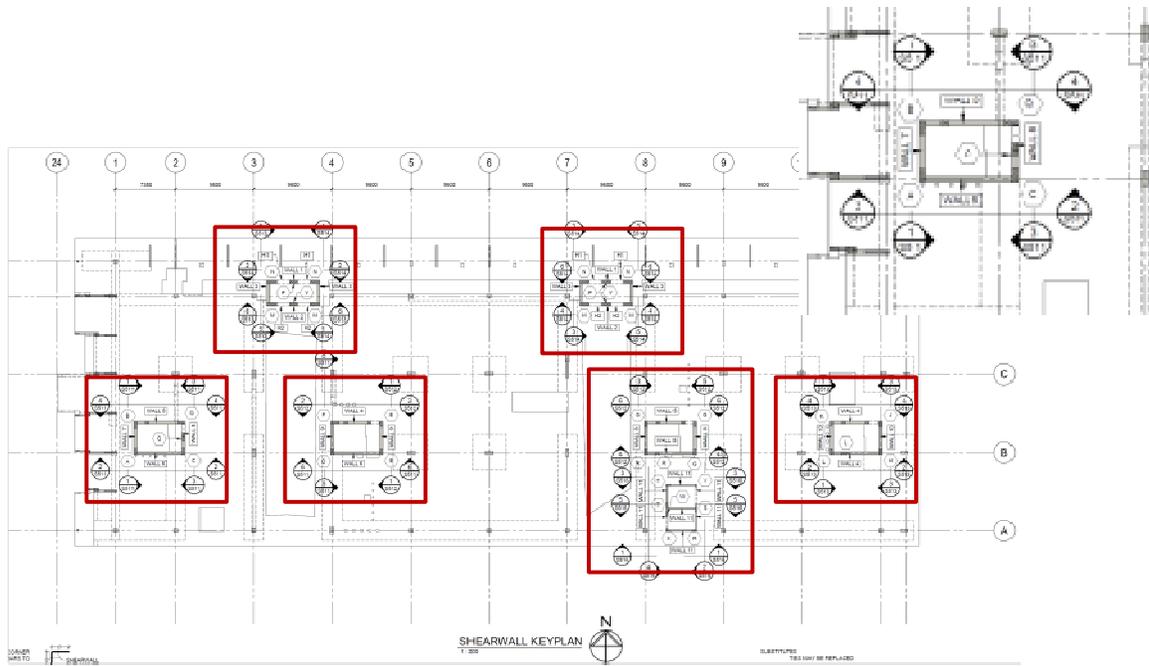


Figure 3.38 Pharmaceutical Building shear wall keyplan

SHEAR WALL SCHEDULE								
LEVEL	$f_c$ MPa	$\Delta$ MAX (mm)	WALL 1	WALL 2	WALL 3	WALL 4	WALL 5	WALL 6
MACH. ROOF		MAXIMUM INELASTIC INTERSTORY DEFLECTION	HOOK 90° TO TOP OF SLAB TYP	HOOK 90° TO TOP OF SLAB TYP	HOOK 90° TO TOP OF SLAB TYP			
ROOF			HOOK 90° TO TOP OF SLAB TYP	HOOK 90° TO TOP OF SLAB TYP	HOOK 90° TO TOP OF SLAB TYP	HOOK 90° TO TOP OF SLAB TYP	HOOK 90° TO TOP OF SLAB TYP	HOOK 90° TO TOP OF SLAB TYP
6		70						
5		68				10M@200 E/W, E/F	10M@200 E/W, E/F	
4		61	15M@300 E/W, E/F					10M@300 E/W, E/F
3	35 MPa	40	15M@175 HEF 15M@300 VEF					
2		26						
GROUND		12						
LEVEL -1 FDN	40 MPa		450 WALL 20M@150 HEF 15M@300 VEF	450 WALL 15M@200 E/W, E/F	350 WALL 10M@200 E/W, E/F	350 WALL 15M@200 HEF 15M@300 VEF	350 WALL 15M@200 HEF 15M@300 VEF	350 WALL 15M@200 HEF 15M@300 VEF

DOWEL TO MATCH COLUMN VERT TYP LINO

Figure 3.39 Pharmaceutical shear wall schedule

**Table 3.5 Availability of the required quantities for shear walls for each piece of software**

		Revit		Tocoman		On-Screen Takeoff	
		Availability	Comments	Availability	Comments	Availability	Comments
Cost Estimating	Volume	☺	These values are not grouped based on building's levels.	☺	In addition to total value, it groups each component based on the building's levels.	☺	The length can be measured from the available plan views. The height and thickness should be found from the drawings.
	Surface Area	☺		☺			
	LCA	Length	☺	☺			
		Height	☹	☹	The software provides accumulated height of all walls of that type, which is not useful for.	☹	
		Thickness	☺	☹	☹		

☺ The quantities can be extracted from the software directly.

☹ The quantities can be extracted from the software indirectly, for instance surrounding area can be calculated by having length and thickness.

☹ The quantities cannot be extracted from the software.

### 3.5.2.2 Consistency/ Variability

In 2D drawings, there are ten types of shear walls named as Wall 1 to Wall 10. These walls vary in thickness, height and reinforcement; however, some of them have the same thickness. For instance, walls 7, 8, 9, and 10 have a thickness of 400 mm but they are different in reinforcement and height. In the 3D model, all of these walls are modeled as “GS Shearwall-400 concrete”. In order to distinguish between these different types, in the “Mark” field of the component it is specified whether it is Wall 7, Wall 8, Wall 9, or Wall 10 by the consultant.

On-Screen takeoff uses 2D drawings with the Wall1 to 10 naming rule. To compare BIM-based software results with On-Screen takeoff results, the walls had to be sorted and

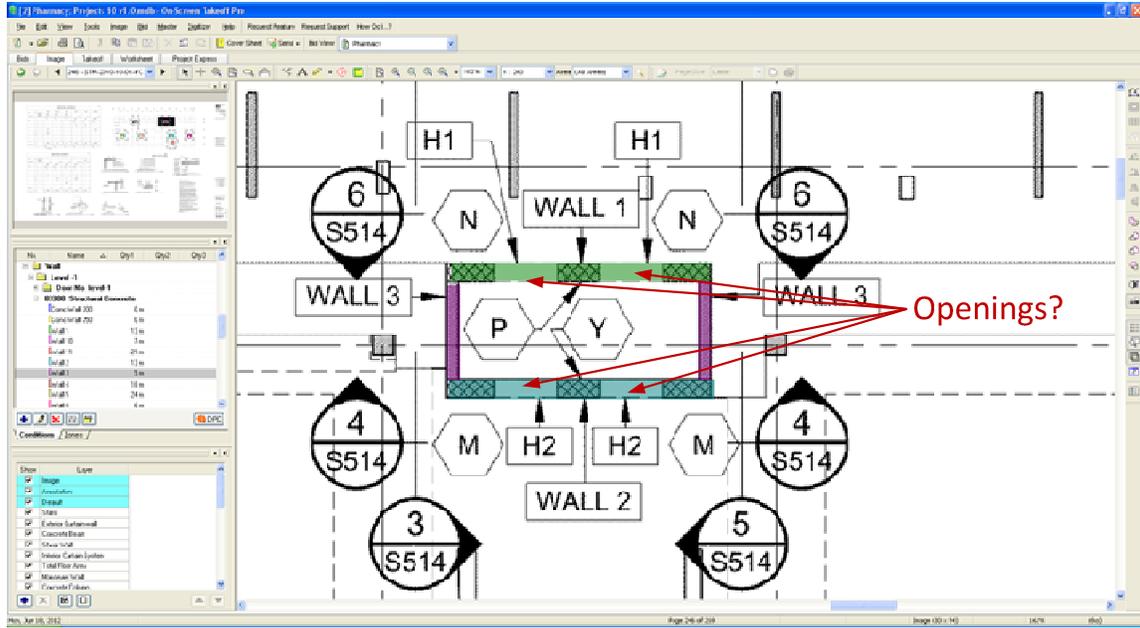
grouped By “Mark” in BIM-based software. As a result, Walls 7 to 10 were separated and grouped. In Revit, the quantities were extracted using this method; however, in Tocoman there is no option to group the components by “Mark”; therefore the results could not be shown in the following table.

**Table 3.6 Result comparison for shear walls between different software based on how they are tagged in 2D**

Concrete Wall	Volume(m3)			Area(m2)		
	Revit (from MTO)	Tocoman	On-Screen Takeoff	Revit (from MTO)	Tocoman	On-Screen Takeoff
Wall 01	123.10	-	200.05	273.55	-	444.56
Wall 02	122.96	-	200.05	273.25	-	444.56
Wall 03	122.40	-	92.33	408.01	-	307.77
Wall 04	205.61	-	208.53	587.47	-	595.80
Wall 05	274.51	-	278.04	784.32	-	794.40
Wall 06	69.65	-	69.51	199.00	-	198.60
Wall 07	45.33	-	52.96	113.32	-	132.40
Wall 08	154.22	-	145.64	385.56	-	364.10
Wall 09	101.08	-	105.92	252.71	-	264.80
Wall 10	102.90	-	92.68	257.26	-	231.70
Wall 11	78.78	-	139.02	393.90	-	695.10

A look at Table 3.6 shows that the quantities are either close or display some differences. For the walls with differences three things might have happened:

1. *On-Screen Takeoff results > Revit results:* when doing the QTO in On-Screen Takeoff the user forgot to subtract the openings from the quantities and therefore the quantities are higher than the quantities from Revit.



**Figure 3.40** Part of the shear wall key plan showing the openings not being considered in the QTO process

2. *On-Screen Takeoff results < Revit results:* The wall boundaries are not specified clearly in the 2D models; therefore, what is defined as Wall 3 might be estimated as Wall 1 (Figure 3.41)

3. *Inaccuracies in On-Screen Takeoff:* In On-Screen Takeoff, the user draws lines or areas over the 2D drawings, raising the possibility that he or she hasn't drawn the line from edge to edge of the wall, which can cause some inaccuracies (Figure 3.42).

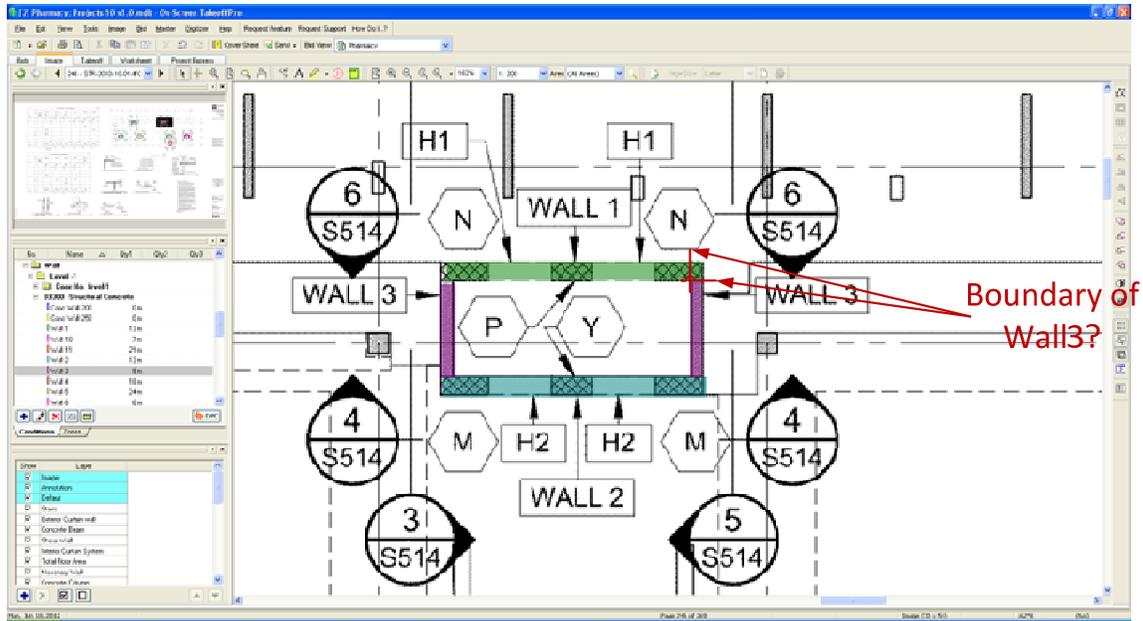


Figure 3.41 Part of the shear wall keyplan showing the vagueness of the wall edge

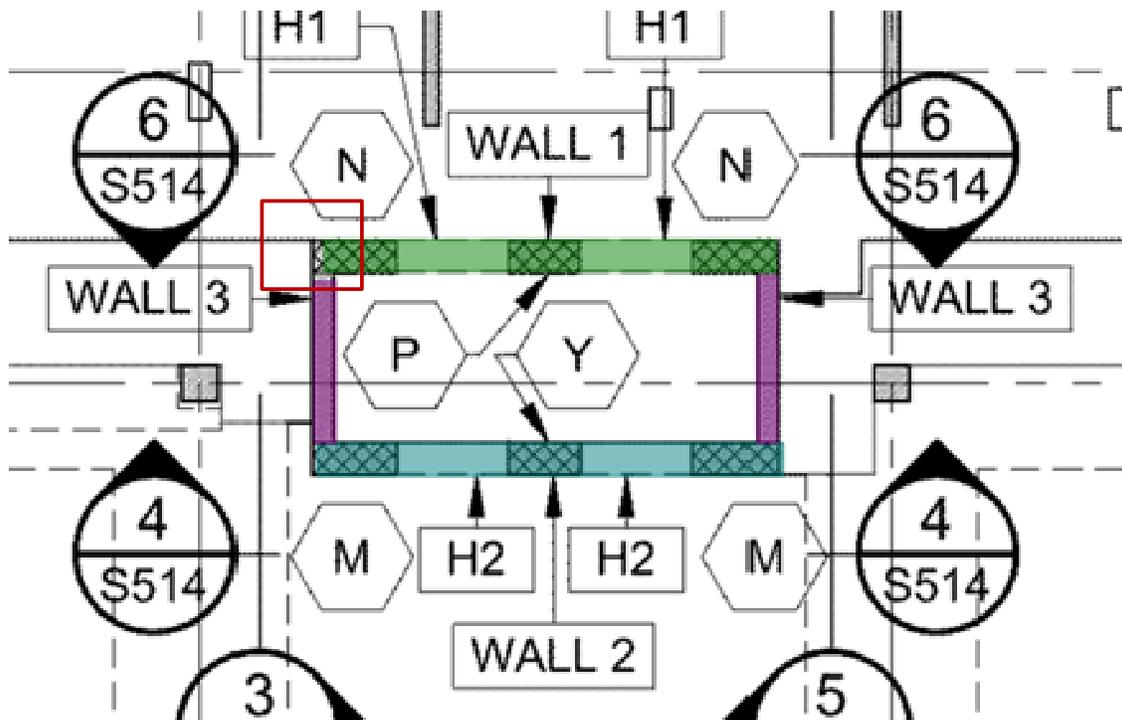


Figure 3.42 Part of the shear wall keyplan showing the inaccuracies in On-Screen Takeoff

4. Negligence in specifying the “Mark” Fields for some walls in Revit: Looking at Table 3.6, I noticed a difference between Revit results and On-Screen takeoff results. In the

process to find the reasons for the inconsistencies, I added up the quantities obtained from Revit in Table 3.6 which are grouped by “Mark” based on their thicknesses. For instance, I added quantities of walls 4 to 6 which all have 350mm thickness and compared them with the quantities that I obtain when I group the wall based on “ Family & Type” (Shearwall-350 thickness). The results are compared in Table 3.7.

**Table 3.7 Results comparison for the shear walls with different types of grouping (Revit Architecture)**

Concrete Wall	Including walls	Volume(m3)			Area(m2)		
		Grouped by "Family & Type"	Grouped by "Mark"	Error %	Grouped by "Family & Type"	Grouped by "Mark"	Error %
Shearwall-200 thickness	11	105.92	78.78	25.62%	529.54	393.9	25.61%
Shearwall-300 thickness	3	130.16	122.4	5.96%	433.88	408.01	5.96%
Shearwall-350 thickness	4,5,6	551.54	549.78	0.32%	1,575.56	1,570.79	0.30%
Shearwall-400 thickness	7,8,9,10	403.55	403.54	0.00%	1,008.90	1,008.84	0.01%
Shearwall-450 thickness	1,2	277.65	246.06	11.38%	616.99	546.81	11.37%
<b>Total</b>		1,468.82	1,400.56	4.65%	4,164.87	3,928.35	5.68%

The quantities are expected to be equal for both ways of grouping; however, they are different. Looking more closely at the model, it became clear that the “Marks” of some of the shear walls were not specified by the modeler. Therefore they are not included in the quantities in Table 3.6. Figure 3.43 shows that in the “Mark” field there are some walls that are not assigned to “Wall 01” to “Wall11”. These walls are as follows:

- Eight shear wall-200 thickness,
- Four shear wall-300 thickness,
- One shear wall-350 thickness,
- One shear wall-400 thickness,
- Thirteen shear wall-450 thickness

As a result, these walls are not considered in the quantities listed in Table 3.6 grouped under “Mark” and the quantities are less than those grouped by “Family and Type”. Table 3.7

shows that there were errors in the quantities for volume (4.65%) and for area (5.68%). Considering the total volume of 1,468.82 m<sup>3</sup> and the total area of 4,164.87 m<sup>2</sup> the estimates are 68.26m<sup>3</sup> and 236.53m<sup>2</sup> were less than what should be calculated. This is a substantial error and considering the possibility of the same error happening for other types of components might result in substantial errors in the construction cost estimate.

In order to use the results from Tocoman and eliminate the errors resulting from not specifying the “Mark” of some walls, Walls 1 to 10 are grouped by their thicknesses from 200 to 450. The results from Revit are sorted by “Family and Type” fields and the results from On-Screen Takeoff are accumulated based on thickness, for comparison purposes and are shown in Table 3.8. It can be seen that the quantities from Tocoman and Revit are the same. The benefit of using Tocoman is that the quantity of each wall can also be grouped by level. For example, if one wants to know the volume of ‘shear wall-200 thickness’ in the ground floor level, it can be found using Tocoman (Revit does not have this functionality).

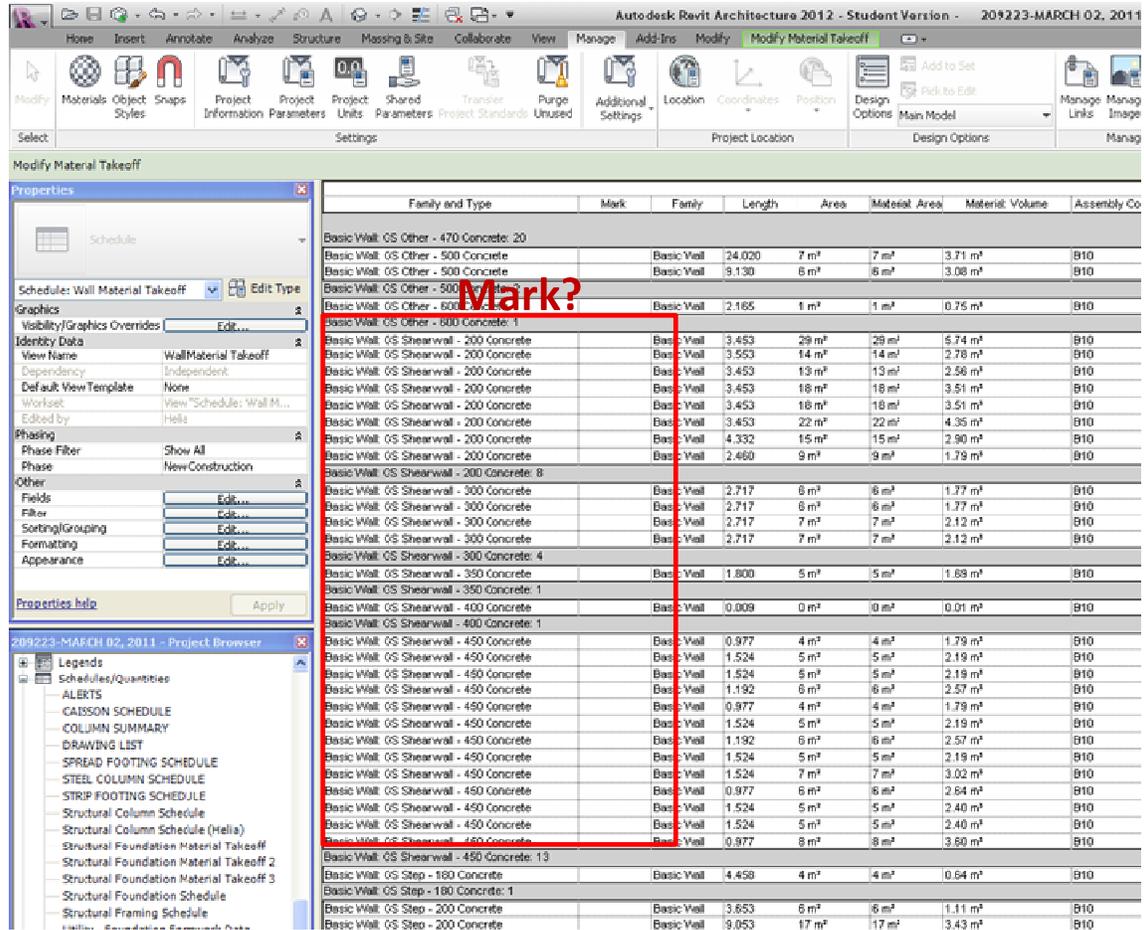


Figure 3.43 Snapshot of Material takeoff in Revit Architecture showing the missing walls

Table 3.8 Result comparison for shear walls between different software based on thickness

Concrete Wall	Including walls	Volume (m3)			Area (m2)		
		Revit	Tocoman	On-Screen takeoff	Revit	Tocoman	On-Screen takeoff
Shear wall-200 thickness	11	105.92	105.91	139.02	529.54	529.55	444.56
Shear wall-300 thickness	3	130.16	130.17	92.33	433.88	433.94	444.56
Shear wall-350 thickness	4,5,6	551.54	551.46	556.08	1,575.56	1,575.62	307.77
Shear wall-400 thickness	7,8,9,10	403.55	403.55	397.20	1,008.90	1,008.88	595.80
Shear wall-450 thickness	1,2	277.65	277.62	400.10	616.99	616.93	794.40

### 3.5.2.3 Grouping

In terms of grouping, Revit is able to group the walls using the same fields required in the QTO sheet. Fields for the Pharmaceutical Building are shown in Figure 3.44.

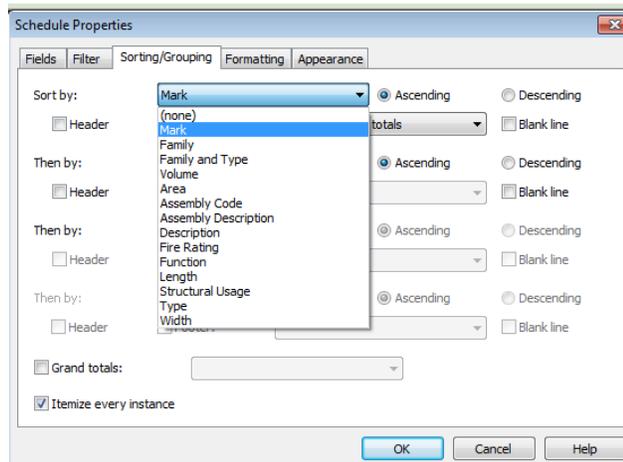


Figure 3.44 Grouping criteria for shear walls in Revit

Looking at Figure 3.44, there are still some criteria which an estimator might need to group the walls based on that and Revit doesn't provide. For instance, if the user needs to know the volume of concrete needed for shear walls at a certain level, it is not possible to calculate the amount using Revit. The user can break the shear wall down by levels, put the number of each level in the "comments" and try to group the wall based on the "comment", though this process is time-consuming. If the model has already been provided, the user should break the walls into levels. Because this is also a tedious task, it is better to consider modeling by level when the model is being created during design.

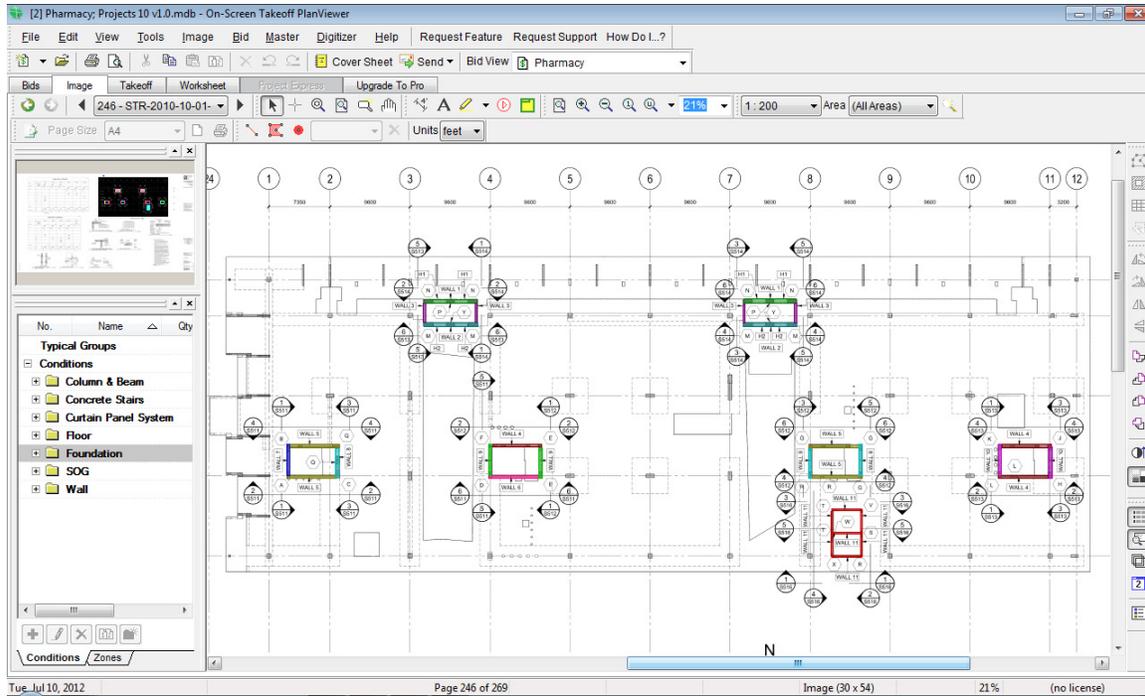
In Tocoman, the shear walls can be grouped by area (gross), area (net), assembly code, comment, description, family, group ID, group level, group name, unconnected height, keynote, length, material, model, phase, phase demolished, story, thickness, type, type mark, volume and weight. One very good point about Tocoman is that in the final report, the

required information is shown in total as well as for each level. For instance, the user can have the total volume of concrete for wall 400 and the concrete volume for each level. The problem with Tocoman is that it gives the accumulated amount for each group and by each level but the itemized information is not accessible like Revit.

In On-Screen Takeoff, the grouping is a manual process. As for the foundation, the user can group the wall based on each category by making different folders. If the walls are to be grouped by levels, the user can create folders for each level and try to create the conditions for the wall in the related folder. The user should have a good understanding of how he or she wants to group the components from the beginning.

#### **3.5.2.4 Visual Verification**

In On-Screen Takeoff, the quantities are calculated using the shear wall keyplan and schedule. Looking at the shear wall keyplan (Figure 3.45) one can see that all the shear walls are selected; however, it is not verified that the whole height is being calculated because the height is given as an input to On-Screen Takeoff using the shear wall schedule (Figure 3.39). In addition, the estimator can easily forget to consider openings in the QTO.



**Figure 3.45 Visual verification in On-Screen Takeoff for shear walls**

In Revit, the components for each group can be visualized in the model. If the user knows where the walls are and what the best view is to visualize them, he or she can make sure that view is open. However, even in the appropriate views, some components may be blocking the view of the component, which would require the user to further manipulate the view to visualize the component of interest. The software tries to automatically show the selected components by opening different views that are related to that component; however, the component is typically not visualized clearly in these views as again, the other components often blocks the view . In addition, depending on the size of the model, it takes time for the software to find the related views and open them. Therefore, creating the appropriate visualization of these components requires extra effort and time. Figure 3.46 shows some of views that were used to visualize shear walls, which were not particularly useful because the component of interest was hidden behind other components in the model.

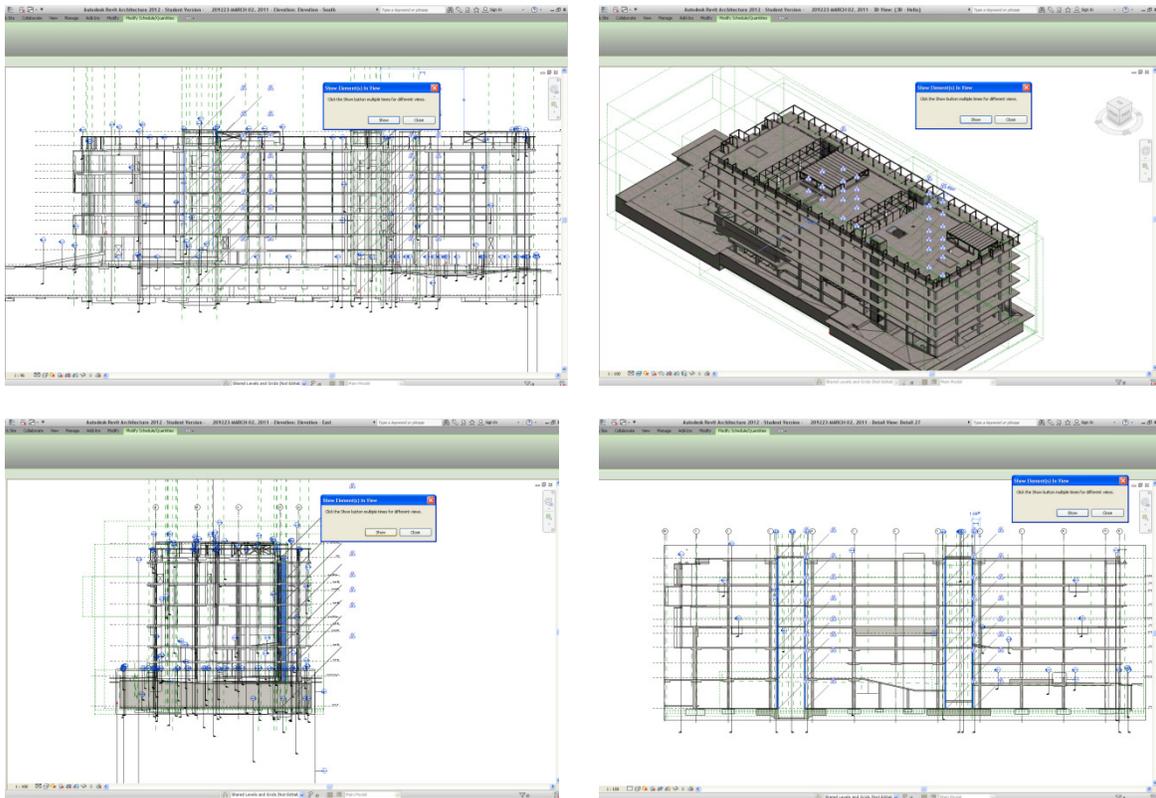


Figure 3.46 Visual verification in Revit for shear walls

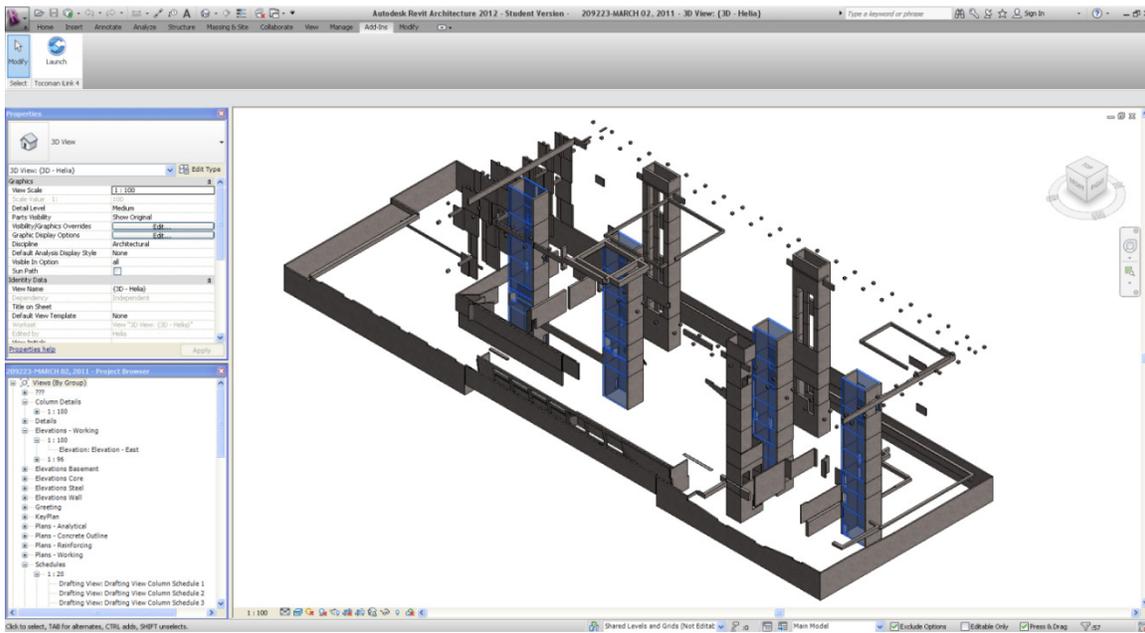


Figure 3.47 Visual verification in Tocoman iLink for shear walls

In Tocoman, the visualization of the each type of the wall is done by isolating all the concrete walls in the BIM model and highlighting the selected group of walls (Figure 3.47). In this way, the walls can be better visualized in Tocoman compared to Revit.

### **3.5.2.5 Reporting**

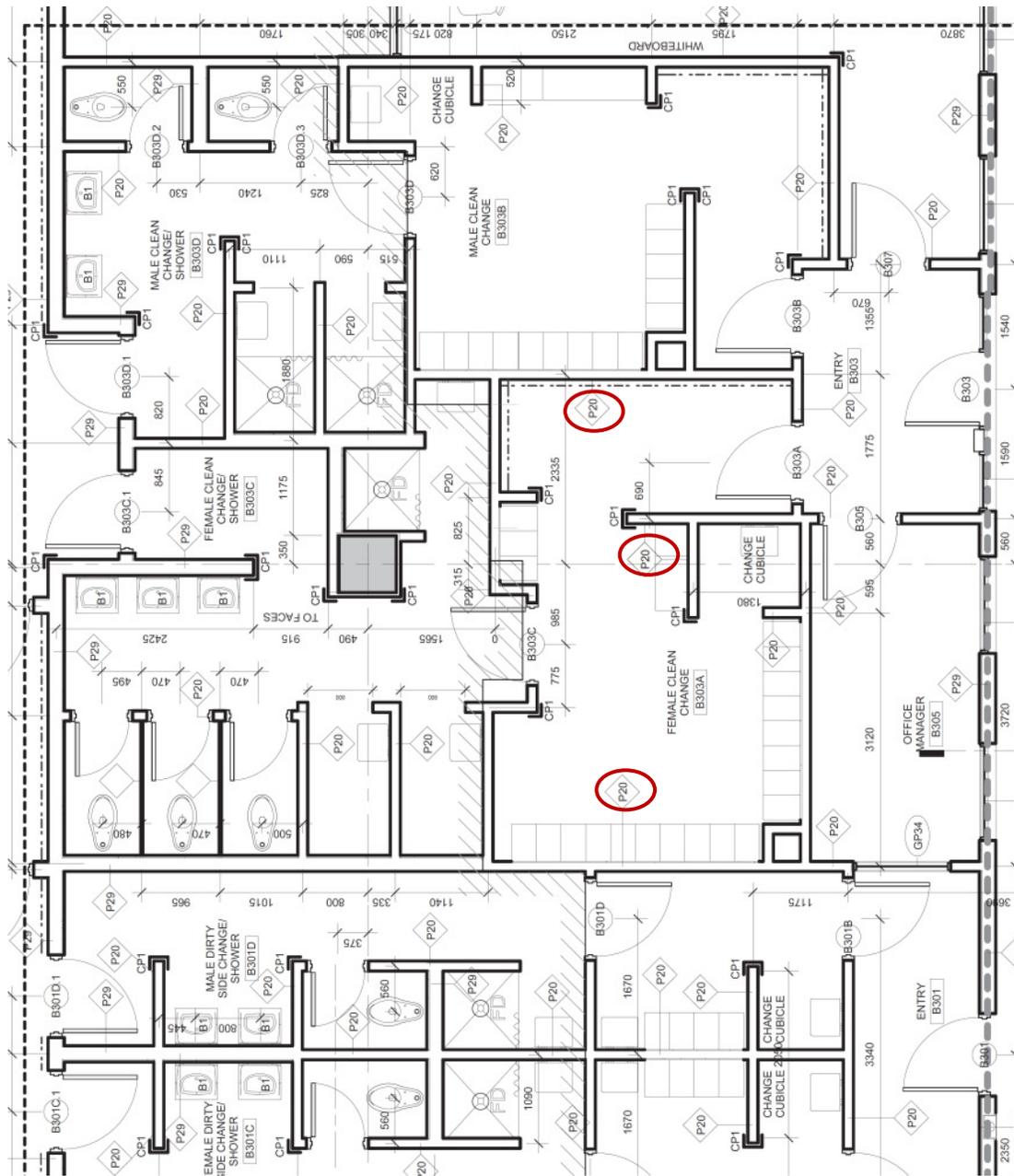
The reporting functionality would be the same as for the foundation for the different software.

In this section we tried to compare and evaluate different types of QTO software for concrete walls in a project. Again each type of software has strengths and weaknesses. For instance, the best feature that Tocoman has which the other two types of software can't provide, is that it can show the quantities of the walls by level which is a useful piece of information for cost estimating and QTO purposes. Or, the ability of Revit in providing the required information is better than two other types of software. The next section evaluates the three types of software for partition walls in Pharmacy building.

### **3.5.3 Partition Walls**

The Pharmacy Building contains 44 different types of interior partitions that include various types of interior partition walls, interior shaft walls, and interior furred walls. Figure 3.48 shows a part of the 2D drawing indicating the different types of walls. On each level, various types of partition walls are used and they are tagged on the drawings. However, the various types of walls on each floor and the huge amount of information shown on the drawings makes it hard to read and increases the chances of missing some walls when performing QTO. Figure 3.49 shows a part of the 2D drawings with the wall types tagged.





**Figure 3.49 Snapshot of 2D drawings showing the partition walls and their types**

For simplicity in conducting this research, I focused on five types of partition walls to evaluate the different QTO software.

### **3.5.3.1 Availability**

The availability of the required information for each type of software is shown in the table below. There are nearly 44 different types of partition walls in the Pharmaceutical Building, which are made of different materials. The only software that gives the quantity of the materials of which the walls are composed of is Revit. In On-Screen Takeoff and Tocoman, the dimensions of the wall are given as one component and the estimator should calculate the quantities of the materials using the partition types sheet which is a time-consuming, error-prone task. For Instance, if a wall has 152mm steel stud at 400mm O.C., in order to calculate the number of steel studs for the wall, the estimator must divide the length of the wall in mm by 400 and add one to the result. This calculation is correct if there are no openings on the wall. Figure 3.50 is a part of the partition type sheet showing different composition materials for a partition wall.

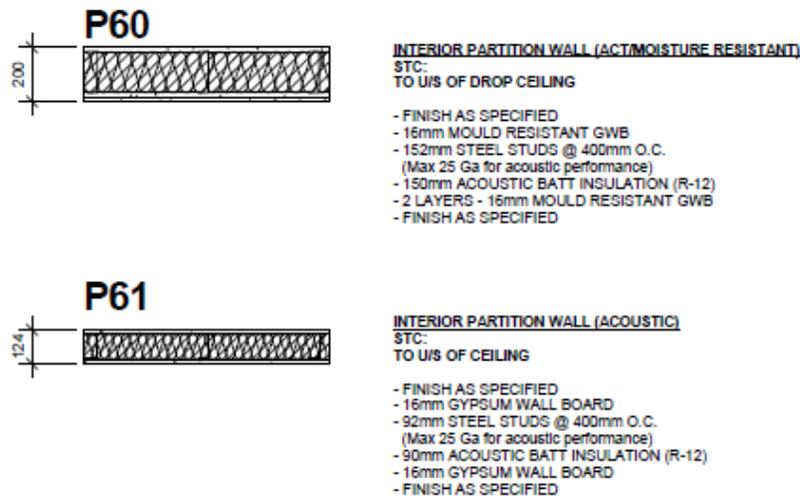
**Table 3.9 Availability of the required quantities for partition walls for each piece of software**

		Revit		Tocoman		On-Screen Takeoff		
		Availability	Comments	Availability	Comments	Availability	Comments	
Cost Estimating	Materials	☺	The materials and their specifications such as area, description, and name are provided.	☺		☺	The height can be calculated from the elevations and the materials can be found in wall specification.	
	Area	☺		☺		☺		
	LCA	Length	☺		☺		☺	
		Height	☹		☹		☹	

☺ The quantities can be extracted from the software directly.

☹ The quantities can be extracted from the software indirectly, for instance surrounding area can be calculated by having length and thickness.

☹ The quantities cannot be extracted from the software.



**Figure 3.50 Examples of different partition types in Pharmaceutical Building**

It should be noted that in Revit, the materials must be explicitly modeled to calculate the quantities. If a material is not modeled for some reason or the modeler missed it by mistake and did not include it in the Revit family, it might cause the estimator to be mistaken about the quantities.

The way in which the walls are modeled can affect the quantities or can be confusing for the estimator. For instance, if the BIM modeler models the walls in one piece from level 1 to 3, in the QTO the height would be the height from level 1 to 3; however, in reality the wall will be built separately for each floor. Or, if a wall in a floor is modeled as two pieces, quantities (e.g., as the total length of the wall) obtained from the software will be wrong. These kinds of modeling issues can cause problems for QTO so a user must be careful when using a BIM created by others to ensure its completeness and accuracy.

### **3.5.3.2 Consistency/ Variability**

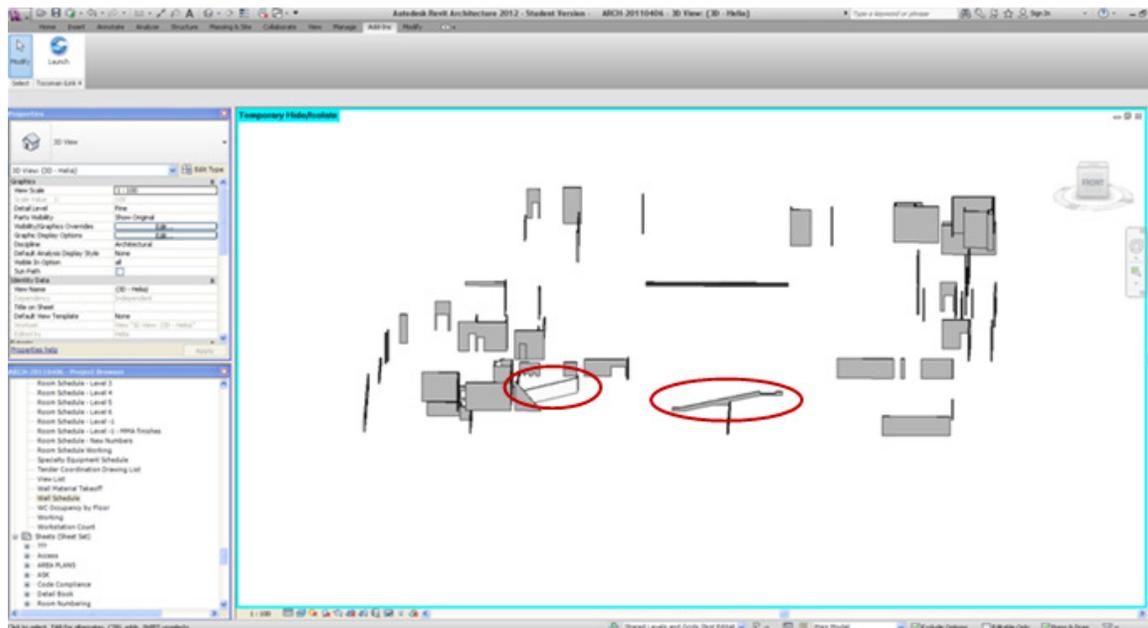
The results for the six types of partition walls are shown in Table 3.10. The results from Revit and Tocoman are almost the same except for wall P21. Figure 3.51 shows all P21 walls in the building. There are some walls in the figure that are inclined walls or are not attached to the ceiling. Tocoman and Revit might have different methods for calculating the quantities of these kinds of walls. The variation in the results between 2D and 3D drawings can have different explanations. For instance, a wall can be modeled as two pieces in a level where one of the pieces is standing above the other. As a result the calculated length would be twice as much although the area remains the same.

In On-Screen Takeoff, it is assumed that all the walls are attached to the ceiling and the only openings on the walls are the door openings. However, there can be window

openings on the wall which On-Screen Takeoff did not consider. In some cases, the wall was not tagged on the drawings; therefore, in On-Screen Takeoff it is not considered and the quantities will be less than those calculated by the 3D-based software. The same thing can happen using BIM-based software if the modeler assigns a different wall type to that wall by mistake.

**Table 3.10 Result comparison for partition walls using different software**

Partition Wall	Length (m)			Area(m2)		
	Revit	Tocoman	On-Screen Takeoff	Revit	Tocoman	On-Screen Takeoff
P20	934.22	934.11	838	3534.99	3535	2422
P21	320.04	406.85	309	1000.16	1152.65	1184.18
P22	207.36	207.36	203	589.58	589.58	696
P23	339.54	339.53	303	1315.88	1315.85	1417.14
P24	151.17	151.17	139	556.05	556.07	545.81
P25	258.37	285.38	278	1166.56	1166.55	1281.14



**Figure 3.51 Partition wall P21 in the whole building**

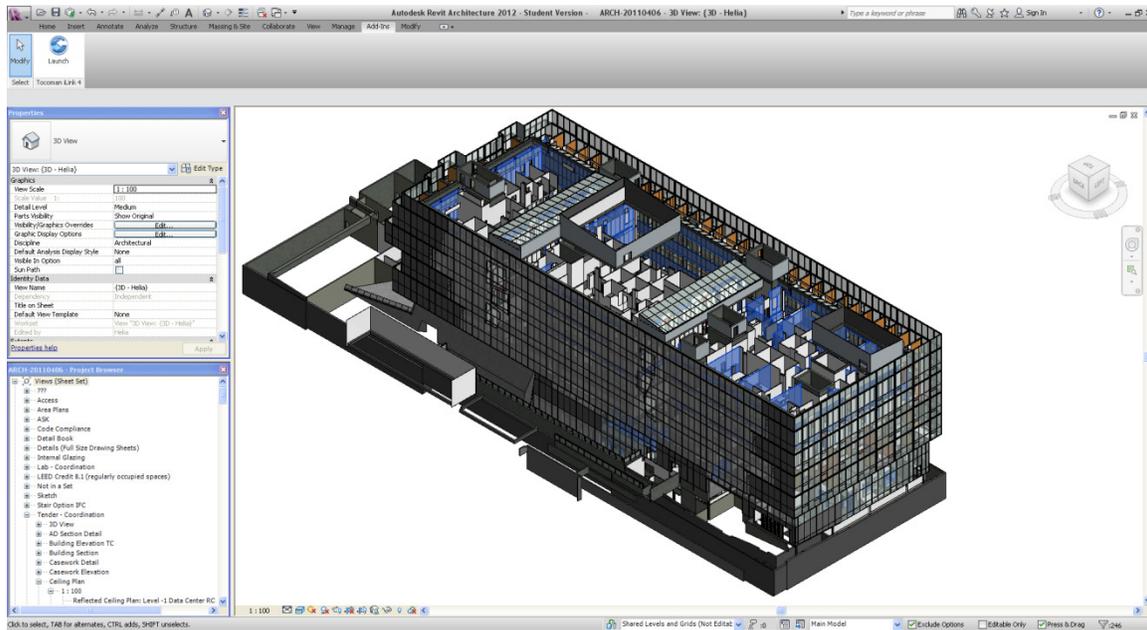
### **3.5.3.3 Grouping**

The grouping features for the partition walls are the same as for the shear walls.

### **3.5.3.4 Visual Verification**

Similar to the shear walls, the partition walls are measured in On-Screen Takeoff using color coding. Looking at the color coded drawings makes it easier to notice if a wall is missed; however, when the drawings are cluttered it is still possible to miss a wall. Figure 3.14 shows a partition drawing of the Pharmacy Building. Highlighting the partition walls is possible in Revit; however, it is still hard to visualize them, as the other components are often blocking the view.

Tocoman tries to make the components that are blocking the view invisible to improve visualization; however, in this case, because the wall exists on different floors it is still hard to see all the walls. Figure 3.52 shows Tocoman's visualization for Wall P21, which illustrates the superior visualization capabilities.



**Figure 3.52 Tocoman visualization of wall P21**

### 3.5.3.5 Reporting

Reporting for the partition walls is the same as for the other components investigated. Tocoman reporting has a great benefit in that the quantities for each wall are also shown for each level; however, it only provides the accumulated quantity and not itemized quantities like Revit.

In this section we evaluated and compared the three types of software for partition walls. There are some strengths and weaknesses for each type of software. For example, Revit has the advantage of providing the materials that the wall is composed of over the other two types of software. Or, considering the various numbers of partition walls on a level, Tocoman has the ability to visualize the calculated walls better than the other two types of software. In the next section, we provide a summary of our findings and conclusions we made.

### 3.6 Conclusion

QTO and cost estimating are among the most time-consuming tasks on a construction project, and they are performed an average of seven times throughout the life of a project (Laitinen, 1998). In order to provide an accurate cost estimate, the quantities must be accurate. Considering the dynamic nature of a construction project, changes will occur during design and construction. Therefore, the stakeholders should be able to get rapid cost feedbacks when a change is made to allow a choice between different alternatives. We believe that BIM models can give the users an accurate QTO in a timely manner.

Various tools have been developed to help the user perform the QTO quickly and accurately. These include digitizers, 2D-based QTO software, and BIM-based QTO software. However performing the QTO using 2D tools is a tedious task and prone to error. With the construction industry's increasing interest in BIM, much research has been conducted into using BIM for QTO; however, there is a limited number of case studies performed to show its use in practice.

In this chapter, I used the Pharmacy Building project to evaluate BIM-based QTO and compared it with 2D-based methods. I evaluated two types of BIM-based software and compared them with a popular 2D-based software. I developed a criteria for evaluating the software that was based on the requirements of construction cost estimators and LCA consultants. I compared the QTO process for three types of components: foundations, shear walls and partition walls, using the developed criteria. I then assessed the benefits and shortcomings of each piece of software.

Each of the software evaluated has strengths and weaknesses. On-Screen Takeoff is a software designed specifically for the purpose of QTO; therefore, much attention is paid to

the needs of estimators. For instance, to perform QTO for a foundation, the software can provide all the parameters that an estimator might need, such as surface area, surrounding area, total area, volume, etc. So in terms of availability, On-Screen Takeoff has the benefit of providing lots of information needed by estimators. Its main weakness, however, is that measuring the components based on 2D drawings can be tedious and time-consuming. In addition, the 2D drawings can't be updated automatically and when changes are made it is not easy to update the quantities. In contrast, the process of QTO in Revit and Tocoman is faster and easier as they use the 3D model.

It is important to note that the type and timing of effort required in 2D and BIM-based QTO varies. In the 2D-based approach using construction drawings, the main effort goes into performing the QTO. However, in BIM-based software, the effort is put into developing the model. In Revit and Tocoman, the QTO can be completed faster when the BIM model is ready to use. However, the model should be created correctly to provide precise quantities.

Typically, I found that Revit provides more quantity information than Tocoman. For instance, Revit provides information about the component materials while Tocoman does not. The reason might be that Tocoman is an add-on to Revit and it runs in the Revit environment. Because the user has access to such information through Revit, Tocoman doesn't need to duplicate the information. Rather, Tocoman adds information about quantities to what Revit already provides. For example, Revit provides the itemized quantities for each type of component (quantities of each item in the group); however, it doesn't usually provide the grand total for each group. In contrast to Revit, Tocoman provides the accumulated quantities of each type but not itemized quantities.

In terms of consistency, when Revit and Tocoman provide quantities, the quantities are almost equal. On-Screen Takeoff sometimes deviates from these quantities for various reasons, such as the estimator neglecting to subtract openings from the walls or slabs.

In terms of grouping, Revit is more robust than Tocoman and On-Screen Takeoff. Tocoman doesn't provide many options for grouping while Revit provides different grouping and filtering options that help the estimator manage the required data. In On-Screen Takeoff, grouping should be done when the estimator begins the QTO process as the grouping criteria cannot be easily changed during or after the takeoff is complete; however, in Tocoman and especially in Revit the grouping can be changed easily at any stage of the project.

Use of different colors, signs and patterns in On-Screen Takeoff helps to verify quantities by looking at the drawings and assessing whether all the components have been taken off; however, in cluttered drawings it is easy to miss a component. In addition, because the components are shown in 2D, it cannot be verified whether any mistake was made in the third dimension. For instance, the quantity of walls is calculated using the floor plans; however, the surface of the wall cannot be visualized and as a result, mistakes might be made regarding the height of the wall or the existence of openings. Tocoman has better visual verification capability than the other software evaluated as it usually isolates the considered components in the 3D view and the user has a better understanding of what is being calculated and what is not.

In terms of reporting, On-Screen Takeoff provides a useful chart with a nice framework for reporting the results; however, there are some weaknesses in that. For instance, the results are shown as Qty1, Qty2, and Qty3; therefore, the reader doesn't have any idea what these quantities are unless s/he checks the condition for measuring that

component. Revit provides the information in a chart and the user can change the sequence of the columns and organize it; however, the software doesn't show the units of measurement for some of the quantities which can be confusing. Tocoman exports the report to a nice and useful Excel format. Each quantity is recorded with the name and the unit of measurement. In addition, each quantity will be shown by level as well as in total, which is useful information. For instance, the user can identify the volume of a wall in total and by level.

Overall, BIM-based QTO tools provide accurate quantities faster than 2D-based QTO as long as the models are created accurately. BIM-based software has more benefits than 2D-based software based on the identified criteria.

Creating a 3D model serves more purposes than just QTO. It can be used in creating the 2D drawings, coordinating the different disciplines, identifying clashes between systems, and simulating construction in 4D. These benefits make it more compelling for companies to create a BIM model. Once a BIM model is created, QTO can be done easily and in a timely manner, which is critically important when rapid cost feedback is required.

## **Chapter 4:**

### **Summary and Conclusion**

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This chapter summarizes the results of my research that investigated the use of BIM for formwork construction and quantity takeoff (QTO). In the following sections, I briefly discuss the content of each chapter and summarize the outcomes. I also provide some direction for future research to expand the body of knowledge related to BIM applications in construction and beyond.

#### **4.1 Introduction**

Recent advancements in BIM hold great promise for addressing the challenges of the construction industry by allowing project teams to “test out” a design prior to construction. Projects that have successfully implemented BIM demonstrate benefits such as increased design quality, improved field productivity, cost predictability, reduced conflicts and changes, less rework, increased fabrication, and reduced construction cost and duration (Staub-French et al. 2011). However, the focus of most of the BIM applications to date was on the preconstruction phase with less research on the construction phase of the project, particularly at the construction work face.

The goal of this research was to evaluate the use of BIM to address today’s project constraints: time, cost, and sustainability. Therefore, I studied two applications of BIM: (1) BIM for developing lift drawings to support formwork construction in the field on the BC Hydro Substation project, and (2) BIM for QTO to support life-cycle assessment (LCA) and

construction cost estimating on the Pharmaceutical Sciences project. The following sections describe my findings resulted from my research.

## **4.2 BIM for Concrete Construction**

In this section, I summarize my research that investigated how BIM can be used to support formwork crews in the field.

### **4.2.1 Summary and Conclusions**

The first case study, the BC Hydro Mount Pleasant Substation project, is located in the False Creek area of Vancouver with concrete work of 12,000 m<sup>3</sup>. The crew had to place a large amount of concrete for a wall in a lift using 14-foot high panels as forms. The complex geometry of the walls and slabs -with lots of openings and steel embeds required- made the formwork challenging. Considering the complexity of the forming, tight schedule, and the confined space of the site, providing all information necessary for the crew to build the forms was a time-consuming and error-prone task which could potentially decrease their productivity. This project gave us the opportunity to examine the use of BIM at the workplace, a topic that hasn't been investigated in depth much in the literature.

I attended the site for six months and observed the traditional process of providing information for the forming crew and highlighted the challenges and difficulties that they encountered. Using the BIM models, I developed a format for lift drawings that allowed the forming crew to find all the information needed for forming a concrete component. Creating the BIM-based lift drawings gave the crew the opportunity to visualize the components they were forming and to find the related information in a single sheet. I included all the relevant

features, such as embeds and openings, and resolved all the conflicts between the different sub-trades' shop drawings and consultants' designs prior to construction, thereby avoiding delays and rework. I observed that using the BIM-based lift drawings improved field productivity since the field personnel didn't use their working time to browse through different source of information, and because conflicts and errors were avoided by coordinating different designs and providing it in a simple and clear format. The lift drawings also facilitated communication and coordination as the sub-trades showed their design on the lift drawings and sent it to site. The BIM-based lift drawings being used and trusted on site is a good indicator of the effectiveness of such drawings on site.

There were also challenges in creating lift drawings. For instance, a critical question for PCL was whether the type of component and the complexity of the formwork warrants the time and energy that it takes to create the models, essentially questioning the return on investment. I concluded that some of the components, such as openings and sleeves that affect both sides of the wall, are better to be modeled in BIM, while the other components, such as steel embeds, are better to be shown in a 2D format.

From a process and workflow perspective, another significant challenge in creating the lift drawings was when Design Change Notices (DCNs) were issued. As the BIM-based drawings couldn't be updated automatically and providing the already issued drawings from the updated models meant that the drawings had to be provided from scratch, using the updated BIM model for the already issued drawings was not possible. Therefore, the old BIM model had to be changed to incorporate the DCN into the drawings. This is a time-consuming and error-prone task and resulted in their being several BIM models of which some of the drawings were extracted.

I also provided 4D mock-ups for specific areas that helped to highlight schedule errors and to assign resources more conveniently. Using the structural, mechanical, and electrical BIM models, I performed clash detection tests and highlighted the major clashes that should be resolved prior to construction. The clash detection tests not only helps to avoid delays and extra costs by resolving the conflicts prior to construction, but also improves communication and knowledge transfer as it provides a platform for the involved parties to communicate and share their knowledge. There were some challenges, such as numerous minor clashes or having problems locating the clash on the BIM model, but these challenges were manageable.

#### **4.2.2 Suggestions for Future Research**

For future work, it would be better to quantify the impact of BIM in the construction process using specific metrics that could be measured across projects, such as the number of mistakes resolved prior to construction, the decrease in RFIs during construction, and changes in crew productivity from using the BIM. The results could then be compared with productivity of the crew using the traditional methods in the same project or similar projects if available to better understand the return on investment.

As the main challenge in providing lift drawings are DCNs, there is a need to provide a framework or process to handle DCNs in order to decrease the amount of rework required when creating lift drawings. In addition, there needs to be research into possible automatic updates of existing BIM-based lift drawings when an updated model arrives.

This case study was a good example of the usefulness of using BIM by field personnel at the construction work face. This case study demonstrated that BIM allows

information to be extracted and visualized in a way that suits the needs of field personnel accustomed to 2D representations. BIM can be used on site for different purposes, some of which have already been discussed by researchers, such as modeling rebar for fabrication, having the BIM model on a portable device on site instead of relying on drawing sheets, and showing the workflow of the crew using BIM models. Future work could be done on the various uses of BIM in construction as case studies to better identify the challenges involved.

### **4.3 BIM for Quantity Takeoff**

In this section, I summarize the results of my research that investigated the efficacy of BIM tools to support QTO for the purpose of construction cost estimating and life cycle analysis.

#### **4.3.1 Summary and Conclusion**

The second case study is a \$155 million building for the Faculty of Pharmaceutical Sciences and Center for Drug Research (Pharmacy) located at the UBC campus in Vancouver. It is a six-storey building incorporating different types of shear walls, partition walls, foundations and curtain walls. These types of large and complex projects with compressed construction schedules require accurate and fast feedback on the cost and environmental impacts of decisions before and during the construction. I therefore looked specifically at QTO for the purpose of construction cost estimating and LCA because cost and sustainability are such important parameters in the construction industry today. The scale and complexity of this building made it an ideal project to study the use of BIM for QTO.

In this case study, I evaluated a popular 2D-based QTO software called On-Screen Takeoff and compared it with two pieces of BIM-based software, Tocoman and Revit. I identified the required quantities that a user will need for construction cost estimating and LCA for three major components in the buildings; the foundation system, shear walls, and partition walls. I developed criteria to evaluate the software based on an assessment of the user requirements. In essence, the criteria for evaluation included the availability of the required quantities, the consistency of the results, the ability to group components based on user-defined parameters, the ability to provide visual verification or presentation of the results, and the reporting capabilities. Each piece of software was assessed based on these criteria for each of the different components analyzed. I also identified the benefits and shortcomings of each of these pieces of software.

I found that each piece of software has benefits and limitations in providing the quantities. On-Screen Takeoff, which is 2D-based software, provides most of the quantities that an estimator needs to calculate a cost estimate; however, creating QTO using this software is a time-consuming and tedious task as the QTO is done manually. In addition, calculating the quantities using this software is prone to error. For example, the user might forget to set the correct scale while performing the takeoff, or the user might neglect to count openings or doors on the wall or miscalculate the height of the wall as s/he cannot visualize the face of the wall. Handling changes is also a cumbersome task as the QTO process must be repeated manually for the changed components. As everything is manual in this software, grouping is a challenge as well. The user should have in mind how s/he needs the grouping to be done from the start of the QTO process since changing the grouping criteria during the process is tedious. The software provides different colors, patterns, and symbols for

performing the QTO, which makes the visual verification process easier compared to other types of software.

Revit is BIM-based software that is robust in grouping, filtering, and sorting the quantities. These are important criteria for an estimator as s/he should be able to create the quantities based on different grouping options; however, this software doesn't show the information based on level, which is an important grouping category. In addition, Revit is not usually useful in terms of visual verification, as when highlighting the components in a view other components are often blocking the component of interest. The software provides fast QTO results and the results are accurate if the model is created with good accuracy. In addition, changes in the model will be reflected in the results automatically; therefore, rapid QTO feedback for different design alternatives is possible using this software.

Tocoman is also a BIM-based software tool that works as an add-on to Revit. This software has a good ability to visualize the components in 3D as it usually makes the components that are blocking the view invisible or transparent. The other benefit of this software is its reporting capabilities. Tocoman exports the quantities to an Excel sheet in a clear and useful format. Again, performing QTO is fast and accurate if the model is created accurately. In terms of weaknesses, Tocoman doesn't provide all the calculations needed by the user and it has fewer options for grouping than Revit.

I found that BIM-based software provides the quantities more efficiently and with greater accuracy when the model is created accurately and with sufficient detail. However, it is important to note that when assessing the 'efficiency' of the software that the level of effort involved is different for 2D-based tools compared with BIM-based software. For 2D-based software, the user's main effort is primarily in the QTO stage. However, in BIM-based

QTO, the main effort is put into creating the model; therefore, if the model is created accurately and correctly, the process of QTO is fast and accurate. However, BIM-based software can have problems in terms of visual verification, grouping, and availability of the required quantities, which need further work.

#### **4.3.2 Suggestions for Future Research**

For future work, I think additional research is needed to better understand the techniques for modeling that are required to obtain accurate quantities. If the modeling is not done in an appropriate way, the quantities will not be reliable. Further research is needed into different types of components and systems beyond those mentioned in this thesis to further understand the requirements of BIM-based estimating tools. Also, there are several other 2D and BIM-based software systems that should be evaluated to better understand the benefits and limitations of the different tools available. Finally, as quantities are going to be used for cost estimating purposes, additional research must be done into the robustness of each piece of software when linked to cost estimating software.

#### **4.4 Conclusion**

This thesis provides evidence for the benefits of BIM for construction uses at different stages in the project. The BC Hydro case study provides significant detail on how a BIM can be utilized by construction field personnel. The Pharmaceutical Sciences project demonstrates the benefits and challenges of utilizing a BIM for QTO. More case studies are needed to demonstrate the benefits of BIM for different applications in the project delivery process to enable more widespread BIM adoption.

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