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COMPARING TIME AND ACCURACY OF BUILDING
INFORMATION MODELING TO ON-SCREEN
TAKEOFF FOR A QUANTITY TAKEOFF
OF A CONCEPTUAL ESTIMATE

by

M. Adam Alder

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

School of Technology

Brigham Young University

August 2006

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

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ABSTRACT

COMPARING TIME AND ACCURACY OF BUILDING INFORMATION MODELING TO ON-SCREEN TAKEOFF FOR A QUANTITY TAKEOFF OF A CONCEPTUAL ESTIMATE

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Master of Science

Estimating is a critical aspect of every construction project. The most tedious component of an estimate is the quantity takeoff. Different tools are available to improve an estimator's productivity for a quantity takeoff. Faster quantity takeoffs enable estimator to bid more jobs.

This study analyzed the time and accuracy of performing quantity takeoffs when using building information modeling (BIM) through a comparison study using Revit (BIM software) and On-Center's OST. In preparation for the study the researcher conducted a pilot study. Participants of the study were asked to perform a quantity takeoff using both Revit and OST. Their resulting data was then, analyzed comparing

both the time and accuracy of each item taken off. The subjects' perspectives on the two different methods of performing takeoff are also included in the findings of this study. This study focused on a conceptual estimate takeoff for a small commercial building. The results of the study showed that, on average, those using BIM were able to perform the overall takeoff faster than those using OST while still maintaining equivalent accuracy.

This study includes methods to improve productivity for quantity takeoff through an analysis of the takeoffs of counts, areas, and lengths. Findings of this study include methods, techniques, and cautions for performing a quantity takeoff using BIM.

ACKNOWLEDGMENTS

I wish to express my appreciation my loving wife who encouraged me to pursue construction management, and stood by me through this education process. I would also like to thank my committee for their time and wisdom they have shared with me.

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1 Introduction

The construction industry is unique in that the contractor must guarantee a price to an owner, before knowing the actual completion costs. Because no two construction projects are exactly alike, new estimates must be calculated prior to each new job, which can be a time consuming and costly process (The Associated General Contractors of America [AGC], n.d.). A project's design is the primary factor that determines construction costs, and estimators play an essential role in evaluating them. Estimators perform quantity takeoffs to estimate labor costs and equipment and materials needed to construct the project. The financial success of a construction project is dependent on an accurate initial estimate that correctly allocates the costs to the work.

Traditionally, the lowest bidder on a construction project is awarded the project. Estimators are responsible for calculating the cost of a project including contractor fees. Current methods of construction estimating can be very time intensive and tedious. Many hours are spent on each estimate, accounting for and measuring each item needed to complete the project and evaluating their associated costs. In any project large or small, items can be easily overlooked or miscalculated, reducing potential profits. "The financial commitment to a construction project is very large, and inaccurate project estimates can have a detrimental effect on all parties" (Schuette & Liska, 1994).

1.1 Estimating Overview

Prior to performing a project estimate, the company management team must evaluate whether or not to bid on the project. “Each bid effort is expensive and diverts management time from administering the work in progress” (AGC, n.d.). Bidding for projects requires a lot of time and resources; therefore, potential profits drive the decision to bid. Once the management team decides to bid on a job, an estimator begins to thoroughly examine it to evaluate the construction cost.

Many methods are used to account for all of the quantities and costs associated with a construction project. An estimator must take into account: building plans, specifications, site conditions, costs, probable inflations, potential profits, time, special situations, legal, municipal, administrative, and safety considerations. Correctly quantifying each of these items can be challenging and time consuming. Construction projects incur both direct and indirect costs. Direct costs-those costs attributed to a specific project-include labor, material, construction equipment, and services. When calculating the costs of the project, the indirect expenses, potential profits, and company overhead costs must not be forgotten. Estimators must account for all of these items by quantifying them and evaluating their associated costs (AGC, n.d.).

1.2 Quantity Takeoff

A quantity takeoff is an essential step in estimating. “Before the cost of the work can be determined the quantity of work to be done must be measured” (AGC, n.d.). Quantity takeoffs can be performed both manually and electronically depending on the preference and tools available to an estimator.

1.2.1 Manual Takeoff

Traditional methods of performing a quantity takeoff include measuring and counting all the elements of a building, using a scale, and keeping an inventory of all the items on a ledger (Toenjes, 2000). This method can be quite tedious, particularly when an estimator transfers measurements to a ledger. Measurements transferred to a ledger must be carefully checked to ensure accuracy.

1.2.2 Electronic Estimating Methods

Electronic estimating methods are programs in which quantity takeoffs and pricing estimates are calculated using computer spreadsheets and databases. Electronic estimating can save time and reduce the possibility of mathematical error or missed bid items. Electronic estimating can also enable standardization and integration with other departments such as accounting and job costing operations within a company (Toenjes, 2000). “Because the estimator does not have to spend as much time in determining quantities and doing math calculations a good opportunity exists to determine the impact of the construction method on the estimated cost of construction” (Schuette & Liska, 1994).

1.2.3 Spreadsheets

The spreadsheet is the foundation of most estimating software programs. A spreadsheet uses cells organized into rows and columns where formulas can be entered to perform mathematical computations (Toenjes, 2000). Using spreadsheets helps organize an estimate and a quantity takeoff in a way that allows for clear and concise recall of the items taken off as well as the calculations performed.

1.2.4 Database Interactivity

Database interactivity helps an estimator store and recall important historical costs. “Database interactivity is the direct transfer of stored information by a software program from a database into a spreadsheet” (Toenjes, 2000). Databases can store the important historical costs of materials, labor, and construction equipment. Many construction estimating programs have been developed that incorporate database interactivity. A major advantage of using estimating software is the consistency of data. Estimating software has the flexibility to rearrange the information for various types of reports without having to reenter data previously entered.

1.2.5 Digitizers

A digitizer is a hardware device that, by using an electronic pointing device generates X,Y coordinates into a program. As the user traces the plans, these X,Y coordinates are used by a software program to calculate measurements and quantities (Vertigraph Inc., 2004). The measurements and quantities can then be transferred directly into a spreadsheet or estimating program-eliminating potential transposition errors. Digitizers can also greatly speed up the takeoff process, especially for irregular areas. Using a digitizer can also eliminate potential errors from non standard scales, miscalculations, and transpositions.

1.2.6 On-Screen Takeoff

“On-screen takeoff programs allow the user to view a variety of drawing files and electronically measure items using a mouse rather than a scale or a digitizer” (Vertigraph Inc., 2004). On-screen takeoff programs further the estimating process by creating visual representations of exactly what has been quantified. These visuals greatly, aid in design

build scenarios where a contractor is assists in assessing the design based on an owner's budget. One on-screen takeoff software package parametrically models the project according to the takeoffs performed. This model helps the estimator ensure the takeoff is complete and provides the contractor with a clear communication tool for proposals and cost changes (E-Ring, Inc., n.d.).

1.2.7 Quantity Takeoff Using CAD

Estimating from computer aided design (CAD) is now in everyday use by many designers. Some designers offer the contractor the CAD files for estimating (AGC, n.d.). Several studies have been conducted at Stanford University to demonstrate the abilities of estimating using CAD. One study found that those who used CAD software for estimating recorded an 80% reduction in required time to complete an estimate with an accuracy margin of error of +/-3% (Schwegler, Fischer, O'Connell, Hanninen & Laitinen, 2001).

1.2.8 Takeoff Using Building Information Modeling

Building information modeling BIM is a parametric modeling program in which a designer uses objects with predefined properties, to model a construction project. Traditional CAD software programs create two-dimensional drawings using lines used to represent design elements. BIM differs from CAD in that, when using BIM, the user drafts a project using objects rather than just lines. BIM contains predefined properties, or user defined properties, that track material quantities, and any additional building information to quantify the scope of the project (Autodesk Inc., 2005a). At the time of this study, those using BIM were using it almost exclusively for design purposes. The

long-term goals for those firms using BIM include using it for quantity takeoffs and cost estimating (Khemlani, 2004).

1.3 Time is of the Essence

The traditional flow of estimating begins when an architect gives a cost per unit estimate to a client. This preliminary estimate is based on a cost per square foot of a similar project. Preliminary drawings of the design are created and then taken to a contractor for a conceptual estimate. The scope of a conceptual estimate can vary substantially depending on the level of detail in the construction documents. Design-build and construction management delivery systems rely heavily on conceptual estimates. These two delivery systems incorporate the builder at an earlier stage in the project, as an attempt to help the project go faster with fewer problems. If the project begins and the conceptual estimate is not reliable, there may not be enough capital to complete it (Schuette & Liska, 1994). A detailed estimate is then performed once the completed construction documents are available for the project. Detailed estimates are more inclusive than conceptual estimates and are quantified and priced according to the specific materials called for in the completed construction documents.

Each level of estimating can be very time consuming and quite costly. Construction projects require accurate estimates for each stage of the design process. However, as builders get involved earlier in the project estimating costs are often transferred to them. To avoid spending significant resources estimating every design change, estimators need tools that can quickly adjust the estimated costs as the design adjusts. Tools that increase the speed an estimate can be performed ease the burden of the estimator and can help the design of the project to stay within the budget.

1.4 Statement of the Problem

Conceptual level estimates are limited by time and yet they need to be as accurate as possible. Increasing the speed of the estimating process allows an estimator to bid more jobs, which helps the company acquire more work. Performing quantity takeoffs is considered the most time-consuming portion of an estimate. Because of this estimators need more efficient methods to perform accurate quantity takeoffs.

1.5 Research Questions

1. Can BIM improve time and accuracy for a quantity takeoff of a conceptual estimate as compared to on-screen takeoff?
2. What perceptions do the subjects of the study have related to quantity takeoffs using BIM compared to on-screen takeoff?

1.6 Significance of the Study

The cost estimating tools available in construction are continually improving. A traditional design process begins with an architect taking a three-dimensional idea and drawing it into a two-dimensional building plan. An estimator then uses these two-dimensional drawings and estimates the various costs of the three-dimensional project. This transfer from two-dimensional building plans to a three-dimensional estimate can be difficult because an effective estimator must not only quantify what is shown on the drawings and specifications but also anticipate all construction activities (Schuette & Liska, 1994). Many steps in this process can be eliminated by using BIM. For example, an architect can initially design a project using three-dimensional components. Using this same three-dimensional model, an estimator can then compile an estimate.

As construction projects increase in complexity BIM is becoming more prevalently used in the industry. From a survey of designing firms currently using BIM, it was found that their long-term goals included using it for quantity takeoffs and cost estimation (Khelmlani, 2004). BIM has many attributes that can assist in the quantity takeoff and estimating process:

1. The BIM model allows the user to quickly visualize and understand the scope of the project.
2. BIM allows dimensional attributes to be extracted directly from objects eliminating any problems of using the wrong scale.
3. As a model is created, material lists, lists parametrically linked to the objects in the model, become available. These lists can be modified to display the parameters of the objects in the model such as quantities and dimensions. Additionally, as the model changes these material lists simultaneously update.

Other factors affecting BIM may hinder its ability for use of quantity takeoffs.

1. Material takeoffs in BIM require the use of different methods; therefore, estimators must adapt their takeoff techniques in order to extract accurate data from the model.
2. The design and building team's resistance to change.
3. Those performing the takeoff must own and be able to use the software.
4. Designers must be willing to draw complete and accurate models and must also be willing to release those models to the contractor.

Contractors need to be up-to-date on this technology and able to understand it, in order to use it for their advantage.

1.7 Delimitations

The following delimitations define the purpose and scope of this study:

1. This research is limited to performing a quantity takeoff on certain key elements in two, small commercial projects.
2. The quantity takeoffs were performed for a conceptual level estimate.
3. The participants were students at Brigham Young University who had a basic knowledge of drawing using BIM and who had completed some courses in the construction management program.
4. The BIM model used was drawn by the researcher with the intent of extracting quantities from it for estimating.
5. The methods for extracting quantities from the model were developed and taught to the students by the researcher.

1.8 Assumptions

The assumptions of this research included the following:

1. The construction bid documents will be available in a building information modeling format.
2. The estimators will have the software and knowledge needed to extract quantities from the model.
3. The model must be drawn correctly so that the measurements and quantities of the objects in the model are reliable.

1.9 Definitions

Autodesk Revit- A building information modeling software referred to in this study as Revit.

Building Information Modeling- Software used for designing buildings that utilizes three-dimensional objects to create models and construction documents with parametric attributes.

Cost Estimator- An individual who uses construction documents to determine the cost of a construction project.

Estimate- A forecast of the construction cost for a project that is determined through an orderly process (AGC, n.d.).

On-screen takeoff- A software program in which electronic plans are imported, allowing quantity takeoffs to be performed on a computer screen.

OST- On-Center Software's version of an on-screen takeoff software program.

Parametric Modeling- Refers to the inter-elemental relationships of all of the components in the BIM model. In other words, changes update simultaneously to all plan views as changes are made to the BIM three-dimensional model.

Quantity takeoff- The act of determining the quantities of items of work to be performed on a project, also referred to as quantity survey (AGC, n.d.).

2 Review of Literature

This chapter discusses the literature reviewed in order to conduct this study. Similar studies have been performed that use new technology to challenge existing methods of performing a quantity takeoff in an attempt to increase the performance of the estimators. The various types of estimates and methods of estimating are discussed in this chapter.

2.1 Types of Estimates

Several types of estimates are performed throughout the pre-construction and construction process. The scope of the estimate depends on the amount of information available to the estimator. This section reviews the functional unit price, cost per square foot, system, and detailed estimates.

2.1.1 Functional Unit Price Estimate

The functional unit price method of estimating is derived from the overall costs of similar projects stored in a data bank. An estimator uses these historical costs to approximate the cost of a proposed project. Examples of this type of estimate are for example, the cost per parking stall for a parking garage, or the cost per student for building a school (Schuette & Liska, 1994).

2.1.2 Cost per Square Foot Estimate

A cost per square foot conceptual estimate is the most common type of conceptual estimate. This method is based on the historical costs per square foot of similar buildings. This type of estimate is only reliable at the early stages of the project. In addition to building square footage function, location, escalation, and finishes need to be considered (Schuette & Liska, 1994). Square foot estimates assist the owners and designers in allocating their space according to their budget.

2.1.3 Conceptual System Estimate

A conceptual system estimate requires that an estimator complete some quantity takeoffs. An estimator first divides the project into functional systems. In a system estimate, for example, walls are separated by systems such as a brick exterior wall with sheathing, studs, drywall and paint. A different wall system might be an interior wall with drywall and paint on either side of a stud. These systems are then priced using historical data, for instance cost per square foot of wall system (Schuette & Liska, 1994). A conceptual system cost estimate assists the designers and the owners in determining the level of finishes of the project according to the budget.

2.1.4 Detailed Estimate

Detailed estimates are usually prepared from complete sets of construction documents prior to the submission of a formal bid. This type of estimate begins with a thorough review of the complete construction documents for a given project. The final compilation of costs in a detailed estimate includes a comprehensive breakdown of all the work to be performed and the materials to be placed. This breakdown includes the costs associated with each item of work to be performed (Peurifoy & Oberlender, 1989).

Detailed estimates define the cost of the project. Detailed estimates are the most accurate type of estimates due to the high level of detail of the construction documents when the estimate is performed.

The functional unit, cost per square foot, systems, and detailed estimates are periodically being performed throughout the course of a project. Throughout the construction process, as changes occur, conceptual estimates help to evaluate the cost associated with those changes. Designers usually rely on contractors for conceptual estimates prior to actually drafting detailed documents for the changes. Once the drawings reflecting the design changes are complete, estimators use them to perform a detailed estimate. This detailed estimate usually results in a contractual price for the work to be performed.

2.2 Takeoff Overview

A quantity takeoff is the base of any estimate. The skills needed to perform a quantity takeoff are arithmetic, geometry, and trigonometry. An estimator will use tools to measure the plans and then use math to calculate the three-dimensional properties of the building's objects (O'Brien, 1994).

The quantity takeoff is the systematic breakdown of the project into units of work in order to evaluate the cost and time needed to construct a project. As the takeoff is performed, "The quantity surveyor must consider the specific method of construction anticipated, for the cost of the work" (AGC, n.d.). The takeoff process is a method for measuring the quantities needed for pricing. The quantities must include the material to be procured, both temporary and permanent. Additionally, labor and construction equipment costs to install the materials must also be included. An estimator must also

consider services associated with the work. An accurate estimate requires complete and detailed quantity takeoffs. The estimator is responsible to check every detail, note and specification no matter how obscure (AGC, n.d.).

2.3 Takeoff Methods

Several methods are available to assist estimators in performing their takeoffs. With the help of technology methods of quantity takeoffs have evolved improving the efficiency, accuracy, and organization of estimating.

2.3.1 Manual Takeoff

Traditional estimates were performed by scaling objects on construction documents and entering their dimensions onto ledger sheets for calculating and pricing. Manual takeoff was usually performed with printed drawings on which the estimator would use colored markers to keep track of the different materials taken off (Toenjes, 2000). 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.

2.3.2 Digitizers

Digitizers can accelerate the takeoff process, especially for irregular shaped areas. Using digitizers can also eliminate potential errors from non-standard scales,

miscalculations and transpositions (Vertigraph Inc., 2004). A digitizer consists of a tablet, with which an estimator uses a stylus or a mouse to trace drawings. As the operator traces the plans, the digitizer mathematically calculates the distances between points and tracks these distances for faster takeoff. Digitizers have been especially useful for earthwork quantity takeoffs. As the operator traces the contours, the digitizer creates a three-dimensional map of the proposed versus the existing contours, helping to quantify cut and fill (Johnston & Mansfield, 2001). The use of digitizers has been a big step in improving the process of performing a quantity takeoff.

2.4 Electronic Methods of Takeoff

Computers have aided in the takeoff and estimating process. Computers help estimators with calculations and organization, which in turn can improve the time needed to complete and the accuracy of a quantity takeoff.

2.4.1 On-Screen Takeoff

On-screen takeoff software allows the user to view a variety of drawing files and electronically measure items using the mouse rather than a scale or a digitizer tablet. In addition, on-screen takeoff programs require no additional hardware. To assist with organization, on-screen takeoff software programs offer a choice of colors, line styles, count symbols, and area fill patterns for the items measured (Vertigraph Inc., 2004).

On-screen takeoff software has allowed for faster takeoffs using a computer generated list of counts, areas, and lengths. These electronic takeoff programs are set up to perform calculations that return volumes or surface areas of the three-dimensional objects represented by the plans.

In a previous study, research was performed to determine if a correlation would show that electronic takeoff was faster than manual takeoff.

“Performing quantity takeoffs with electronic documents was studied by comparing two groups. One group used electronic construction documents, and the control group used paper construction documents. A pilot study was conducted prior to the principal study. The findings of the principal study indicated no significant difference in the amount of time to obtain the dimensions for a quantity takeoff between the electronic and the paper documents. The principal study indicated no significant difference in accuracy between the electronic documents and the paper documents. While the findings demonstrated no significant difference regarding the time required for quantity takeoffs, the electronic documents may save reproduction costs and may require less time and effort to distribute than paper construction documents” (Miller 2003).

This previous study was performed with an electronic takeoff software called FastLook. On-Centers’ OST used during the experiments in this study, is considered to be faster and easier to use than FastLook.

On-screen takeoff programs carry additional benefits in that the plans are digital-saving printing and distribution costs. These electronic files allow for easy storage and review when needed. One on-screen takeoff software program available, Capture Pro, parametrically creates a three-dimensional model of the project being quantified. This three-dimensional model helps the estimator to review the takeoff, and verify that each item has been quantified (E-Ring Inc., n.d.).

2.4.2 Spreadsheets

Spreadsheets can be very useful in organizing and calculating the quantity takeoffs. They use cells organized into rows and columns to enter material quantities and descriptions. Formulas can be placed in these cells to perform any needed calculations. However, special precautions should be taken to verify that the formulas in the spreadsheet are calculating using the proper cells (Toenjes, 2000).

2.4.3 Special Estimating Programs

Many estimating programs are available that can reduce the need to reenter redundant data. Estimating software programs usually consist of a combination of spreadsheets and databases. This combination helps improve the consistency of the estimate by storing material pricing formulas in the database allowing for reuse (Toenjes, 2000).

Electronic databases and estimating programs have been developed to help increase accuracy and reduce the time needed for estimating construction projects.

“Detailed estimating is the most accurate approach, but it also takes the most time to complete. In a 1999 survey at the International Builders’ Show, builders reported taking an average of 12.7 hours to complete a detailed estimate...Computers have taken much of the drudgery out of estimating, increasing the accuracy of estimates and decreasing the time needed to complete them. In the same survey, builders reported that by using computer programs to generate their estimates, the average time required to complete each estimated dropped to 4.9 hours”(Christofferson, 2003).

Specialized estimating programs have improved the productivity of estimators and helped to improve the estimates accuracy and ability to recall the calculations performed.

2.4.4 CAD Integration

Estimating from computer aided design (CAD) is in everyday use by many designers. However, for competitive bidding, CAD is very limited. A designer providing the quantities for the estimate opens the door for problems such as: who is responsible for errors, and other similar liabilities (AGC, n.d.).

2.4.5 Virtual Building

Virtual building has been studied in great depth at the Center for Integrated Facility Engineering (CIFE) at Stanford University. Virtual building is a process created

to improve the design and construction processes through better coordination. Virtual building consists of creating “smart models” in which incorporate schedules and estimates. Virtual building recognizes the loss of productivity through multiple models and collaborates to improve the process. CIFE has performed much of the research related to virtual building.

“Several years ago YIT Corporation embarked on an ambitious R&D program to base their estimating and production planning software on product models. YIT management had concluded that documents transfer information poorly between project phases because they do not make design information amendable for direct interpretation by other computer programs. In recent years, YIT has converted their estimating and production planning software (COVE) to be compatible with the Industry Foundation Classes (IFC R2.0). The goal is to provide decision support for YIT’s customers by giving them, in the briefing phases, reliable estimates for income, costs and the hand over date, as well as data about the project’s economy over its life cycle (Laitien 1998). YIT had seen the following results from their product model-based cost estimating and production planning systems:

- 80% reduction in time to generate cost estimates (including model analysis and creation of alternatives),
- Cost estimation accuracy of +/-3%, and
- Quick generation of visualizations from the COVE model including studies of alternative solutions and their impact.

Including all the effects of a product-model-based system like COVE, the approach promises savings of up to 10-15 percent of the total building costs. When compared to the typical 4 to 7% profit of construction companies the need for these model-based systems become obvious” (Schwegler et al., 2001).

The model-based systems have helped to demonstrate the value of three-dimensional estimating. These models, however, have shown some major flaws. These models have been instrumental in providing material quantities but fail to show the estimators rationale. In estimating, special design conditions require added materials, labor, and specialty tools. Estimating software programs are being written to recognize special design conditions and ask for the user’s input on the costs of these items (Staub-French, Fischer, Kunz & Paulson, 2003). Programs designed to perform an estimate

from a CAD model require a very extensive databases. These databases must relate all information relative to the construction project to specific costs. Programs such as these must be able to recognize changes in productivity for all constructability issues, and quantify them accordingly.

CIFE has been at the forefront of virtual building. Much of the research performed by CIFE consists of a complex web of programs linked together to produce a virtual model. Some of these programs used are estimating software packages that automate an estimate by using the design to extract the quantities and then link those quantities to an associated cost. This study differs from those conducted by CIFE in that it maintains an estimator performing the quantity takeoffs. The takeoffs performed in this study are at the conceptual level and require the judgment of the estimator.

2.5 Building Information Modeling

Building information modeling has been gaining popularity among project designers and builders. “There are strong indicators that building information modeling is finally going mainstream in the AEC industry” (Khemlani, 2004). Building information modeling is a different method of drawing in which all components of the model are inter-related.

“The original premise of a CAD system was to automate the task of drafting. As such, the original focus of CAD applications was to represent 2D geometry via graphical elements, such as lines, arcs, symbols, et al. In this context, walls, for example, are merely represented as parallel lines. To establish some meaning behind these graphical elements, the concept of layering was introduced to group related elements, such as the lines used to represent walls on a given ‘wall layer.’ By doing so, discrete 2D drawing files could be generated and plotted from CAD, but more complex information, such as the relationships between elements could not be represented. The emergence of 3D CAD initially focused almost entirely on creating geometry in support of visualization, and subsequent advances concentrated on creating realistic rendering and lighting effects.

More recently, object-oriented CAD systems (OOCAD) replaced 2D symbols with building elements (objects), capable of representing the behavior of common building elements. These building elements can be displayed in multiple views, as well as having non-graphic attributes assigned to them. The inclusion of parametric 3D geometry, with variable dimensions and assigned rules, adds “intelligence” to these objects, permitting the representation of complex geometric and functional relationships between building elements. In this paradigm, walls are objects which can be stretched, joined, have height, be of a specific cross-section type, and “own” associated properties, such as a fire rating or insulation value. Similarly, doors and windows are represented as objects, capable of representing their relationship to the walls in which they are placed and behaving accordingly. More importantly, abstract objects, such as a space, can be defined by the relationships between physical building elements, identified (e.g. room number, room name, etc.), described (e.g. area, volume, use, occupancy, etc.), and referenced (e.g. listed in a room schedule, counted to calculate total floor area, etc.). Capturing these relationships and behaviors and the richness of the intelligence are just not possible in the previous CAD paradigm. Building information modeling (BIM) is the latest generation of OOCAD systems in which all of the intelligent building objects that combine to make up a building design can coexist in a single ‘project database’ or ‘virtual building’ that captures everything known about the building. A building information model (in theory) provides a single, logical, consistent source for all information associated with the building” (Howell & Batcheler, n.d.).

Building information modeling has parametric qualities which synchronize all elements in the project helping designers create more complete building plans.

Designing with BIM has many benefits. Some of BIM’s key strengths are as follows:

- Ease of use compared to CAD.
- Consistent and parametrically linked drawings.
- Coordination of building objects to reveal clashes between design elements.
- Comprehensive schedules (material lists) are kept up-to-date with any changes in the model.

- Ability to visualize as a single 3D model versus a multitude of 2D drawings.
- Better communication.

Although BIM has many strengths, it also comes with challenges. Some of the challenges are as follows:

- Overcoming the resistance to change.
- Developing a new workflow from the existing design process.
- Training for the new software.
- High end hardware.
- Large file sizes.

These strengths and challenges were taken from a study performed through surveys and information gathered from BIM users (Khemlani, 2004). Of the challenges listed the greatest is managing change. “Many architects are very conservative and think that their designs are too unusual, too specific and too customized to be modeled using a BIM solution, which is assumed to be useful only for modeling standard designs.”

When using BIM you can not fake or cheat design, you cannot get away with leaving out information. All parts of BIM are co-related and require 100% modeling all of the time. Traditional three-dimensional modelers often create images that coordinate with the project. Such modelers usually resist BIM because of the rigor and honesty it imposes (Khemlani, 2004). BIM is designed so that a complete model naturally creates accurate quantities.

2.6 Virtual Construction Solutions

Virtual Construction Solutions is a program designed by Graphisoft. Graphisoft also developed ArchiCAD, one of the first software to use the BIM concept. Virtual Construction Solutions allows construction companies to “create their own intelligent models of building projects from scratch and use them for constructability analysis, accurate estimating, scheduling, and so on” (Khemlani, 2004). The contractor employs a construction modeler who then uses this program to develop a construction model from the architect’s plans. Projects that have used Virtual Construction Solutions claim to have gained 2-3% cost savings. These cost savings are realized through efficiencies gained through constructability analysis, faster and more accurate estimates, sequencing, and improved data flow (Gallelo & Freeman 2006).

2.7 Visual Estimating

Estimating is more complex than merely obtaining a list of materials and their dimensions. “It involves analyzing the building, grouping objects into appropriate assemblies for construction, setting assembly and item variables, and then pricing the objects” (Khemlani, 2006). Due to the complexity of estimating, those who perform the quantity survey need to visualize the items they are quantifying. Visual Estimating is a software program that imports a BIM file and allows the estimator to visualize and color code the items being quantified. An estimator links the objects in the model to the items in the estimate. This link transfers the dimensional data from the model to the estimate for pricing. Visualizing all the items being taken off reduces the chance of the estimator missing items. The link from the items to the estimating program also reduces the chance

for transposition errors as the design changes the linked model updates the estimated quantities (Khemlani, 2006).

Virtual estimating incorporates the dimensional information already present in the model and allows an estimator to visualize the takeoffs. Visual Estimating relies on the architect to produce a model using BIM.

2.8 Conclusion

Estimating is the backbone of financial success for any construction project. Estimating and quantity takeoffs are performed at several different levels of a project depending on the stage of the design. Performing quantity takeoffs can be a time consuming and can expend valuable resources. Digitizers, spreadsheets, on-screen takeoff, and specialized estimating programs can greatly increase an estimator's productivity. Due to the continual need of faster and more accurate estimates, additional methods such as CAD integration and BIM are also being used by some estimators.

3 Methodology

For this study, the time and accuracy of BIM was compared to that of an on-screen takeoff, for a quantity takeoff of a small commercial project. This study is limited to the comparison of two software programs, OST and Revit.

3.1 On-Center's On-Screen Takeoff

The on-screen takeoff tool used in this study is On-Center Software's OST. OST was recommended for this study by a Brigham Young University professor Kevin Miller, an expert in construction cost estimating. At the time of the study OST was the leading on-screen takeoff software (K.R. Miller, Personal Communication, April 13, 2006). OST is a computer program specifically designed for performing quantity takeoff in construction. To use OST, an estimator sets up a bid and then loads the project's electronic drawings. The most critical element when using OST is that the user must set the correct scale for each drawing. Prior to the takeoff the user creates "takeoff items" inside the program that relate to the items to be quantified. Measurements in OST can be performed using areas, lengths, or counts. The user then traces the plans on-screen as the program electronically records the measurements. OST is a fairly simple program to use and is designed primarily for quantifying and marking electronic construction documents.

3.2 Autodesk's Revit

Autodesk Revit is a building information modeling software primarily used by project designers for drawing projects. Using Revit, architects draft the project using objects that contain predefined properties to create their model. This model has parametric properties, meaning the designer creates one complete three-dimensional model which can be sliced to reveal, floor plans, elevations, sections, or any other views needed. The objects in the model carry dimensional properties such as lengths, areas, and volumes. These dimensional properties allow estimators to extract precise quantities from the architect's model (Autodesk Inc., 2005a).

3.3 Takeoff Using BIM

BIM is capable of exporting quantities to databases and spreadsheets. At the time of this study, software vendors were in the process of developing programs that would link BIM's exported quantities to their cost estimating programs (Autodesk Inc., 2005b). Exported quantities carry a risk of error in that they may not represent the work package showing where or how the material is to be placed. As estimators perform a quantity takeoff they must evaluate the work processes and locations of the material to be placed (Staub-French, 2002). For example, installing masonry on the first floor of a building might not incur the additional costs for scaffolding and hoisting required for the fourth floor. Estimators must understand and visualize exactly what is being quantified to analyze such varying scenarios.

To assist in the takeoff process the researcher developed a five-step process to extract quantities from BIM. This process was taught to those who participated in the study.

The five steps for performing quantity takeoff using BIM include the following:

1. Visualize the project by using a three-dimensional view
2. Modify the model to display the items being quantified
3. Sort the list of materials to best evaluate the objects in the model
4. Isolate the objects in the three-dimensional view to verify correct quantification
5. Analyze the data

3.4 Overview of the Takeoff Study

Participants of the study were students enrolled in the Construction Management program at Brigham Young University. These students were enrolled in the spring term Advanced Estimating course taught in the Construction Management program. The participants were already familiar with basic skills in quantity takeoffs, drawing using Revit, quantity takeoffs using OST, and estimating. See pre-survey results Appendix A-1, B-1.

3.4.1 The Pilot Study

Prior to the study a pilot study was conducted by the researcher. The pilot study consisted of six construction management students. The subjects in the pilot study were already familiar with drawing using BIM, but had little experience in quantity takeoffs and estimating. However, participants had no prior experience in using BIM or OST for quantity takeoffs. Prior to the pilot study, the participants attended three, two-hour training sessions with the researcher. These training sessions covered basics of quantity takeoff and instructions on how to use on-screen takeoff as well as BIM for quantity

takeoffs. The participants then completed a pre-survey, seven quantity takeoffs using BIM, seven quantity takeoffs using on-screen takeoff, and a post-survey.

3.4.2 Preparing for the Study

The subjects in the pilot study mentioned that the plans used in the on-screen takeoff program were difficult to read, because they were in Design Web Format (DWF). To remedy this problem the plans for the on-screen takeoff program were prepared in Tagged Image File Format (TIFF) for the study. Using TIFF format with the on-screen takeoff program helped to darken the plans and helped the program run more efficiently. The pilot study used the same building for the takeoffs performed in both the on-screen takeoff program and BIM. For the study, the plans were changed so that subjects would not try to input the same quantities for the different methods. The BIM takeoff was performed using a rectangular shaped Wendy's restaurant. In contrast, the takeoffs performed with on-screen takeoff used a square shaped Wendy's restaurant.

The pre and post-surveys were modified from the pilot study with minor changes to better clarify the questions. The worksheet questions were also modified to define the limits of the items being taken off.

3.4.3 Construction Documents

For the study, plans for a Wendy's restaurant were used to perform the quantity takeoffs. Two different forms of electronic documents were provided. Plans were prepared in a TIFF format for the on-screen takeoff portion of the study. A Revit file was used for quantity takeoffs of the BIM method. The BIM model used in the study was redrawn by the researcher using an imported CAD file and took approximately seven hours to draw. It should also be noted that the BIM model was drawn with the

intent of using it for a quantity takeoff. This meant that the researcher verified that each item in the model had the correct parameters attributed to them. It is expected that professional designers may draw using BIM some items that have incorrect parameters. As demonstrated in the findings of this study, it is the estimator's responsibility to verify that the items being taken off have the appropriate dimensions.

3.4.4 Pre-Survey

The subjects were given a pre-survey a few days before the study to record their level of construction and estimating experience as well as their experience using OST and Revit. For results see appendix D-1.

3.4.5 The Worksheet

An electronic worksheet containing the seven items to be taken off and space for the measured quantities was provided to all participants. The worksheet was set up in Microsoft Excel and contained a timer that recorded the time used to perform each takeoff. As students completed a question they clicked on a button which recorded the time, and allowed them to proceed to the next question. Two worksheets were used to record answers one for the BIM method and one for the on-screen takeoff method. The two worksheets contained the same 7 takeoffs to perform. For worksheet see Appendix D-3.

The results of the worksheets were compared for time versus accuracy, and accuracy versus time. Accuracy measurements were based on previous quantity takeoffs performed by three professional estimators.

3.4.6 Post-Survey

Following the timed tests a post-survey was given to the subjects for feedback. This survey allowed the participants to share their perspectives on the two takeoff methods.

3.5 The Study

The volunteers for the study were students enrolled in the Advanced Estimating Course taught at Brigham Young University. On May 31, 2006 volunteers were requested during class time, for which the entire class volunteered. At this time the volunteers filled out a consent form and a pre-survey to assess their skill level. The students who participated in the study were already familiar with performing quantity takeoff, performing a quantity takeoff using OST, and drawing using Revit. The subjects did not have, however, prior experience using BIM to perform quantity takeoffs.

The study took place on Monday, June 5, 2006, during the Advanced Estimating Course's class time 26 of the 27 students who volunteered for the study were present. The researcher began the study by teaching quantity takeoffs using BIM. The participants were then given some practice questions to try performing quantity takeoffs. Training, practice, and question answering lasted approximately one hour. The researcher then passed out the instructions and directed the participants to the electronic worksheet and test file.

Participants were randomly selected to begin the study using either BIM or the on-screen takeoff program. The study was administered so that participants began using one of the two methods, completed the seven takeoffs, then switched and

performed the same takeoffs using the comparison method. The researcher was present during the takeoffs for technical support. After completing the takeoffs the subjects were again surveyed for feedback.

3.6 Analysis

Each of the participants' takeoffs were checked for accuracy and then compared for time. Accuracy levels were evaluated by dividing the participants' quantity per takeoff by the control quantity. A comparison of the deviation was performed for each takeoff comparing the average percent of error of BIM users to that of on-screen takeoff users.

The average time for each question in BIM was also compared to the average time for each question in on-screen takeoff. The overall times were also compared to evaluate which method was faster. The participants' perceptions of these two methods were gathered through the post-survey and analyzed for further feedback.

4 Findings

This chapter presents the findings of the study of performing quantity takeoffs between the BIM method and the on-screen takeoff method. The results discussed in this section include the time and accuracy of the quantity takeoffs and the perceptions of the participants pertaining to the two methods of takeoff.

4.1 Findings Related to Drawing Using BIM

In preparation for the study, the researcher drew the BIM model over imported CAD files of a Wendy's restaurant. As the researcher was drawing the model in BIM, it was found that the architectural plans and with the structural plans for this building did not line up. The researcher opted to use the architectural plans for the BIM model. Changing the footings to match the architectural plans altered the quantities of the footings and slab on grade as quantified by the structural plan. This difference in the plans created a one cubic yard difference in the quantity for the continuous footings. BIM is a parametrically linked program; consequently the three-dimensional model created in BIM is sliced to reveal floor plans, sections, or details. This meant that every page of the drawings created in BIM would lineup correctly to each other. This error associated with plans not lining up could occur in any building where the designer is not using BIM. This drawing error leads to quantification error in which all types of takeoff are susceptible with the exception of takeoffs performed using BIM.

The second item takeoff during the pilot study requested the volume of the continuous footings. Many students had difficulty creating a list of materials for the continuous footings because they were listed in the wall schedule rather than the structural foundation schedule. This is an issue that is applicable to any BIM model; the designer can draw the elements of the model using any object type that fits the elements criteria. In this case, the continuous footings were classified as wall types. This issue is not expected to occur with estimators more experienced using BIM. The continuous footings were changed to the structural foundation object type for the study.

4.2 The Study

The study included 26 students. Of the 26, three were excluded because they did not complete both parts of the study. An additional six students were excluded from the takeoff portion of the study because they had no previous BIM experience. Quantity takeoffs are not a basic function of BIM; consequently, prior experience is required to properly perform takeoffs. The results showed the percentage of error and the time to complete the takeoffs were obviously skewed for those who had noted no prior BIM experience. Although this study excludes their takeoff data, their post-survey data is included and compared to the other participants with previous BIM experience.

The average time taken to complete the takeoffs using the on-screen takeoff program was 43 minutes and the minimum time taken was 20 minutes. The maximum time was 86 minutes. The standard deviation was 18.9 minutes.

The average time taken to complete the takeoffs using BIM was 24 minutes. The minimum taken time was 9.5 minutes and the maximum time was 39 minutes. The standard deviation was 8.1 minutes.

The overall values above show that the takeoffs performed using the BIM method were on average, 44% faster than those using the on-screen takeoff program. However, a reduction in the time needed to perform a quantity takeoff is of no value if the accuracy of the takeoffs is significantly reduced. To evaluate whether or not BIM is an effective tool for quantity takeoffs each takeoff item must be evaluated individually.

Prior to the study a pilot study was performed. Results from the pilot study were consistent with the study.

4.2.1 Area of Slab on Grade

The first item taken off was the area of the slab on grade. Those using the BIM method had, on average, a percentage of error of 1% for this takeoff, whereas on-screen takeoff users had a 3% percentage of error. On average on-screen takeoff users' time was shorter by .24 minutes. This takeoff was limited in that the project was a single story building.

Table 4-1: Results Time Area SOG

	TIME IN MINUTES			
	AVG	MIN	MAX	STDEV
REVIT	4.8	1.86	10.54	2.74
OST	4.55	1.66	9.18	2.04

When completing a standard area takeoff using an on-screen takeoff program, an estimator marks the perimeter of the area. In contrast, those takeoffs performed using the BIM method involve examining the object drawn (S.O.G.) to ensure it is inclusive of all desired areas (e.g. areas in doorways). In this instance the slab in BIM was drawn

extending to extend through the doorway and this may not always be the case; therefore, the estimator must also account for what is not drawn.

4.2.2 Volume of Slab on Grade

Question number two of the study asked, “What is the volume of the slab on grade?” To determine the volume when using either program the participants should set their takeoffs so that the previously taken-off area is be multiplied by its height. If the parameters are set properly, both programs should return the correct volume instantly. Participants who recognized this feature were able to perform this takeoff in less than two minutes. Two participants, one for each program, were able to answer this question in .24 minutes or less. The largest percentage of error was from one subject had his answer in cubic yards instead of cubic feet. This type of error can occur using either method. The average time taken by the on-screen takeoff program users was faster than BIM users by .15 minutes. The percentage of error for this question carried over from the area takeoff of the item.

Table 4-2: Volume of SOG

	TIME IN MINUTES			
	AVG	MIN	MAX	STDEV
REVIT	3.12	0.24	9.71	2.57
OST	3.29	0.2	12.87	3.25

4.2.3 Volume of Spot Footings

The only significant data gathered from the spot footing takeoff showed that all estimators perform a quantity takeoff differently. The different quantities achieved through alternate methods of quantity takeoffs are remedied by adding a corrective

waste factor to the estimate. The plans used with the on-screen takeoff program contained thickened interior slab on grade in place of interior spot footings, the BIM plans had no interior footings or thickened slab. The instructions given for calculating the volume of the slab on grade excluded the thickened slab. This instruction was intended to keep the two takeoffs equal. The researcher did not anticipate that participants would include the thickened slab in the spot footing takeoff. Therefore, the answers from the participants using the on-screen takeoff program averaged a percentage of error of 35%. The added time used to calculate the thickened slab may be attributed to the difference in time between on-screen takeoff and BIM.

Participants using the BIM method averaged a 51% percentage of error. One out of the seventeen who were included in the study answered with a percentage of error of 797%. The researcher was unable to identify where the error was made. Excluding this answer from the data yields an adjusted percentage of error of 5%.

Table 4-3: Volume of Spot Footings

	TIME IN MINUTES			
	AVG	MIN	MAX	STDEV
REVIT	4.29	1.36	13.47	2.93
OST	6.11	1.88	14.03	3.71

4.2.4 Volume of Continuous Footings

The results for this question favor BIM considerably. Those using the BIM method had a percentage of error of 15% whereas the on-screen takeoff program users experienced a percentage of error of 22%. Also, the BIM method users completed the task almost four times faster than those using the on-screen takeoff program. This is

because the materials list created for the spot footings in BIM functions for the continuous footings as well. Because the materials list was already created the user only needed to ensure that it contained the correct footings intended for the takeoff.

Table 4-4: Volume of Cont. Footings

TIME IN MINUTES				
	AVG	MIN	MAX	STDEV
REVIT	2.18	0.14	11.61	3.02
OST	8.49	1.09	24.42	5.89

4.2.5 Area of Roof

The roof area takeoff resulted in a 4% percentage of error for those using the BIM method and a 45% percentage of error for those using the on-screen takeoff program. The majority of errors made in the on-screen takeoff portion were obvious cases of individuals not using the correct scale. Of the seventeen participants, three used the wrong scale. This error occurred because the sheet used for the takeoff was drawn using a different scale than the other pages. Adjusting the answers for the correct scale yielded a 5% percentage of error for the on-screen takeoff users. The average time for this takeoff resulted with the BIM method users time being more than twice as fast as those using the on-screen takeoff program.

Table 4-5: Area of Roof

TIME IN MINUTES				
	AVG	MIN	MAX	STDEV
REVIT	2.01	0.84	4.69	1.07
OST	4.6	1.44	8.48	1.74

4.2.6 Number of Doors

The percentage of error for a takeoff of doors using the BIM method was 8%. BIM functions by using object to model the project. These objects are named to distinguish one from another. The door objects in BIM can be either doors or door openings and, in this case, 10 were doors and 1 was a door opening. Only five of the seventeen participants recognized that one door type was actually a door opening. Those participants not paying close attention counted the door opening as a door. This takeoff represents a very real potential for errors applicable to any BIM application. In BIM the designer can label objects with any given name. If the designer labels a spot footing 10'x10'x10" but the footing is drawn 10'x10'x14" the list of materials will only calculate for what is drawn. Because of this an estimator must be careful to setup the list of materials in such a way that the dimensions are shown, thereby double-checking accuracy of the takeoff. This error can also be common to any plans. The designer may also draw one size of object and then specify another size in the schedule. BIM has been a solution to these types of errors in schedules due to its parametric design because the dimensions in the schedules in the plans simultaneously update any changes in dimension.

Those participants using the on-screen takeoff program recorded an average percentage of error of 9%. In a count situation an estimator must go through and count every door, marking them as he goes. These results imply that either the students were not paying close attention to their takeoffs or they did not read the instructions carefully enough.

Table 4-6: Number of Doors

TIME IN MINUTES				
	AVG	MIN	MAX	STDEV
REVIT	2.6	0.54	6.74	2.15
OST	3.83	1.79	6.37	1.31

The time used to complete this takeoff demonstrates how useful BIM can be for count takeoffs. Using the BIM method, an estimator can create a list of all the doors on the project in seconds and then use this list to display where the doors are located. Some say, though that any estimator could look at the door schedule for any plans and count them in about the same time. However, plans for a conceptual estimate do not typically include door schedules.

4.2.7 Area of Exterior Brick

The exterior brick takeoff yielded a high percentage of error: 32% for those using the BIM method and 46% for those using the on-screen takeoff program. A high percentage of error was expected for this takeoff. One form of error noticed by the researcher was that the instructions differed for those using the on-screen takeoff program to the BIM method users. The instructions for users of the BIM method included, “Subtract the copper roofs and aluminum trim” from the quantities. Although, these additional instructions seemed to favor BIM users, only two BIM users even attempted to subtract the items from the walls. The results showed that the two who subtracted the area under the copper roofs failed to subtract the area under the aluminum trim. One of the two participants attempted subtract part of the aluminum trim but failed to recognize that the trim was two-feet tall.

Table 4-7: Area of Exterior Brick

TIME IN MINUTES				
	AVG	MIN	MAX	STDEV
REVIT	4.94	1.01	13.32	3.27
OST	12.32	4.6	29.82	6.88

This takeoff has displayed a major weakness of performing quantity takeoffs using BIM. The lists of materials for walls in BIM will calculate the surface area, volume, or length and any openings are subtracted out of the area and volume. Project designers will often draw the walls from floor to floor. If a wall contains half brick and half stucco BIM would calculate the total surface area of the entire wall. If an estimator understands this concept then simply measuring the height of the brick and multiplying it by the length of the wall would correct this problem.

The study's results show that the on-screen takeoff program users were not hindered by this lack of the above mentioned additional instructions because the plans used in the takeoff clearly labeled what was brick and what was not. Of all the participants, two out of the seventeen had a large percentage of error: 275% and 164%. Excluding this data from the study yields an adjusted percentage of error of 23%. Typically, this error comes from students not including the brick returns. Of the participants, twelve of seventeen did not include the brick returns in their takeoffs.

It is of interest to note that the subject with the maximum time for a brick takeoff using BIM, 13.32 minutes, was also the closest to the correct answer. Taking into account that the on-screen takeoff users would use additional time to include the brick returns, the time comparison for this takeoff is unreliable.

4.3 The Post-Survey

Following the study, the participants were given a post-survey. The post-survey provided feedback on the participants' thoughts regarding the comparison of the two methods. Post-survey comments from the pilot study were consistent with the study.

The post-survey was distributed upon completion of the second set of takeoffs. Two questions were added to the study during the experiment for documentation. The first question asked for the number of monitors available to the students during the study (one or two). No pattern was observed related to time or accuracy dependent upon the number of monitors used by the subjects. The second question asked which of the two programs the participant began with. It was observed in several instances that, when a person performed a takeoff using one program, their time improved when using the comparison program. The table of the participants' responses to the post-survey is found in Appendix E-3. The study participants reported the following responses to the questions:

1. Quantity takeoffs can be performed faster using...

All seventeen participants in the study noted that BIM was faster. Additionally, the six participants whose data was excluded due to no prior experience with BIM also responded that BIM was faster.

2. I feel accuracy is greater by using...

Only one participant noted that on-screen takeoff had greater accuracy. All of the six participants with no prior BIM experience marked that BIM was more accurate.

3. For future quantity takeoffs I would prefer to use...

Of the seventeen participants, two noted that they would prefer to use the on-screen takeoff program for future takeoffs. One out of the six participants with no prior BIM experience would prefer to use on-screen takeoff for future takeoffs.

Please explain:

Of the seventeen participants in the study, eleven remarked that BIM was easier, faster, more accurate or a combination of these responses. One student made the comment that, "You don't have to think using BIM." It is of interest to note that this same student had the greatest percentage of error when using on-screen takeoff for three of the takeoffs. This same student also tied with another participant for the least amount of error in BIM overall. Of the six who had no prior BIM experience, only two remarked that BIM was a faster method. Other remarks from the participants included that using BIM for takeoffs had better views, and the ability to isolate objects.

4. What advantages or disadvantages did you find for each program...

On-Screen Takeoff

Advantages:

Four of the students remarked that it is easy to use. Four students referred to on-screen takeoff's ability to track takeoffs. Others mentioned they liked viewing the plans. Of the six with no prior BIM experience two mentioned that the on-screen takeoff program was "Fast and accurate." Two students also referred to the on-screen takeoff program's tracking and marking abilities.

Disadvantages:

Two-thirds of the participants noted that performing a takeoff using the on-screen takeoff program was slow, tedious, or time consuming. Only one respondent mentioned the importance of checking your scale. Also, mention was made to on-screen takeoff not having a three-dimensional view. The remarks from the six with no prior BIM experience included: slow, no three-dimensional view, and accuracy.

Revit

Advantages:

Of the seventeen participants, thirteen remarked that takeoffs were faster with BIM. Other remarks included reference to three-dimensional visuals, the ability to locate items in plans, and better accuracy. Of those who had no prior BIM experience, four mentioned that the three-dimensional views helped understand the scope of the project, and two mentioned accuracy.

Disadvantages:

Included in the disadvantages of BIM, six students commented that the plans must be drawn correctly. Three students made comments related to the increased learning curve. Other comments included that the program is harder to use, unable to catch mistakes, and an estimator might be tempted not to search plans as thoroughly. Those with no BIM experience made similar comments including learning curve, trust in the designer, and availability.

6. During the Experiment did a specific event influence your answers to any of the above questions? If yes, explain...

Those who responded yes to this question included answers which referred to the following: setting the correct scale using on-screen takeoff, visualizing the project in a three-dimensional view, unfamiliarity with BIM, and takeoff using BIM. Responses from those with no prior BIM experience included unfamiliarity, and visualization in a three-dimensional view.

5 Conclusions and Recommendations

The goal of this research was to compare the time and accuracy of two methods of performing a quantity takeoff, BIM and on-screen takeoff.

5.1 Conclusions

The results of the study conclude that, in a conceptual estimate using BIM, quantity takeoffs were faster while still maintaining an equivalent accuracy compared to the on-screen takeoff program for the sample of student estimators with little experience. For three of the seven takeoff items the BIM method was clearly faster. Due to the inexperience of those estimating, two of the items being taken off were not comparable. The remaining two takeoffs were similar in time and accuracy. This study was performed using construction management students with varying skill levels of estimating and BIM experience. None of the students had previous experience performing a quantity takeoff using BIM.

The results from the post-survey show that all participants of both the pilot study and the study felt that the BIM method was faster. Of the participants, 96% felt that the BIM method was more accurate. However, the results showed that accuracy was in fact equivalent between both programs. Of the participants, 87% said they would prefer to use BIM for future takeoffs. In the post-survey one of the subjects commented, “You don’t have to think using BIM.” This same subject had the highest accuracy using BIM

and the greatest amount of error using on-screen takeoff. The ability for BIM to recognize all items in the model is very beneficial. However, as shown in the door and brick takeoff of the study, estimators must still carefully think through and clearly understand the items they are taking off.

The researcher believes that current methods of estimating will continue to play a major role in the construction industry. However, those contractors whose designers are already drawing with BIM can increase their estimator's productivity by embracing BIM.

This study recognizes that three conditions must exist to improve the estimator's productivity using BIM.

1. A BIM model must be available.
2. Quantity takeoffs using BIM require advanced training for the estimator. This advanced training requires many hours of BIM training as well as time spent in the program to understand what the quantities extracted from BIM represent.
3. The estimator must have the necessary software.

5.2 Recommendations for the Industry

Designing in BIM is quickly gaining popularity and estimators who understand this technology will be able to benefit from it. Already, estimating programs for BIM have become available such as Visual Estimating and Virtual Construction Solutions. These programs maintain similar takeoff methods of this study but they aid the takeoff tracking issue with BIM by highlighting quantified items. Designers of these estimating

software packages have anticipated a move to BIM. As BIM increases in popularity and circulation, other similar estimating programs are expected to be produced.

Mistakes made in an estimate can be very costly to a construction company. For this reason, the researcher recommends that those who embrace this method of quantity takeoff do so with caution. The switch to performing takeoffs using BIM will probably begin with less experienced estimators who have an understanding of BIM. The researcher recommends carefully thinking through and double checking all quantities and working closely under the supervision of an experienced estimator. A further recommendation is to develop a systematic method of takeoff for which items will not be missed or double counted. It is anticipated that this system will take some time to build confidence.

5.2.1 Autodesk Revit Building 9

The availability of Autodesk Revit Building 9 was announced during the progress of this thesis, however, at the time of this writing it had not been released. The researcher used Autodesk Revit Building 8.1 during the comparison experiments. Autodesk Revit Building 9 contains a new material takeoff tool. “Material Quantity Takeoff Tool simplifies the tracking of material quantities. As a project evolves, the Revit Building parametric change engine helps to ensure that the material quantity takeoffs are always up-to-date” (Autodesk Inc., 2006).

The Material Quantity Takeoff Tool should greatly assist tracking quantity takeoffs using Revit. This software update did not affect the experiment for this study but may be very useful for more complex takeoffs. For current methods of paint takeoff using Revit, the user must understand and use a system to differentiate between single or

doubled-sided walls. The Material Quantity Takeoff Tool can provide a material list of the square footage of paint drawn in the model and can be troublesome if the model is not drawn accurately. One example of a this type of potential error is that in commercial construction paint and drywall often stop two feet above the ceiling tile, whereas the studs may continue to the deck. It is doubtful that the architect will go to that much detail when drawing the building plans; therefore, the estimator must always be aware of the potential quantity errors the software may present, and account for them in the estimate. Fast conceptual takeoffs increase productivity by providing quicker feedback thus assisting the architects to design within the budget.

5.3 Recommendations for Future Study

Future studies should include a more in-depth look into using BIM for detailed estimate takeoffs and full estimates. These studies should include considering Revit 9.0 and its new takeoff tool. These studies should also evaluate Visual Estimating and Virtual Constructions Solutions for time and accuracy. It would also be appropriate to evaluate these type of BIM takeoff tools compared to on-screen takeoff. A more complete study would include takeoff by professional estimators using their takeoff tool of choice compared with a professional estimator's experienced in takeoff using BIM. This comparison should include a professional designers complete construction documents drawn in BIM and printed for use with on-screen takeoff. The research must be set up for accurate comparison with everything that must be taken off written out exactly. For example, if exterior brick were one of the takeoff items, the instructions might include: exclude windows and doors, include 6" of brick under soffits. The difficulty in comparing quantity takeoffs is that no two quantity takeoffs are exactly the

same. Estimators quantify projects using their systematic method and then apply corrective waste factors depending on the accuracy of their takeoff.

Additional studies should also be performed utilizing homebuilders.

Homebuilders with an in-house design team can setup a template in BIM such that unit costs are included in the objects. As the design evolves, prices would be simultaneously updated based on unit prices for the systems drawn. Unit prices would have to be updated at regular intervals. This system would need to be monitored for special construction conditions but could provide rough estimates as the designer draws. The benefits of quantity takeoff using BIM does not end with homebuilders. Additional studies should be performed to analyze the time savings for specialized contractors such as electrical contractors and mechanical contractors.

5.4 Implications

The information obtained in this research has provided insight into a less commonly practiced method of quantity takeoffs. This study has provided a baseline for which future estimating methods may be compared.

Using building information modeling for quantity takeoffs is currently very limited. The biggest current limitation is that the drawings must be created in a BIM program, and must be available to the estimator. Another limitation includes tracking the actual takeoffs using BIM. This limitation can be overcome on an individual basis having the estimator create a systematic method of performing takeoff. Additional limitations include overcoming the estimator's learning curve for BIM takeoff. This includes learning new software, and modifying their methods and systems of performing takeoff.

Performing a quantity takeoff can be the most tedious portion of the estimating process because of this faster more accurate methods are continually sought after. Faster methods of estimating increase an estimator's productivity. Project designers also seek quicker means of cost feedback which allows them to avoid costly design rework. Takeoffs using BIM may soon become the means for which cost estimating is carried out.

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APPENDICES

Appendix A. Pilot Study Forms

This appendix includes the forms used in the pilot study. These forms include: a pre-survey, post-survey, instructions for takeoff of Revit and On-Screen Takeoff.

A-1 Pilot Study Pre-Survey

Name _____

1. How many years of construction experience do you have?

2. Rate your skills at reading construction drawings
 - a. None
 - b. Beginner
 - c. Intermediate
 - d. Advanced

3. How many years of estimating experience do you have?

4. How many hours did it take you to feel comfortable using On-Screen Takeoff?

5. How many hours did it take you to feel comfortable using Revit?

6. Age?
 - a. 18-20
 - b. 21-25
 - c. 26-30
 - d. 30+

A-2 Pilot Study Post-Survey

Name _____

1. Quantity takeoff can be performed faster
 - a. On-Screen takeoff.
 - b. Revit
2. I feel accuracy is greater by using
 - a. On-Screen Takeoff
 - b. Revit
3. For future quantity takeoff I would prefer to use:
 - a. On-Screen Takeoff
 - b. Revit

Please explain why

4. What Advantages or disadvantages did you find for each program
On-Screen Takeoff

Revit

5. During the experiment did a specific event influence your answers to any of the above questions?
If yes, please explain.

A-3 Pilot Study Instructions for Using Revit for Takeoffs

Starting Revit

1. Navigate to the J:\group\rvt study\”Your Name”\Revit File.rvt.
2. Double click and open this file.

Questions

1. Open the excel file saved in J:\group\rvt study\”Your Name”\RVT Q.xls
2. DO NOT CHANGE YOUR ANSWERS TO THE QUESTIONS ONCE YOU CLICK NEXT.
3. For any questions raise your hand and the researcher will assist you.

The 5 steps for Takeoff with Revit

1. Visualize the Project
2. Modify the model to show what you’re taking off
3. Develop a schedule
4. Use show and comment to Isolate the items you’re taking off
5. Analyze the data

A-4 Pilot Study Instructions for On-Screen Takeoff

Starting On-Screen Software

1. Start the On-Screen Takeoff by pressing the START button.
2. Select CM Program/On Center Software / On-Screen Takeoff.
3. DO Not use the On-Screen Takeoff (Caedm Server). DO NOT Start the Program any other way.
4. Click File, Click Open. Navigate to the J:\group\rvt study\”Your Name”\Onscreen Takeoff.

Questions

1. Open the excel file saved in J:\group\rvt study\”Your Name”\OST.xls
2. DO NOT CHANGE YOUR ANSWERS TO THE QUESTIONS ONCE YOU CLICK NEXT.
3. For any questions raise your hand and the researcher will assist you.

Helpful Hints:

1. Make sure you have the correct SCALE on EVERY page you use.
2. Set up your conditions to do your calculations for you eg. area, volume.

Appendix B. Pilot Study Results Tables

This appendix contains the results tables for the pilot study. Including: the pre-survey results, worksheet results, and post-survey results.

B-1 Pilot Study Pre-Survey Results

Table B-1 Pilot Study Pre-Survey Results

Yrs Const. Experience	Skills at reading Const. Docs	Yrs Estimating Experience	Hrs to feel comfortable with On-Screen Takeoff	Hrs to feel comfortable using Revit	Age
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Revit Pre-survey

1	4-5	Intermediate	1.5	5+	Still not real comfortable	21-25
2	2	Intermediate	0-1	3-5	40-50 but only 2-4 for the estimating part	21-25
3	2	Beginner	0	still not comfortable	8	21-25

On-Screen Takeoff Pre-survey

4	3	Intermediate	0	4	1 semester+	26-30
5	0	Beginner	0	1-2	5	17-20
6	5	Intermediate	1	2	10	21-25

Attended training but did not participate in pilot study

7	None but 1 year of classes	Beginner	None but CM210, 211	2	5 hrs for Drawing 1.5 hrs for Estimating	26-30
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B-2 Pilot Study Worksheet Results

Table B-2 Pilot Study Results

	Began With Revit			Began with OST			AVG	Control
	1	2	3	4	5	6		
#1 CY Spot Footings								
Revit	1.33		1.3	1	1	1.3		1.3
Minutes Revit	4.15		4.583	5.1	5.117	5.767	4.94	7.067
Accuracy	1.02		1	0.7692	0.7692	1	0.91	
%Error	0.02		0.00	0.23	0.23	0.00	0.10	
OST	1	1.72	1	1.33	1	0		1.3
Minutes OST	5.95	14.92	13.117	13.38	20.137	8.717	12.70	4.45
Accuracy	0.77	1.32308	0.76923	1.0231	0.7692	0	0.78	
%Error	0.23	0.32	0.23	0.02	0.23	1.00	0.34	
#2 CY Continuous Footings								
Revit	12.19		12.05	12	174	12		12.05
Minutes Revit	10.617		5.117	11.217	5.683	10.117	8.55	8.583
Accuracy	1.01		1	0.9959	14.44	0.9959	3.69	
%Error	0.01		0.00	0.00	13.44	0.00	2.69	
OST	10	10.99	12	17.33	7	22		11
Minutes OST	2.95	4.429	7.4	10.05	4.267	6.933	6.00	
Accuracy	0.91	0.99909	1.09091	1.5755	0.6364	2	1.20	
%Error	0.09	0.00	0.09	0.58	0.36	1.00	0.35	
#3 SF of Slab on Grade								
Revit	3026		3026	3028	3026	3026		3026
Minutes Revit	1.517		1.55	5.7	2.1	1.75	2.52	4.283
Accuracy	1.00		1	1.0007	1	1	1.00	
%Error	0.00	1.00	0.00	0.00	0.00	0.00	0.17	
OST	2977	2984	2855	2936	2994	2960		2985
Minutes OST	2.4	2.404	2.75	11.983	2.2	2.8	4.09	
Accuracy	1.00	0.99966	0.95645	0.9836	1.003	0.9916	0.99	
%Error	0.00	0.00	0.04	0.02	0.00	0.01	0.01	
#4 CY of Slab on Grade								
Revit	37.33		37.35	37.66	37	37.4		37
Minutes Revit	0.617		0.733	1.233	0.8	0.917	0.86	3.117
Accuracy	1.01		1.00946	1.0178	1	1.0108	1.01	
%Error	0.01		0.01	0.02	0.00	0.01	0.01	
OST	37	442.07	35	109	37	37		36
Minutes OST	0.217	0.402	1.233	0.817	2.55	1.417	1.11	10.783
Accuracy	1.03	12.2797	0.97222	3.0278	1.0278	1.0278	3.23	
%Error	0.03	11.28	0.03	2.03	0.03	0.03	2.24	
#5 SF Roof								
Revit	3248		2835.5	2836	2836	2836		2835.5
Minutes Revit	1.5		2.35	0.633	2.817	1.05	1.67	2.55
Accuracy	1.15		1	1.0002	1.0002	1.0002	1.03	
%Error	0.15		0.00	0.00	0.00	0.00	0.03	
OST	2975	2794	2827	2772	2930	3257		2965
Minutes OST	1.75	3.212	6.183	8.1	3.717	4.85	4.64	
Accuracy	1.00	0.94233	0.95346	0.9349	0.9882	1.0985	0.99	
%Error	0.00	0.06	0.05	0.07	0.01	0.10	0.05	
#6 Doors								
Revit	10		9	11	11	9		9
Minutes Revit	1.9		3.65	4.15	1.8	0.75	2.45	2.25
Accuracy	1.11		1	1.2222	1.2222	1	1.11	
%Error	0.11		0.00	0.22	0.22	0.00	0.11	
OST	11	10	12	11	2	12		12
Minutes OST	3.033	2.32	8.133	5.22	3.633	3.9	4.37	
Accuracy	0.92	0.83333	1	0.9167	0.1667	1	0.81	
%Error	0.08	0.17	0.00	0.08	0.83	0.00	0.19	
#7 Area of Exterior Brick								
Revit	3532		3883	3883	3882	3883		3883
Minutes Revit	3.067		3.15	3.85	5.25	1.95	3.45	
Accuracy	0.91		1	1	0.9997	1	0.98	
%Error	0.09		0.00	0.00	0.00	0.00	0.02	
OST	2869	3396	2153	2795	1970	2620		3080
Minutes OST	0.767	3.242	12.7	16.1	6.35	6.183	7.56	6.233
Accuracy	0.93	1.1026	0.69903	0.9075	0.6396	0.8506	0.86	
%Error	0.07	0.10	0.30	0.09	0.36	0.15	0.18	
Total Time								
Revit	23.368	aprox 22	21.133	31.883	23.567	22.301	24.45	
OST	17.067	30.929	51.516	65.65	42.854	34.8	40.47	

B-3 Pilot Study Post-Survey Results

Table B-3 Pilot Study Post-Survey Results

	Quantity take off can be performed faster with?	Accuracy is greater by using?	For future quantity takeoff I would prefer to use	why	What advantages/disadvantages did you find for each program	On-Screen Takeoff	Revit
Revit Post Survey							
1	rvt	rvt	rvt	It's clean easier to use, so long as it's been drawn correctly. It's very accurate.		You can actually see each part. Time consuming if there are a lot of back outs.	It finds everything for you. It can be confusing sometimes when there are a lot of families in one type.
2	rvt	OST	OST	It is more accurate and user friendly, and Revit needs to do some improvements.		Slow and you have to know how to set it up and go to many views, but it is more accurate, and you can see what your doing and trust it more.	Hard to tell if you really got what you wanted, and there is a lot of overlap. It is nice though that the calculations like volume are done for you. I think with more practice and training, I could really enjoy using Revit
3	rvt	rvt	rvt	Faster and Easier to see accuracy. Less clicking		Estimating # of objects was easier. Zooming & scrolling were so frustrating. Slow drawings	3D is Great. Schedule is easy to use and grouping totals are nice
On-Screen Takeoff Post Survey							
4	rvt	rvt	rvt	Revit allows the User to set up multiple-use quantity schedules much quicker than does OST. Totals can be verified as seen in show mode.		Working with plans is advantageous because notes and exceptions can be read. This helps to verify what is being taken-off.	Recognizes building components and quickly calculates totals
5	No Post survey						
6	rvt	rvt	rvt	If the plans are hard to read Revit will find it anyway.		Dis- It is easy to miss stuff, especially on the scanned Drawings. Adv- You pick exactly where to estimate	Dis - It is difficult at times to find exactly what you are looking for. Adv-It is Fast and Accurate

Appendix C. Study Drawings

This appendix includes the drawings used in the study. The pilot study used the same plan for both Revit and On-Screen Takeoff. The principle study used the same plans for Revit but used a more square shaped building for On-Screen Takeoff.

C-1.1 Drawings Used for Takeoffs with Revit

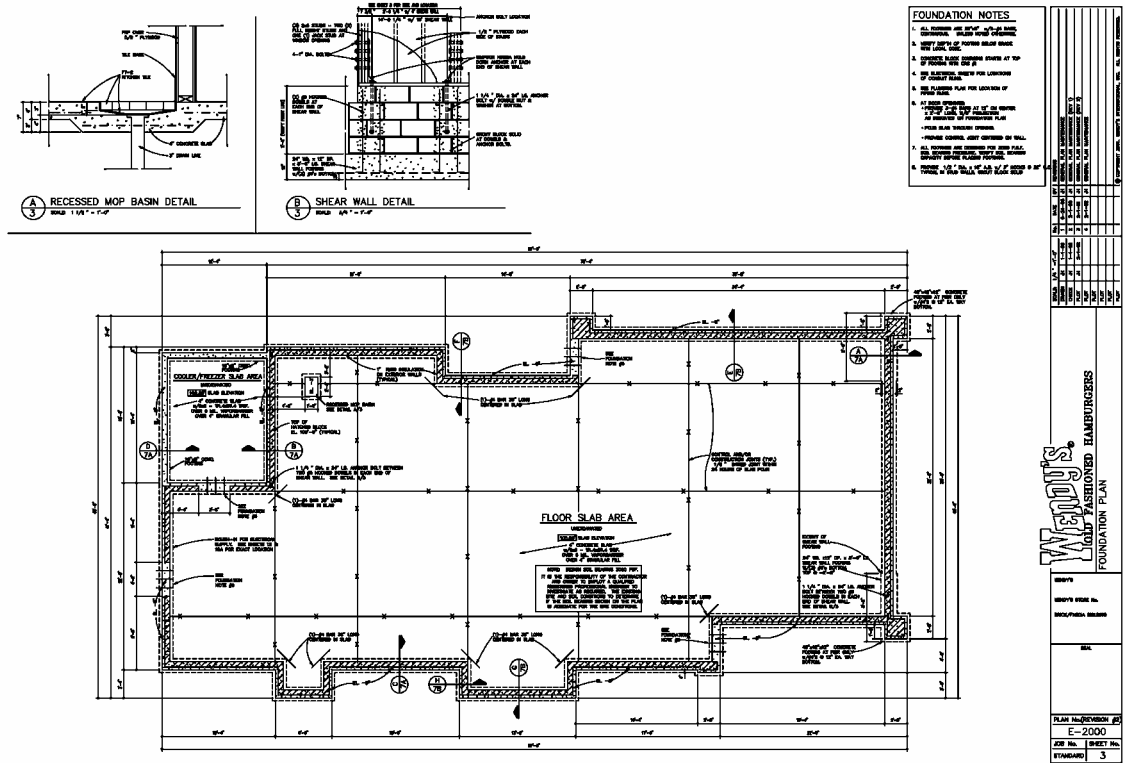


Figure C-1 Foundation Plan

C-1.2 Drawings Used for Takeoffs with Revit

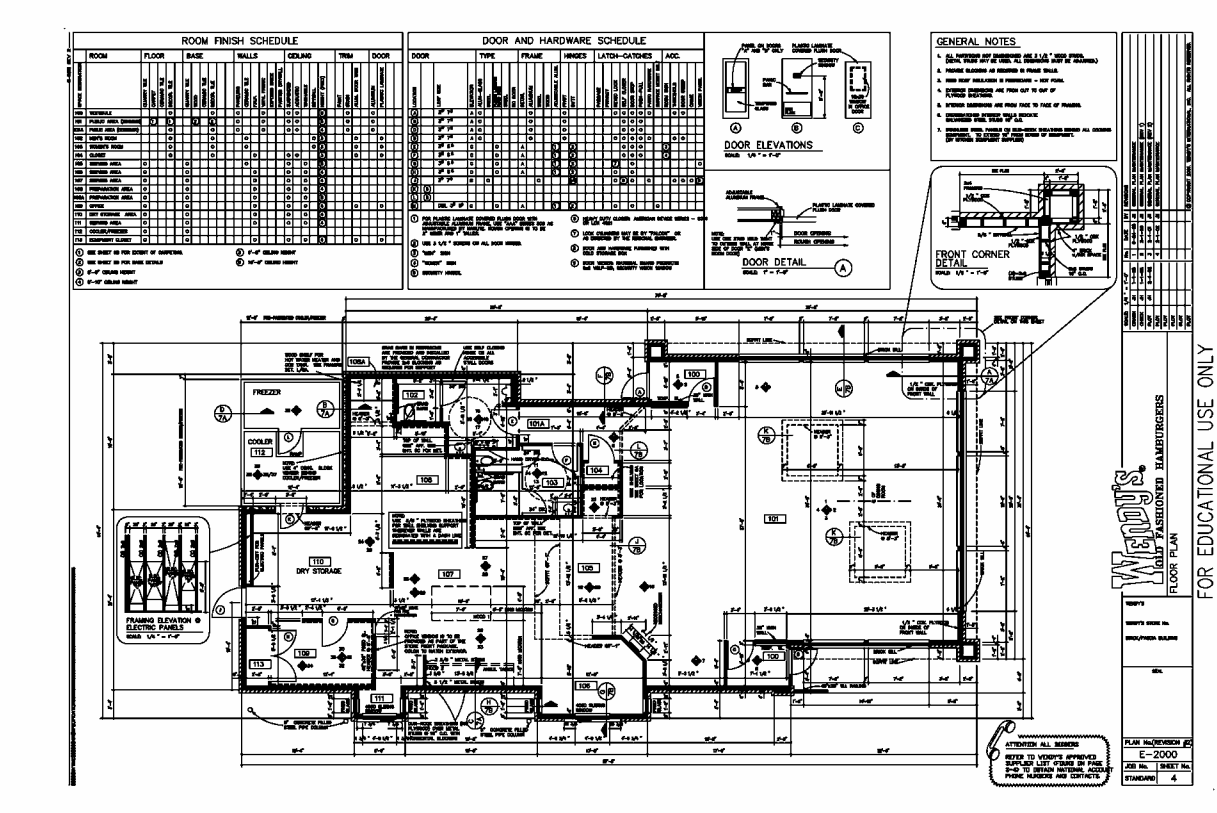


Figure C-2 Floor Plan

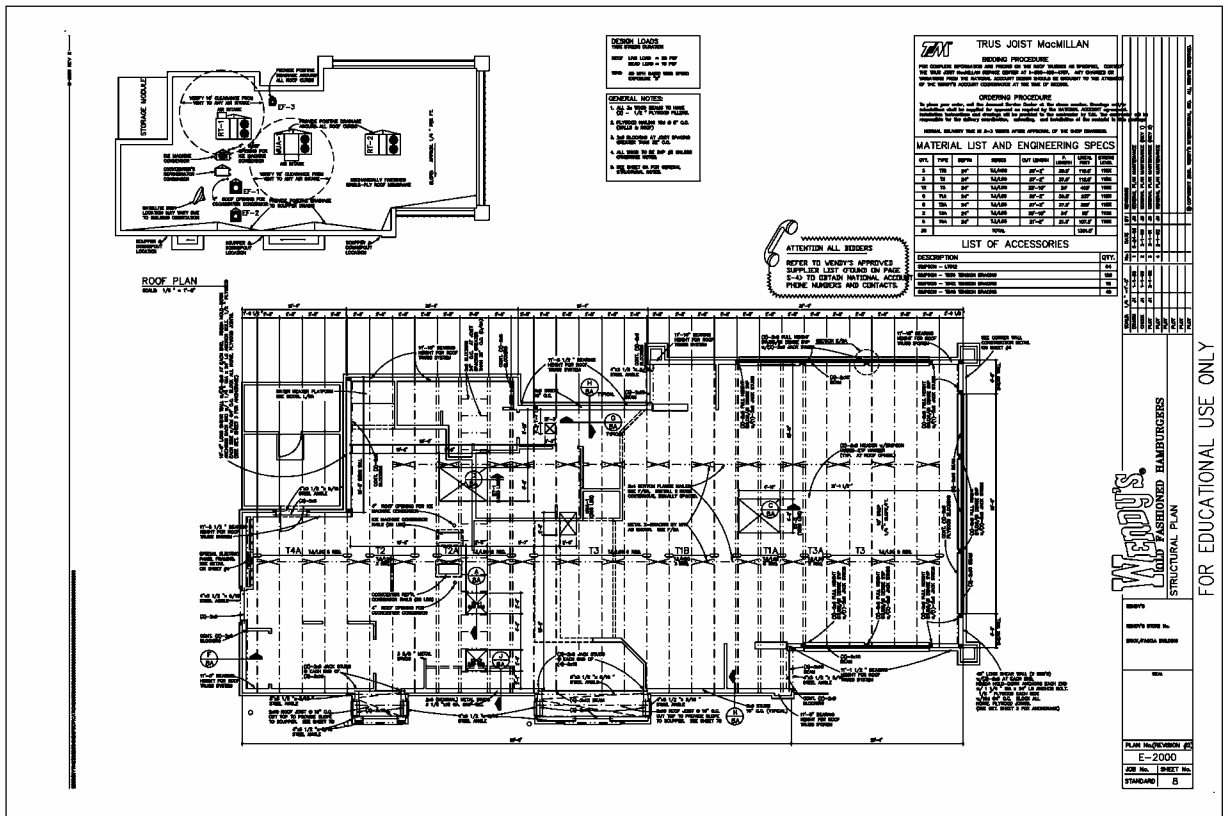
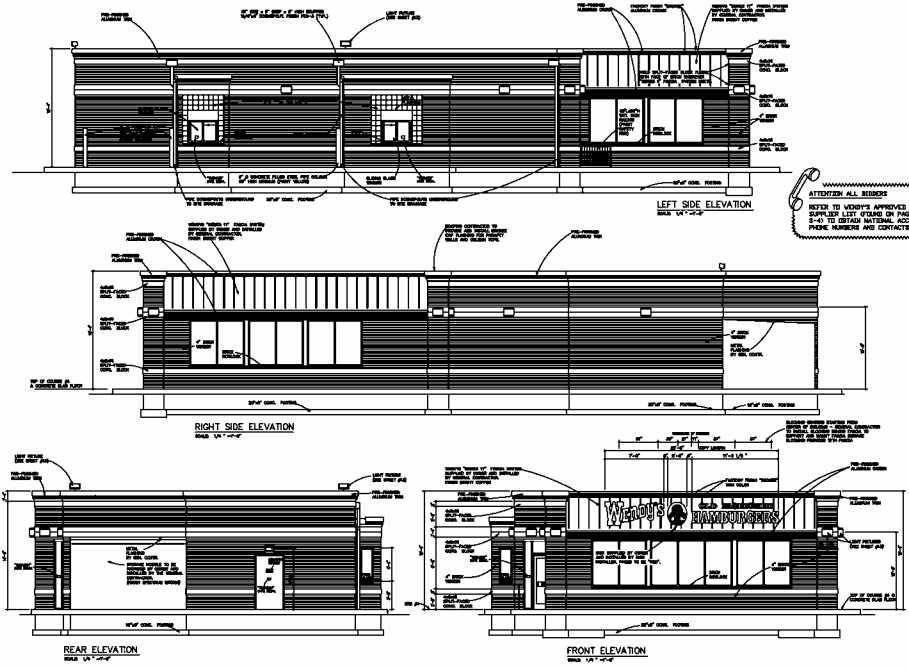


Figure C-3 Structural Framing Plan

C-1.4 Drawings Used for Takeoffs with Revit



FIELD FABRICATED HAMBURGERS 1575 W. UNIVERSITY BLVD. BRICK/SERIES 8 PASCO	
PLAN NO. 02-000000 E-2000 JOB NO. 1 SHEET NO. STANDARD 3	FOR EDUCATIONAL USE ONLY

Figure C-4 Exterior Elevations

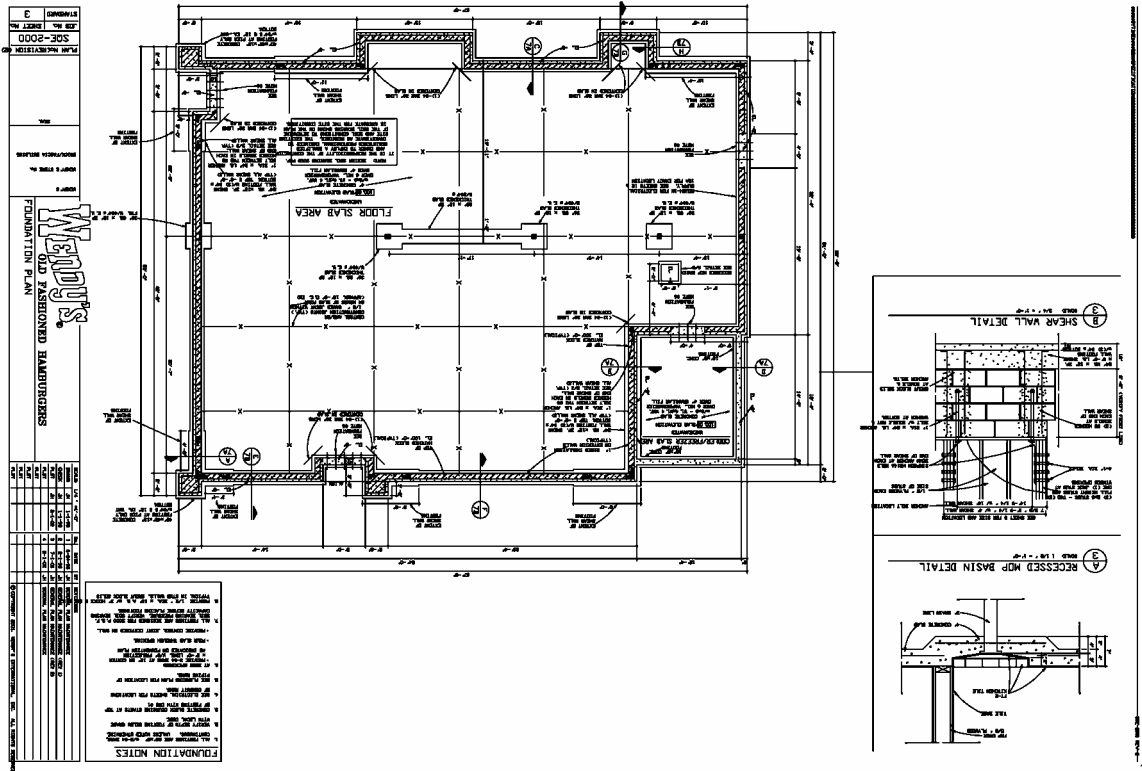


Figure C-5 Foundation Plan

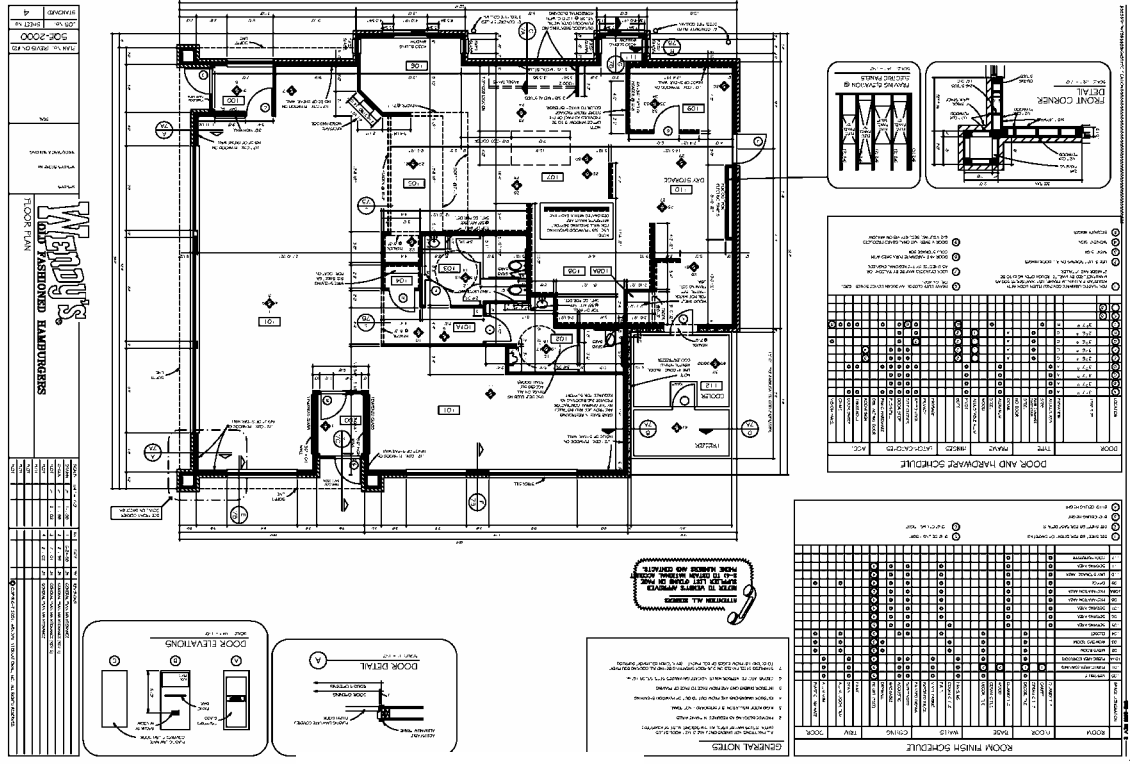


Figure C-6 Floor Plan

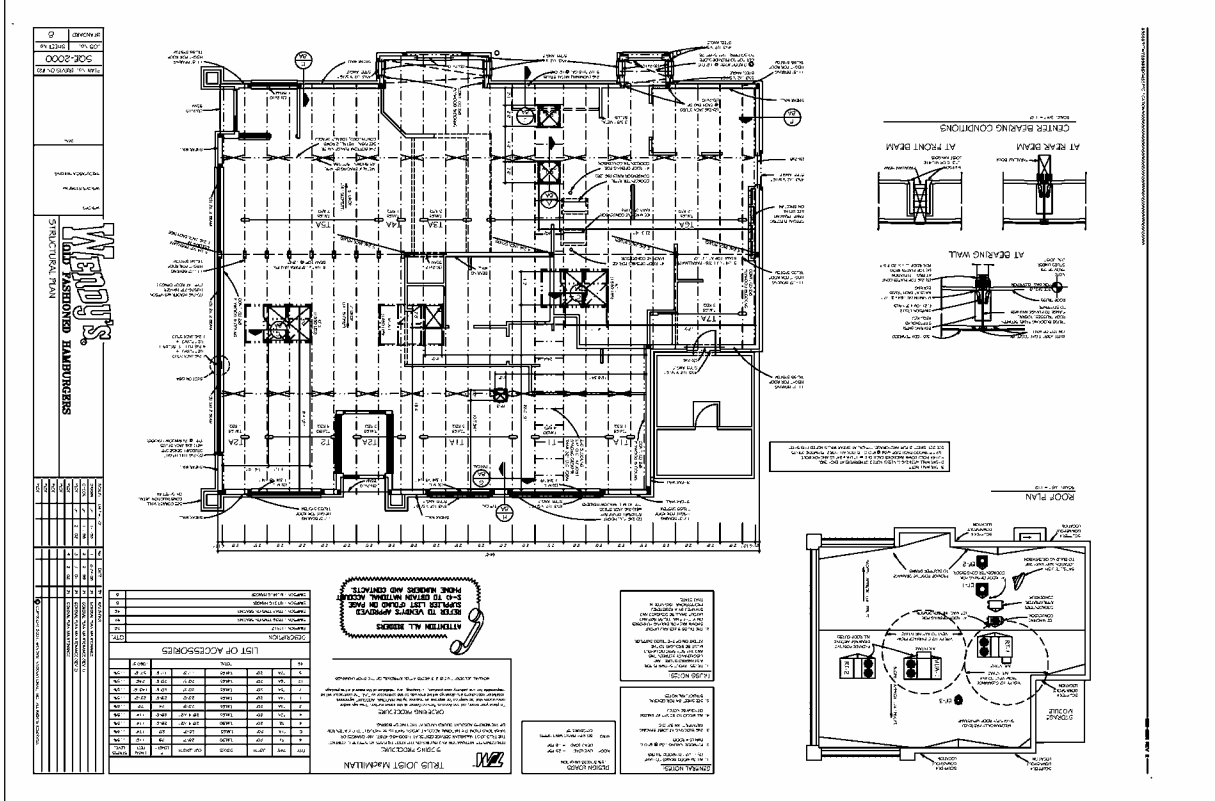


Figure C-7 Structural Framing Plan

C-2.4 Drawings Used for Takeoffs with OST

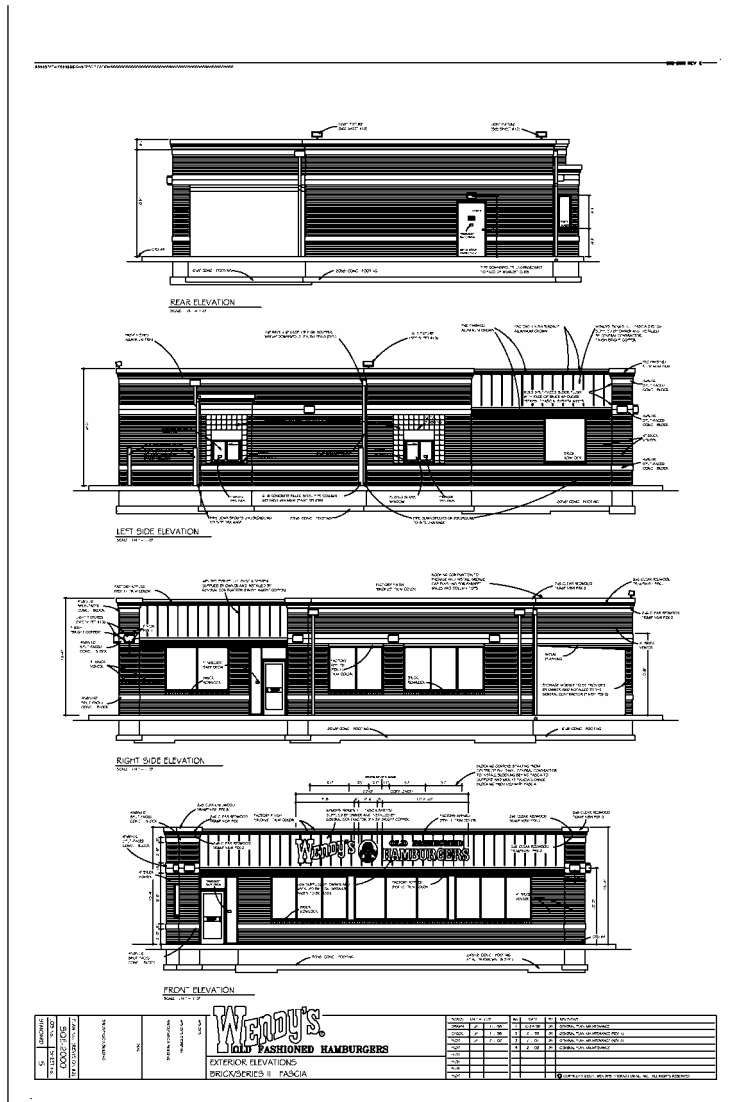


Figure C-8 Exterior Elevations

Appendix D. Study Forms

This appendix includes the principle study forms. These forms include a pre-survey, post-survey, worksheet for both Revit and On-Screen Takeoff, and instructions for the study in both Revit and On-Screen Takeoff.

D-1 Pre-Survey

Name _____

1. How many years/months of construction experience do you have?
2. Rate your skills at reading construction drawings
 - e. None
 - f. Beginner
 - g. Intermediate
 - h. Advanced
3. How many years/months of estimating experience do you have?
4. How many hours have you spent using On-Screen Takeoff?
5. How many hours have you spent using Revit

D-2 Study Post-Survey

Name _____

1. Quantity takeoff can be performed faster
 - a. On-Screen takeoff.
 - b. Revit
2. I feel accuracy is greater by using
 - a. On-Screen Takeoff
 - b. Revit
3. For future quantity takeoff I would use:
 - a. On-Screen Takeoff
 - b. Revit

Please explain why?

4. What Advantages or disadvantages did you find for each program
On-Screen Takeoff
Advantages:

Disadvantages:

Revit

Advantages:

Disadvantages

5. During the experiment did a specific event influence your answers to any of the above questions? Yes No
If yes, please explain.

D-3.1 Worksheet for OST

Onscreen Takeoff ASSIGNMENT: Click "Start" to begin

9:12:54 AM

1 What is the total area (SF) of SOG?

Include the storage modular slab, & Door openings

9:17:16 AM

2 What is the total volume (CY) of Concrete of the SOG?

DO NOT INCLUDE THICKEND SLAB Volume = area x thickness. 1 CY = 27CF

*You must input
answers and push
enter to continue.

9:21:38 AM

3 How many Cubic Yards (CY) of concrete are in the SPOT footings?

Make sure to use CY and Not CF. (27CF=1CY)

*You must input
answer and push
enter to continue.

9:32:52 AM

4 How many Cubic Yards (CY) of concrete are in the Continuous footings?

Make sure to use CY and Not CF. (27CF=1CY)

*You must input
answer and push
enter to continue.

9:41:06 AM

5 Area of flat roof (SF)?

Measure from the inside of wall. Don't include copper roof.

*You must input
answer and push
enter to continue.

9:47:55 AM

6 Number of Doors?

Count double doors as 1. Don't count toilet partitions. Don't count Freezer Module Doors

*You must input
answer and push
enter to continue.

9:51:55 AM

7 What is the Area of the exterior brick?

Exclude Window and Door Openings, Include Behind Freezer Module

*You must input
answer and push
enter to continue.

10:07:23 AM

Figure D-1 Worksheet for OST

D-3.2 Worksheet for Revit

Revit

ASSIGNMENT: Click "Start" to begin

Start

10:16:16 AM

1 What is the total area (SF) of SOG?

Include the storage modular slab, & Door openings

*You must input

Next

answers and push
enter to continue.

10:21:01 AM

2 What is the total volume (CY) of Concrete of the SOG?

Volume = area x thickness. 1 CY = 27CF

Next

*You must input
answers and push
enter to continue.

10:24:46 AM

3 How many Cubic Yards (CY) of concrete are in the SPOT footings?

Make sure to use CY and Not CF. (27CF=1CY)

*You must input

Next

answer and push
enter to continue.

10:28:37 AM

4 How many Cubic Yards (CY) of concrete are in the Continuous footings?

Make sure to use CY and Not CF. (27CF=1CY)

Next

*You must input
answer and push
enter to continue.

10:28:50 AM

5 Area of flat roof (SF)?

Measure from the inside of wall. Don't include copper roof.

Next

*You must input
answer and push
enter to continue.

10:32:08 AM

6 Number of Doors?

Count double doors as 1. Don't count toilet partitions. Don't count Freezer Module Doors

*You must input

Next

answer and push
enter to continue.

10:34:26 AM

7 What is the Area of the exterior brick?

Subtract out area of Copper Roof and Aluminum Trim, Exclude Window and Door Openings, Include Behind Freezer Module

Finish

*You must input
answer and push
enter to continue.

10:38:31 AM

Figure D-2 Worksheet for Revit

D-4 Instructions for using Revit for Takeoffs

Starting Revit

4. Navigate to the J:\groups\study1\001 Revit Wendys
5. COPY and Paste this Folder to your thumb drive or desktop.
6. Open the copied folder and double click on Revit File.rvt

Questions

1. Open the excel file saved in J:\groups\study1\”Your Name”\Revit\Q’s for Revit.xls
2. **DO NOT CHANGE YOUR ANSWERS AFTER YOU CLICK NEXT.**
3. For any questions raise your hand and the researcher will assist you.

The 5 steps for Takeoff with Revit

1. Visualize the Project
2. Modify the model to show what you’re taking off
3. Develop a schedule
4. Use show and comment to Isolate the items you’re taking off
5. Analyze the data

D-5 Instructions for On-Screen Takeoff

Starting On-Screen Software

1. Start the On-Screen Takeoff by pressing the START button.
2. Select CM Apps/On Center Software / On-Screen Takeoff 3.
3. DO NOT Start the Program any other way.
4. Click File, Click Open. Click Find. Click OK. Navigate to the J:\groups\study1\Your Name\OST\OST.mdb Click OK, OK.

Questions

1. Open the excel file saved in J:\groups\study1\Your Name\OST\Q's for onscreen.xls
2. Click Enable Macros
3. **DO NOT CHANGE YOUR ANSWERS AFTER YOU CLICK NEXT.**
4. For any questions raise your hand and the researcher will assist you.

Helpful Hints:

1. Make sure you have the correct **SCALE on EVERY** page you use.
2. Set up your conditions to do your calculations for you eg. area, volume.

Appendix E. Results Tables

This appendix contains the results tables for the study. These results tables include: the pre-survey results, worksheet results, and post-survey results.

Table E-1 Pre-Survey Results

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Years/Months Construction Experience	3yr	1.5	3 yr	2 yr	2 yr	5 yr	2 yr	6	1yr	2 yr	3 yr	10 yr	7 yr	2 yr	4	2	5
Const. Doc Reading Skills	Int	Int	Beg	Int	Int	Int	Beg	Int	Int	Adv	Int	Int	Adv	Int	Adv	Beg	Int
Months Estimating Experience	3	0	4	5	5	2	5	12	5	3	0	6	6	12	12	1	12
Hrs spent using OST	5	4	15	1	5	2	1	20	10	4	2	4	6	4	4	1	40
Hrs spent using Revit	720	100	80	40	25	20	12+	10	10	10	10	8	4	4	4	2	1

E-2 Takeoffs Results

Table E-2 Takeoffs Results

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	AVG	Control
#1 SF of Slab on Grade																			
Revit	3037	3037	3037	3037	3037	3037	2844	3037	3037	3037	2844	3037	3037	3037	3037	3037	3037		3037
Minutes Revit	3.54	2.71	6.17	2.47	4.45	4.20	4.75	3.01	1.86	4.04	2.92	10.54	10.06	2.86	5.80	9.37	2.87	4.80	
Accuracy	1.00	1.00	1.00	1.00	1.00	1.00	0.94	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00	0.99	
% Error	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	1%	
OST	2996	3010	2965	3010	3280	3040	2876	3193	2900	3018	3183	3056	3009	3160	2998	3092	3252		3020
Minutes OST	1.66	4.40	9.18	3.23	4.93	5.50	4.37	6.04	4.50	5.93	2.40	2.15	3.19	8.45	3.40	4.43	3.62	4.55	
Accuracy	0.99	1.00	0.98	1.00	1.09	1.01	0.95	1.06	0.96	1.00	1.05	1.01	1.00	1.05	0.99	1.02	1.08	1.01	
% Error	0.01	0.00	0.02	0.00	0.09	0.01	0.05	0.06	0.04	0.00	0.05	0.01	0.00	0.05	0.01	0.02	0.08	3%	
#2 CY of Slab on Grade																			
Revit	37	37.49	37.49	37.5	37	37.5	37	37.5	37.12	37.49	37.48	37	37.49	37.48	37.5	37	37		37.49
Minutes Revit	1.08	2.27	1.58	1.34	8.24	0.83	3.74	4.60	1.78	1.70	3.29	2.88	4.89	0.24	3.20	1.65	9.71	3.12	
Accuracy	0.99	1.00	1.00	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.99	0.99	
% Error	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	1%
OST	36.99	36.54	36.6	37.0	40.0	1013.0	36.0	39.0	35.5	37.0	39.0	37.7	37.0	39.0	37.0	38.0	40.0		37
Minutes OST	3.48	7.89	12.87	2.35	1.25	7.37	4.37	2.82	1.98	2.44	1.03	1.87	6.68	1.84	1.75	1.79	0.20	3.29	
Accuracy	1.00	0.99	0.99	1.00	1.08	27.38	0.97	1.05	0.96	1.00	1.05	1.02	1.00	1.05	1.00	1.03	1.08	2.57	
% Error	0.00	0.01	0.01	0.00	0.08	26.38	0.03	0.05	0.04	0.00	0.05	0.02	0.00	0.05	0.00	0.03	0.08	158%	
#3 CY Spot Footings																			
Revit	1	1.3	1.334	1.3	1.33	1.33	1	1.3	1.296	1.3	11.66	1	1.3	1.30	1.3	1.3	1.30		1.3
Minutes Revit	3.08	2.17	6.93	3.10	5.35	13.47	3.86	4.28	4.69	3.22	5.11	6.38	1.36	1.67	1.46	1.70	5.04	4.29	
Accuracy	0.77	1.00	1.03	1.00	1.02	1.02	0.77	1.00	1.00	1.00	8.97	0.77	1.00	1.00	1.00	1.00	1.00	1.43	
% Error	0.23	0.00	0.03	0.00	0.02	0.02	0.23	0.00	0.00	0.00	7.97	0.23	0.00	0.00	0.00	0.00	0.00	51%	
OST	2.20	1.2	1.556	4	0.074	1.2	1.18	2	1	1.63	1	1.89	2.15	1.33	1.5	2.05	1		1.63
Minutes OST	7.70	2.50	5.49	1.88	5.03	14.03	11.23	3.88	4.86	13.37	2.65	8.62	4.16	3.29	4.45	6.57	4.08	6.11	
Accuracy	1.35	0.74	0.95	2.45	0.05	0.74	0.72	1.23	0.61	1.00	0.61	1.16	1.32	0.82	0.92	1.26	0.61	0.97	
% Error	0.35	0.26	0.05	1.45	0.95	0.26	0.28	0.23	0.39	0.00	0.39	0.16	0.32	0.18	0.08	0.26	0.39	35%	
#4 CY Continuous Footings																			
Revit	12	11.76	11.76	11.75	11.74	11.81	13	24.3	11.76	11.76	28	12	11.75	11.74	11.75	11.755	11.755		11.76
Minutes Revit	0.26	0.24	5.70	0.96	1.91	5.50	0.21	4.2	2.63	2.08	3.53	0.14	0.68	0.35	0.61	11.61	0.25	2.18	
Accuracy	1.02	1.00	1.00	1.00	1.00	1.00	1.11	2.07	1.00	1.00	2.38	1.02	1.00	1.00	1.00	1.00	1.00	1.15	
% Error	0.02	0.00	0.00	0.00	0.00	0.00	0.11	1.07	0.00	0.00	1.38	0.02	0.00	0.00	0.00	0.00	0.00	15%	
OST	11.23	11.52	12.27	13.00	10.88	12.00	12.00	19.66	12.44	20.00	21.93	21.20	12.00	11.00	11.52	9.00		12.64	
Minutes OST	6.24	8.01	24.42	2.09	6.93	11.98	8.23	17.35	4.54	13.49	2.43	1.09	6.37	9.75	10.56	5.29	5.56	8.49	
Accuracy	0.89	0.91	0.97	1.03	0.86	0.95	0.95	1.56	0.98	1.58	1.73	1.68	0.95	0.87	0.91	0.71		1.09	
% Error	0.11	0.09	0.03	0.03	0.14	0.05	0.05	0.05	0.56	0.02	0.58	0.73	0.68	0.05	0.13	0.09	0.29	22%	
#5 SF Roof																			
Revit	2824	2823	2824	2823	2823	2781	3235	2823	2824	2823	2824	3235	2823	3235	2823	2823	3235		2821.8
Minutes Revit	4.06	2.25	4.69	2.02	1.62	2.10	3.29	1.77	1.28	1.47	1.75	1.73	0.84	0.95	0.87	2.07	1.49	2.01	
Accuracy	1.00	1.00	1.00	1.00	1.00	0.99	1.15	1.00	1.00	1.00	1.00	1.15	1.00	1.15	1.00	1.00	1.15	1.03	
% Error	0.00	0.00	0.00	0.00	0.00	0.01	0.15	0.00	0.00	0.00	0.00	0.15	0.00	0.15	0.00	0.00	0.15	4%	
OST	2839	763	2936	12155	3280	2925	3076	3142	11585	2884	2836	2882	3036	3278	2848	2931	3252		2882
Minutes OST	4.01	6.00	4.14	2.24	4.82	4.51	6.81	3.50	5.92	8.48	3.44	4.08	5.19	4.75	6.05	2.77	1.44	4.60	
Accuracy	0.99	0.26	1.02	4.22	1.14	1.01	1.07	1.09	4.02	1.00	0.98	1.00	1.05	1.14	0.99	1.02	1.13	1.36	
% Error	0.01	0.74	0.02	3.22	0.14	0.01	0.07	0.09	3.02	0.00	0.02	0.00	0.05	0.14	0.01	0.02	0.13	45%	
#6 Doors																			
Revit	11	10	11	11	10	11	11	10	11	10	11	11	11.00	11	11	9.00	11		10
Minutes Revit	0.66	4.21	5.44	6.74	5.05	0.89	2.31	2.31	1.80	6.18	0.54	1.70	0.79	0.79	0.71	3.44	0.67	2.60	
Accuracy	1.10	1.00	1.10	1.10	1.00	1.10	1.10	1.00	1.10	1.00	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.06	
% Error	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.00	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	8%	
OST	10.00	10	10	10	9	11	8	8	9	9	11	10	10	10	10	9	9		9
Minutes OST	6.37	4.44	6.03	3.25	2.71	3.72	4.02	5.04	4.14	5.66	2.47	2.58	3.33	3.39	2.72	1.79	3.44	3.83	
Accuracy	1.11	1.11	1.11	1.11	1.00	1.22	0.89	0.89	1.00	1.00	1.22	1.11	1.11	1.11	1.11	1.00	1.00	1.07	
% Error	0.11	0.11	0.11	0.11	0.00	0.22	0.11	0.11	0.00	0.00	0.22	0.11	0.11	0.11	0.11	0.00	0.00	9%	
#7 Area of Exterior Brick																			
Revit	3795	3795	3795	3383	4988	3498	1130	3795	3792	3795	3795	3795	3795	3795	3795	3795	3795		3936.3
Minutes Revit	5.93	2.23	8.32	13.32	8.08	7.92	4.09	2.58	6.12	6.13	6.38	3.24	1.01	2.58	1.19	2.67	2.14	4.94	
Accuracy	1.29	1.29	1.29	1.15	1.70	1.19	0.38	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.25	
% Error	0.29	0.29	0.29	0.15	0.70	0.19	0.62	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	32%	
OST	1724	2029	2194	10073	2635	7103	1629	3094	2109	2026	1800	2038	3039	1900	2607	1669	1960		2686
Minutes OST	12.21	8.13	23.48	4.60	10.28	19.50	15.47	8.26	5.18	29.82	6.91	9.87	15.11	9.48	16.33	6.47	8.41	12.32	
Accuracy	0.64	0.76	0.82	3.75	0.98	2.64	0.61	1.15	0.79	0.75	0.67	0.76	1.13	0.71	0.97	0.62	0.73	1.09	
% Error	0.36	0.24	0.18	2.75	0.02	1.64	0.39	0.15	0.21	0.25	0.33	0.24	0.13	0.29	0.03	0.38	0.27	46%	
Total Time																			
Revit	18.62	16.09	38.83	29.95	34.71	34.91	22.25	18.98	20.16	24.82	23.51	26.61	19.62	9.44	13.83	32.52	22.17	23.94	8.1
OST	41.66	41.37	85.62	19.62	35.95	66.61	54.49	46.88	31.12	79.19	21.34	30.26	38.04	40.95	45.25	29.12	26.76	43.19	18.9
Average % Error																			
Revit	9%	4%	6%	4%	11%	5%	18%	19%	6%	4%	140%	11%	6%	8%	6%	6%	8%	16%	
OST	14%	21%	6%	108%	20%	408%	14%	11%	61%	4%	23%	18%	19%	13%	5%	11%	18%	45%	

Table E-3 Post-Survey Results with Revit Experience

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Number of Screens	2	2	2	2	2	2	2	1		2	2	1	2		2	2	2
Which program did you start with?	Rvt	OST	OST	Rvt	Rvt	OST	OST	OST	OST	OST	OST		OST	OST	OST	Rvt	Rvt
Quantity Takeoff faster with?	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt
Accuracy greater by?	Rvt	Rvt	Rvt	Rvt	OST	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt
For Future Takeoffs You Would Prefer to Use?	Rvt	Rvt	Rvt	Rvt	OST	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt	OST	Rvt	Rvt	Rvt	Rvt	Rvt
Why	if drawn correctly the faster and more accurate. If project changes, get quantities easily without recalculating everything	Faster & easier, better accuracy	Only if plans are already in Rvt	don't have to think	more confidence	less operator error, dimensions already there and materials can be distinguished.	Faster & more accurate	Easier & faster	as long as can learn more	as long as the documents are accurate and well designed. Revit is faster and more accurate.	Because Revit defines every line drawn it is more accurate	Don't know Revit very well but would use it if you knew it	easier to use faster	easy	faster easier	faster	faster
OST Advantages		liked viewing plans	Easy	easy to find exactly what you are taking off eg. Brick	physically taking off each item	comfortable	easier than other programs other than Revit	You have to think the process through more		know the project more	You see exactly everything you are taking off	Already know it	visually more confidence	easier	tracks exactly, gain familiarity with project	know it better, search the plans more	tracks takeoffs well
OST Disadvantages	slow, no 3D view, Change scale	had to look multiple places to find answers	Plans can be difficult to read	slow	might be outdated soon	greater opportunity for mistakes	Takes Longer than Revit, Not as accurate	you have to locate each individual item	CHECK SCALE	Time Less accurate	you have to manually select everything	have to actually have to do a counts and takeoff	takeoffs take longer	slower, more room for error	slow	slow	tedious and time consuming
Revit Advantages	Automatic counting, recalculating is quick and easy	Fast	better feel for 3d scope	fast	quicker less pointing & clicking with the mouse.	all info already there	Fast easy to use	Revit finds the items	Does it all	faster more accurate	it is fast and easy	faster quantity takeoffs & double checking	faster	fast, accurate	really quick	can be very fast	very fast more accurate
Revit Disadvantages	Drawing has to be exact	colored plans hard to read	have not used it as much	have to be careful that correct items are calculated.	No confidence	learning curve		If items not labeled correctly	Have to check for architect errors	easier to mistake on bad drawings	your takeoff items might be labeled incorrectly	not very familiar with it.	more trust in computer	too many options harder to use.	no way to catch mistakes or learn drawings	Tempted not to search plans as thoroughly	big learning curve
Specific event influence your answers	Yes	no	no	no	no	yes	yes	no	no	yes	no	yes	no	no	no	no	no
If Yes Explain	Inability to see a plan in 3D hurts the ability to see a project conceptually					Confidence in Revit easy to select specific info was quick	Taking off the items in Revit			Have the time to use Revit		I am intrigued w Revit					

E-3.2 Post-Survey Results

Table E-4 Post-Survey Results No Prior Revit Experience

	2	1	2	2	2	1
Number of Screens						
Which program did you start with?	Rvt	OST	OST	OST	OST	Rvt
Quantity Takeoff faster with?	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt
Accuracy greater by?	Rvt	Rvt	Rvt	Rvt	Rvt	Rvt
For Future Takeoffs You Would Prefer to Use? Why	Rvt	Rvt	OST	Rvt	Rvt	Rvt
	faster	user friendly better view of plans	not familiar with Revit	info stored in Revit	isolating helps to see the project better, faster	much more user friendly
OST Advantages	search plans better		Highlights quantity takeoff	see exactly what you are calculating	accurate fast can't see whole picture	accurate fast
OST Disadvantages	no 3D views		Perhaps not as accurate with scale	slow	can't see whole picture	more complete
Revit Advantages	quick scope	better visualization	accuracy	fast easy to understand info	fast see whole picture, isolate easy	accuracy
Revit Disadvantages	checked only 3d plans, availability	learning curve	not familiar with Revit	trust computer, info and sources	learning curve, none relying on designer	none
Specific event influence your answers	yes	yes	yes	no	no	no
If Yes Explain	in Revit I thought foundation walls had brick.	visualize the building using 3D	unfamiliar			