BIM SOFTWARE EVALUATION MODEL FOR GENERAL CONTRACTORS

By

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To my family and friends, for all their support and guidance throughout this entire process

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Building Information Modeling (BIM) is the most recent trend in information technology in the construction industry. With different case studies showing that the proper implementation of BIM technology can add value to the project, reducing costs, schedule, and preventing errors; more and more companies are starting to implement BIM software as a tool in their project workflow. Although, some companies use an appropriate implementation process, other companies tend to just respond to the market trend and implement the software package that is more popular in the industry without looking at the real company needs or software features.

This study looked at the different BIM user expectations and available software features to develop a BIM Software Evaluation Model for General Contractors (BIMSEM-GC) which based on the company needs recommends the top five software packages that best fit those needs. The BIMSEM-GC should not be used alone when starting to implement BIM in any company, but it should be used as part of a structured implementation process, looking at all the changes in the company that an implementation of this kind will require.

The BIMSEM-GC looked at 11 BIM software developing companies to determine a list of 33 different software packages that can be used for the general contractor during the

preconstruction, construction and post construction phases of the project. To determine the user's needs and expectations regarding to BIM a study of the results from two major public surveys was used. Finally the combination of the available software features and the users needs and expectations were used to create the BIMSEM-GC questionnaire using a 5-point Likert scale. By taking into consideration the standard deviation and coefficient of variation at a 95% confidence level for the obtained results, the model is able to recommend the top 5 BIM software packages that best fit the company's needs.

In conclusion, the BIMSEM-GC also shows the degree of involvement that the company has in three different construction phases: preconstruction, construction and post construction, thus allowing the company to detect gaps from one phase to the other one when implementing BIM.

CHAPTER 1
INTRODUCTION

Construction companies are starting to implement Building Information Modeling (BIM) capabilities into their everyday tasks. In order to implement their BIM capabilities needs, companies are also facing a market full of options by the software vendors, promoting software packages that promised to fill all their needs and beyond. With this overwhelming market, most companies are starting to implement software packages that they are familiar with, without making a proper analysis to determine the best option for the company's needs. Jack Micklovich, director of software management consulting at Corporate Software, Norwood, Mass, mentioned in an article for ENR that companies are losing money because of uncoordinated software purchases and a lack of understanding of what they have and how they are using the programs (ref).

The goal of this study is to create a model to be used for general contractors to determine which BIM software package is the one that best fits their company's needs. The creation of the model allows companies to establish their real BIM needs, and serves as a negotiation tool when acquiring the software.

Statement of the Problem

General contractors are changing the way they do businesses. BIM is the new construction technology trend in United States, with an increase in the number of companies trying to implement it. Nowadays, contractors are using technology more than ever and especially BIM tools, based on the proven fact that a well implemented technology can increase productivity, improve quality, safety, reduce delays and reduce cost. Moreover, some of these companies may be contemplating making the decision to adopt a BIM software package based

on marketing campaigns by the software vendor instead of using a rational analysis of their company's needs.

Contractors are starting to realize the major advantages of using BIM and the importance of creating an accurate building information model for use in a virtual construction process. The ability to visualize the entire project and be able to use those parameters to produce value during its construction makes the contractors to look closely at the BIM capabilities and the prompt implementation of these tools into the company. Contractors expect to see the greatest increase in BIM usage in 2009. Thirty eight percent will be heavy users, up from 23% in 2008. Twelve percent expect light use of BIM, compared to 45% the previous year (McGraw Hill Construction 2008).

As the use of BIM becomes more prevalent, general contractors are being bombarded with different software packages and new companies are emerging almost every year, with new BIM solutions. The plethora of packages and lack of knowledge lead construction companies to making their buying decisions based on marketing campaigns or popularity, instead of the selection of the software that offers the best solution for the contractors needs. In some cases the company may not even be aware of the other solutions that the market is offering, making the contractor spend money on a software package that may not fill all the company's needs or overpaying for a software package that does more than the company is ever going to need.

In conclusion, it is important to note the fact that more contractors are starting to use BIM tools in their every day tasks. This usage establishes the need for an optimal implementation to take maximum advantage of BIM capabilities and to assure the buyers that the selected software will produce all that it promises. This research aims to create a model to be used as part of that

implementation strategy, allowing the contractor to have a better understanding of their needs when acquiring BIM software.

Research Objectives

The objective of this study is to analyze the needs of general contractors in the industry when using BIM, and to create an evaluation model to determine the most useful software to implement according to the company's needs. In addition, two BIM evaluation tools were also developed, one from the user point of view and the other based on the software features available from the different software vendors.

Scope and Limitations

The study produced an evaluation model for different BIM software, looking at the different needs of general contractors. The scope of those needs was determined by trying to answer the following questions:

- What are the general requirements for a general contractor when buying any computer software?
- What are the necessary features for a general contractor during the preconstruction phase?
- What are the necessary features for a general contractor during the construction phase?
- What are the necessary features for a general contractor during the post construction phase?
- What is the optimal evaluation technique when determine the best software for a company?

This study took the most common needs and available features required by general contractors and provided by software vendors, and put those needs into evaluation criteria to allow any company to measure the best option when buying BIM software.

Finally, the evaluation model looked at the company's needs and according to their ranking in importance recommended five different software packages that fill those needs The

needs analyzed and taken into consideration covered the involvement of the company in the different areas of preconstruction, construction, and post construction.

This study was conducted as an academic exercise to create a starting point for companies looking to implement BIM software. The model did not determine the best software in the market, but the software that best fits a specific company needs. The created model is not fixed and it should be adapted to every company's reality or variation.

The model is also only useful for a short period of time, due to the frequent improvements and new capabilities that the software vendors offer. Therefore, the model should be updated after a certain period of time. The evaluation model was developed considering that general contractors will have to convert the design into a 3D model. Although more and more design firms are designing using 3D design software, in the future there would be no conversion from 2D to 3D and the contractor's ability to start using the model is immediate and much less expensive than with this consideration.

CHAPTER 2
LITERATURE REVIEW

This literature review is divided into four sections. Each section addresses one of the following characteristics: BIM history, developers of the most used BIM software, the actual needs and expectations of BIM users and the different techniques for the general software evaluation and weighted criteria regarding BIM.

The first section starts with a brief definition of the BIM concept for the purposes of this thesis and continues with a summary of the evolution of object-based parametric modeling along the years to what is actually known as BIM. The second section develops a review of the most used BIM software developers in the market, determining the level of BIM involvement of the BIM developer. The third section of this literature review explores the different needs and expectations of BIM users, separating these needs into the different project phases: preconstruction, construction and post construction. This section also covers the importance and most used applications specifically for contractors trying to identify what the minimum BIM software features would be for a contractor trying to implement this technology in their everyday workflow.

Finally, the last section of this literature review covers research about the different weighted and evaluation models used to evaluate software packages and BIM, looking at the Interactive BIM Maturity Model as a reference to create the BIM Software Evaluation Model for General Contractors (BIMSEM-GC).

BIM History

Since the beginning of history, mankind has been interested in building construction; from the Egyptians to the modern civilizations they all looked into ways to improve the processes of construction. One of the methods that proved to be very efficient was to develop a

model of the new building to be constructed. In construction the master builder would create a mockup of the building or what is called in other industries a prototype. Although, this process was very popular for the manufacturing and other industries, it was not so feasible to develop something like that in the construction industry. This is basically because the buildings are built only once, therefore, there is no room to create a prototype. Sometimes the mockup was only a visual representation, a 3D model of the building in real life with the objective to sell the idea of the building and never to be used as part of the construction management workflow.

Looking at the advances of other industries using digital tools the construction industry started to look for ways to develop their own solutions and answers to the question of how to create a prototype of a building that needs to be build only one time? A response that seems to be very obvious nowadays is to create a virtual project, but this answer involves more than just the ability to draw the project in 2D or 3D, it also involves looking for ways to assign properties to every line and every part of the project. Properties and elements that represent the reality of that particular project, allow all the parties involved in the project to feed the model and finally have an accurate virtual project. This desire has evolved into what is now know as part of the Building Information Model (BIM) technology, where the designers are no longer just making drawings, but making models of the building, models with assigned properties that can be use to virtually build the project.

The introduction of the BIM capabilities into the construction industry has opened a window for designers, contractors, and owners to start looking at those desires again. Nowadays it is possible to simulate the construction of the building at a certain level of detail, reducing risk and creating better perspectives for the management of the construction.

BIM has its beginnings in research conducted decades ago in the field of computer aided design. Moreover, there is no widely accepted definition for the term. For the purposes of this thesis BIM was defined as the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data rich object oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the progress of delivering the facility (AGC, The Contractors Guide to BIM 2007).

BIM or object based parametric modeling (previous name) was originally developed in the 1980s. During the previous years, in 1973, efforts made by three groups, Ian Braid at Cambridge University, Bruce Baumgart at Stanford, and Ari Requicha and Herb Voelcker at the University of Rochester (Eastman 1999); produced two forms of solid modeling, the boundary representation approach (B-rep) and the constructive Solid Geometry (CSG) that latter on merged into one approach (See Figures 2-1 and 2-2). This first generation of tools supported 3D facetted and cylindrical object modeling with associated attributes, which allowed objects to compose into engineering assemblies, such as engines, process plants, or buildings (Eastman 1975, Requicha 1980). This merged approach to modeling was an important precursor to modern parametric modeling (Eastman et al. 2008).

Building modeling based on 3D solid modeling was first developed in the late 1970s and early 1980s. CAD systems, such as RUCAPS, TriCad, Calma, GDS (Day 2002), and University research based systems at Carnegie-Mellon University and University of Michigan developed their basic capabilities (Eastman et al. 2008). These solid modeling CAD systems were functionally powerful but often overwhelmed the available computing power. This is why the

construction industry decided to adopt architectural drawing software packages, such as AutoCAD, and Microstation that augmented the then current methods of working and supported the digital generation of conventional 2D construction documents (Eastman et al. 2008).

Object Based Parametric Modeling: The current generation of BIM architectural design tools grew out of the object based parametric modeling capabilities developed for mechanical systems design. These concepts emerged as an extension of CSG and B-rep technologies, a mixture of university research and intense industrial development, particularly by Parametric Technologies Corporation (PTC) in the 1980s. The basic idea is that shape instances and other properties can be defined and controlled according to a hierarchy of parameters at the assembly and subassembly levels, as well as an individual object level. Some of the parameters depend on user defined values. Others depend on fixed values, and still others are taken from or relative to other shapes. The shapes can be 2D or 3D (Eastman et al. 2008).

The difference in parametric design is that the designer defines a model family or element class, which is a set of relations and rules to control the parameters by which elements instances can be generated and each vary according to their context, while the typical design approach is to design an instance of a building element like a wall or door. The parameters used can be distances, angles, and a different set of rules like parallel to, or distance from. These relations allow the creation of rich data models than can be used later on the next phases of design, construction and/or operation of the project.

BIM Software Developers

Several CAD systems available today, do not offer BIM capabilities, using the old B-rep and CSG drawing standards instead of the object based parametric modeling. Nowadays more companies are emerging with new solutions incorporating BIM tools as part of their software,

and also opening the market for a new type of consultant company, providing BIM solutions as a third party developer with add on applications for the tool.

Four sources of information were looked at as part of this section for the literature review, trying to identify the major software developers for the construction industry: BIM Wiki (BIM Wiki 2009), BIM Handbook (Eastman et al. 2008), AGC BIM Guide (AGC of America 2007), and a survey by AECbytes (Khemlani 2007). Eleven software developers were identified as shown in Table 2-1.

While some of the potential value of a contractor's knowledge contribution is lost if the contractor is not consulted until after the design phase is completed, significant benefits to the contractor and the project team can still be realized by using a building model to support a variety of construction work processes (Eastman et al. 2008). There are many software packages in the market that address one or various necessities for a contractor to fill by using BIM. The following list mentioned the most popular software developers and their main focus in the construction industry.

Autodesk

Autodesk is an American multinational corporation that focuses on 2D and 3D design software for use in architecture, engineering and building construction, manufacturing, and media and entertainment. It was founded in 1982 and it became popular due to its software AutoCAD that was and is still wildly used in the construction industry.

Nowadays, Autodesk has developed a broad portfolio of digital solutions to help users visualize, simulate and analyze real world performance. The most known software packages from Autodesk using BIM in the building construction sector are:

- Autodesk 3ds Max Design
- Autodesk Design Review
- Autodesk Navisworks
- Revit Architecture
- Revit Structure
- Revit MEP

These software packages offer different types of features that go from drafting and modeling capabilities of blending different types of models and to developing clash detection analysis allowing for a better understanding of the building before it is built.

Bentley Systems

Bentley Systems is another important software developer in the market, providing solutions for the building, plant, civil and geospatial vertical markets in the area of architecture, engineering, construction (AEC) and operations. The company was founded in 1984 and its most popular software solution for the building construction is Microstation which is an important competitor for AutoCAD. Nowadays the company's solutions are evolving through BIM and the company just released a new line of packages that are object based parametric. The most used software packages for the building construction include:

- Bentley Architecture V8i
- Bentley Structural V8i
- Bentley Building Electrical Systems V8i
- Bentley Building Mechanical System V8i
- ProjectWise Navigator (Incorporated Project 4D from CommonPoint)
- ConstructSim (Previously part of CommonPoint)

The company is still offering their Microstation software, but is trying to moving forward with the market trends implementing BIM tools into their solutions. The previously listed software packages offer tools from drawing and modeling capacity to design rules reviews and bidirectional capabilities with power and lighting analysis software. The new addition to the

Bentley team of Common Point allows them to offer 5D solutions as part of their portfolio and they are making changes into ConstructSim to upgrade its capabilities.

Nemetschek AG

Nemetschek AG has been developing CAD software for the architecture, engineering, and construction; entertainment; landscape design; and manufacturing fields since 1985 and in the past years the company started to implement BIM technology into their software. The Vectorworks product line is one of their top solutions. Although it is a great drawing and modeling tool, it is not the top company's BIM solution.

Graphisoft was recently bought by Nemetschek and became the company's best BIM solution. Graphisoft is based in Hungary and they claim that they were the first software in the market that implemented BIM technologies. Nowadays the company only offers one main software: Archicad 12, offering upgrades for different solutions like MEP Archicad allowing making clash detection analysis within the models.

Innovaya

Innovaya is one of the new companies that emerged during the BIM boom. The company focuses its solutions on the BIM environment and specifically to the building construction. It also looks at interoperability issues between the Autodesk solutions and other construction management software like Timberline, Primavera or MS Project. The list of software solutions that Innovaya offers are:

- Innovaya Visual BIM
- Innovaya Visual Quantity Take off
- Innovaya Visual Estimating
- Innovaya Design Estimating
- Innovaya Visual Simulation

Synchro Ltd.

Synchro is another company that has emerged during this BIM revolution in the latest years. Synchro focus its solutions to the project management area and specifically to project schedule, linking the geometry of the project to more than 15 scheduling software allowing the simulation of the project as well as resource management. Their basic software is called Synchro Project Construction and the company also offers add on applications with their Synchro professional, Synchro Express, Synchro Server, and Synchro Workgroup.

VICO Software

VICO Software is another new company in the CAD Design world, but in this case VICO was formed through the acquisition of assests from Graphisoft company. They are basically the previous solutions from Graphisoft that now work as an independent company. The company offers a very complete set of programs that linked the design of the project with the construction phase offering programs that allow to create the model from scratch and simulate construction process inputting cost, creating earn value analysis and “what if” scenarios. Their line of solutions included:

- Vico Constructor
- Vico Estimator
- Vico Control
- Vico 5D Presenter
- Vico Cost Explorer
- Vico Change Manager

Gehry Technologies

Gehry Technologies (GT) provides technology and services to owners, developers, architects, engineers, general contractors, fabricators, and other building industry professionals. It was founded in 2002 and since then it has provided BIM solutions. Its main software is the Digital Project Software that as its basic level allows to design and view 2D

and 3D models, but it counts with a number of add on creating Primavera Integration, MEP Systems Routing, Photo Studio, etc.

Tekla Corporation

Tekla Corporation was established in 1966 in Espoo, Findland. It started as a structural design software company but it adapts its solutions to the BIM environment. Nowadays Tekla offers a division of Building and Construction where it looks at the model based design of steel and concrete structures as well as the management of fabrication and construction. Tekla building and construction mainly serves these customer segments:

- Tekla Structures, Full Detailing
- Tekla Structures, Construction Management
- Tekla Structures, Steel detailing
- Tekla Structures, Precast Concrete Detailing
- Tekla Structures, Reinforced Concrete Detailing
- Tekla Structures, Engineering

Onuma

Onuma has been servicing the Architectural community since 1972 and it started offering services through the world wide web in 1995. Nowadays it offers the Onuma Planning System (OPS), an internet server model, where the various users are able to interact during the creation and construction of the model. A unique characteristic of the Onuma solution is that it allows different users to keep using their favorite software and put the models together in the OPS application. The OPS by itself is more a design tool than a construction used tool, but the capacity to bring models and update these models in real time allows the user to implement the OPS during the entire process of the project, including operations and maintenance.

Solibri

Solibri was founded in 1999 to develop and market solutions that improve the quality of BIM and making the design process more effective. With this in mind they offer the following software packages:

- Solibri Model Chacker
- Solibri Issue Locator
- Solibri Model Viewer
- Solibri IFC Optimizer

With the goal of optimizing BIM processes the different Solibri solutions allow the user to analyze the models for integrity, quality and physical security. It also allows the checking for clash detections and code verification, with a function locating the error on the original model. Solibri also allows the user to see models from any IFC standard and to combine them as one model using an IFC optimizer eliminating any redundant information.

Project Blueprint Ltd.

Project Blueprint is a company based in Australia that provides construction consultancy and software development services. Their most popular software package is called Zero Defects and it represents an Internet accessible database and tracking tool for reviewing a project.

General Contractors Needs and Expectations

Contractors are starting to recognize the benefits of BIM technology in their projects. BIM allows for a smoother and better planned construction process that saves time and money and reduces the potential for errors and conflicts (Eastman et al. 2008). More important, to obtain the most possible benefits from the used of this technology, contractors must seek for an early involvement in the project and push their subcontractors and all the parties involved in the project to maximize the use of the tool.

An early involvement from the contractor into the project will allow for a smoother transition of the information and reduce the wasted information value from one phase to the other. While some of the potential value of a contractor's knowledge is lost after the design phase is complete, significant benefits to the contractor and the project team can still be realized by using a building model to support a variety of construction work processes (Eastman et al. 2008).

Another consideration when applying BIM technology in the construction process is to determine the level of detail of the information in model in order to determine the different usages for the model. A contractor looking to utilize the model for scheduling will not need a very detail model comparing to the one that a contractor will require to develop the estimate for the same project.

Looking into the direct benefits of BIM technology for contractors there is a list of applications that apply to most of them. Contractors are using different BIM applications as part as their workflow: clash detection, quantity take off and cost estimating, construction analysis and management, integration with cost and schedule control and other management functions, offsite fabrication, and verification guidance, and tracking of construction activities (Eastman et al. 2008). Gilligan and Kunz (2007) identified in their survey typical uses of BIM and Virtual Design and Construction (VDC): 3D Clash detection, present architectural design, space utilization, 4D clash detection, engage neighbors, present 4D schedule, cost estimation, enhance submittals process, structural analysis, safety analysis, enhance shop drawing process, energy analysis, drive shop fabrication equipment and others. AECbytes in a special report (2007) showed that the most important criteria when looking at BIM software were: 1) Full support for producing construction documents so that no other applications will be needed;. 2) Smart

objects, which maintain associativity, connectivity, and relationships with other objects; 3) Availability of object libraries; 4) Ability to support distributed work processes, with multiple team members working on the same project; and 5) Quality of help and supporting documentation, tutorials and other learning results.

Overall, there is a general set of expectations and needs from BIM users in the construction industry, and software developers are looking at those expectations to come up with new solutions with add on capabilities to their software packages or completely new versions of the software.

Software Evaluation and Weighted Criteria

By definition, to evaluate is to assign value to something, or to judge something. We can improve this definition by considering why we evaluate; essentially we evaluate in order to decide, that is to choose between different possibilities (Carney and Wallnau 1998).

Evaluating and selecting software packages that meet the company's needs is not an easy process. A number of different criteria should be considered to make sure that all the company's needs are being fulfilled at the time to recommend the software. Little research has been done about evaluation methodology when selecting BIM software. The National Building Information Modeling Standard (NBIS) committee published in 2007 the Interactive Capability Maturity Model (I-CMM), but this was with the intent to provide a baseline for the minimum standard criteria for a design to be considered a true BIM. Some software companies also offer evaluation check lists that instead of being an evaluation of the market features are more like a bullet point description of their software biasing the final result to selecting their software. Additionally, magazines showed evaluation articles of specific software packages where the evaluations sometimes were the authors' criteria instead of representing a comparison of a set of general criteria with the needs of a specific company.

Due to very little information being available about software evaluation models, evaluation methodologies for general software, and evaluation criteria to buy educational software packages were used as a baseline to generate the BIM Software Evaluation Model for General Contractors (BIMSEM-GC). Northwest Educational Technology (NETC) published in an article called *Seven Steps for Responsible Software Selection* (1995). In this article NETC mentioned that a software selection should be the result of a process where an analysis of the needs and goals of the final user should be considered as well as specific requirements. The next steps should be to identify promising software, find reviews, try previews about the software and then make the recommendations.

The previous methodology applied to the objectives of this study except for the part that the BIMSEM-GC assumed that the user has no knowledge about any software in the market and only knows what the company needs are. The methodology is not intended as rigid structure that must be followed without any deviation, it is intended as guideline and an aid that can be adapted according to the requirements of the individual organization (Patel and Hlupic 2002). This is why the BIMSEM-GC should be able to interact with the individual organization, allowing the organization to define the interest in certain areas of the BIM technologies.

Carney and Wallnau (1998) state in their research to create a basis for evaluation of commercial software that seem to be three steeps that precede the actual selection and that make it possible: 1) Identifiable alternative courses of action are identified. 2) Criteria are defined for assigning a measure of merit and 3) Measure of merit is assigned to selected alternatives. This approach seemed to fit more the requirements of a possible BIM software evaluation model, where the first step would be to identify the possible software packages in the market, then

define the evaluation criteria and finally assign merit to those criteria, recommending the software packages that fit company's criteria the most.

Jadhav and Sonar (2009) proposed in their study a generic stage based methodology for selection of any software package which consist of following seven stages:

- Determine the need for purchasing the system and preliminary investigation of the availability of packaged software that might be a suitable candidate, including high level investigation of software features and capabilities provided by vendor.
- Short listing of candidate packages
- Eliminating most candidate package that do not have required feature or do not work with the existing hardware, operating system and database management software or network.
- Using an evaluation technique to evaluate remaining packages and obtain a score or overall ranking of them.
- Doing further scrutiny by obtaining trial copy of top software packages and conducting an empirical evaluation. Pilot testing the tool in an appropriate environment.
- Negotiating a contract specifying software price, number of licenses, payment schedule, functional specification, repair and maintenance responsibilities, time table for delivery, and options to terminate any agreement.
- Purchasing and implementing most appropriate software package.

Although the Jadhav and Sonar (2009) methodology covered more steps than the intended for this research it is also a great baseline to consider when creating the BIMSEM-GC. For the three steps this study assumed that the general contractor does not count with the time or does not have the knowledge to define which may be the list of software candidates, therefore the model should be able to perform this tasks for them. For the fourth step of the Jadhav and Sonar (2009) methodology, the model should be able to compare the company's needs with the software features, ranking them accordingly. The next fifth, sixth and seventh steps are not part of this research, but are valuable recommendations for any BIM implementation process by a general contractor.

With a possible methodology from the literature, the next step was to look at the best way to evaluate the software packages. For this purpose the I-CMM weighted criteria was taken as a baseline, where the different BIM levels were considered and are weighted by the designer according to the characteristic of the project, giving a final score that is compared with the minimum BIM score. Similarly weighted criteria was used for the BIMSEM-GC where the general contractor will rank the importance of certain criteria to finally compare the score with the different software packages score and recommend the top solutions.

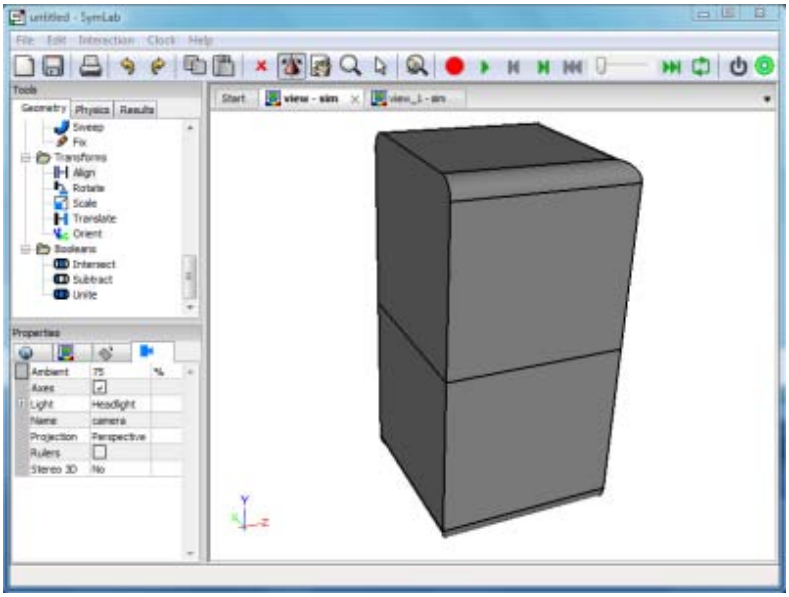


Figure 2-1. B-Rep Approach

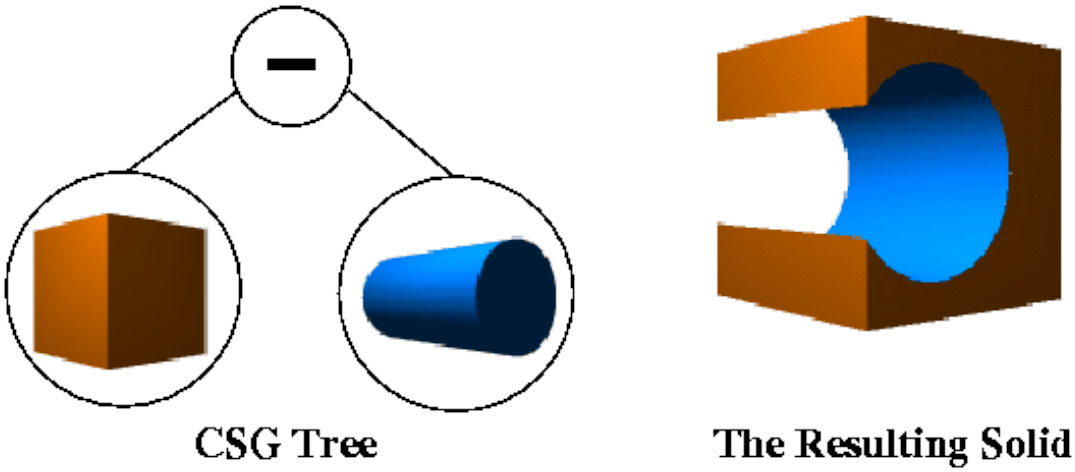


Figure 2-2. CSG Approach (Source: OpenGL 1996)

Table 2- 1. Major BIM Software Developers

Major BIM software developers	
BIM handbook	AGC BIM guide
Autodesk	Autodesk
Bentley Systems	Bentley Systems
Graphisoft (Bought by Nemetschek AG)	Graphisoft (Bought by Nemetschek AG)
Common Point Inc (Bought by Bentley Systems)	Nemetschek VectorWorks
Innovaya	
Synchro ltd.	
VICO Software	
AECbytes survey	BIM wiki
Autodesk	Autodesk
Bentley Systems	Bentley Systems
Graphisoft (Bought by Nemetschek AG)	Graphisoft (Bought by Nemetschek AG)
Gehry Technologies	Nemetschek SCIA
Tekla Corporation	Onuma
Nemetschek	Solibri
	Tekla Corporation
	Project Blueprint ltd
	VICO Software
	Gehry Technologies

CHAPTER 3
METHODOLOGY

This study looked at the creation of an evaluation model to be used by general contractors as part of their implementation BIM process. To create the evaluation model 11 different software developers and 33 software packages were used to recognize all the market offerings and the results from two public surveys were used to recognize the user needs and expectations from BIM.

The results from the analysis of the offer and demand regarding to BIM were summarized for the different phases of the project were the general contractor may be involved: preconstruction, construction and post construction. From this summary a questionnaire was created to be answered by the general contractor using the model as part of the evaluation model, trying to identify the company's needs and involvement at the time of implementing certain software. Followed is a detail explanation of the followed methodology to come up with the BIM Evaluation Model (See Figure 3-1).

- The first phase was to conduct a literature review about the history and evolution of BIM, starting by setting the BIM concept to be used during the elaboration of this thesis. The AGC definition was the most appropriate, filling the essence of the concept and trying to explain what BIM is? from the contractors' point of view. The analysis of the history of BIM covered its beginnings as a parametric object oriented technology and some of the obstacles that the people pushing this technology suffer from during its development. The next step of the literature review was to identify the major BIM software developers in the US market, were four different sources of information were looked at, including books, surveys, web pages, and associations reports regarding to BIM. From these four sources of information 11 software developers were identified and a detailed description of the company was developed during the literature review. Next in the literature review, two major public surveys results were analyze to identify the general contractor's needs and expectations regarding to BIM. Finally as part of the literature review, a research about the different methods to evaluate different software packages was done by looking at journal papers and published books about the topic.

- The second phase was to create both check lists: one for the available features from the different BIM software packages in the market that can be used by the general contractor and the other check list where the user needs were identified. To develop the first list, 33

software packages were analyze from the 11 companies identified in the literature review phase.

- During the selection of the programs to be analyzed the main criteria was to look at software packages that could be used by the general contractor during the preconstruction, construction and post construction phase. On the other hand, to create the user expectations check list, the two surveys analyzed during the literature review phase were summarized to identify the main expectations and needs when using BIM.

- The next phase after the creation of both check lists was to create the evaluation model. The evaluation criteria were developed taking into consideration items from both check lists and looking at the contractor needs during the preconstruction, construction, post construction and general consideration when buying any software package. A 5-point Likert scale was selected to rank the importance of the different questions that the model asked to the contractor giving a final score for every area of the project. After the questionnaire and the Likert scale were applied, the next step of this phase was to rank the 33 software packages with the questioner and the developed knowledge. This ranking was used after the programming step to compare and recommend the top five software packages that fit the best the company's needs. For the comparison and recommendation of the top five software a measure of dispersion and variation between the answers from the company and the different company's needs was used. The answers were compared by calculating the standard deviation and the coefficient of variation at 95% confidence for all the 33 software packages and the company's needs. Visual Basic due its the automated link with Microsoft Excel was used to write the program that generates the calculations automatically once the user of the model has input all their evaluation criteria.

- The last phase was to analyze the different possible results from the model at the time of its implementation giving future directions, recommendations and conclusions.

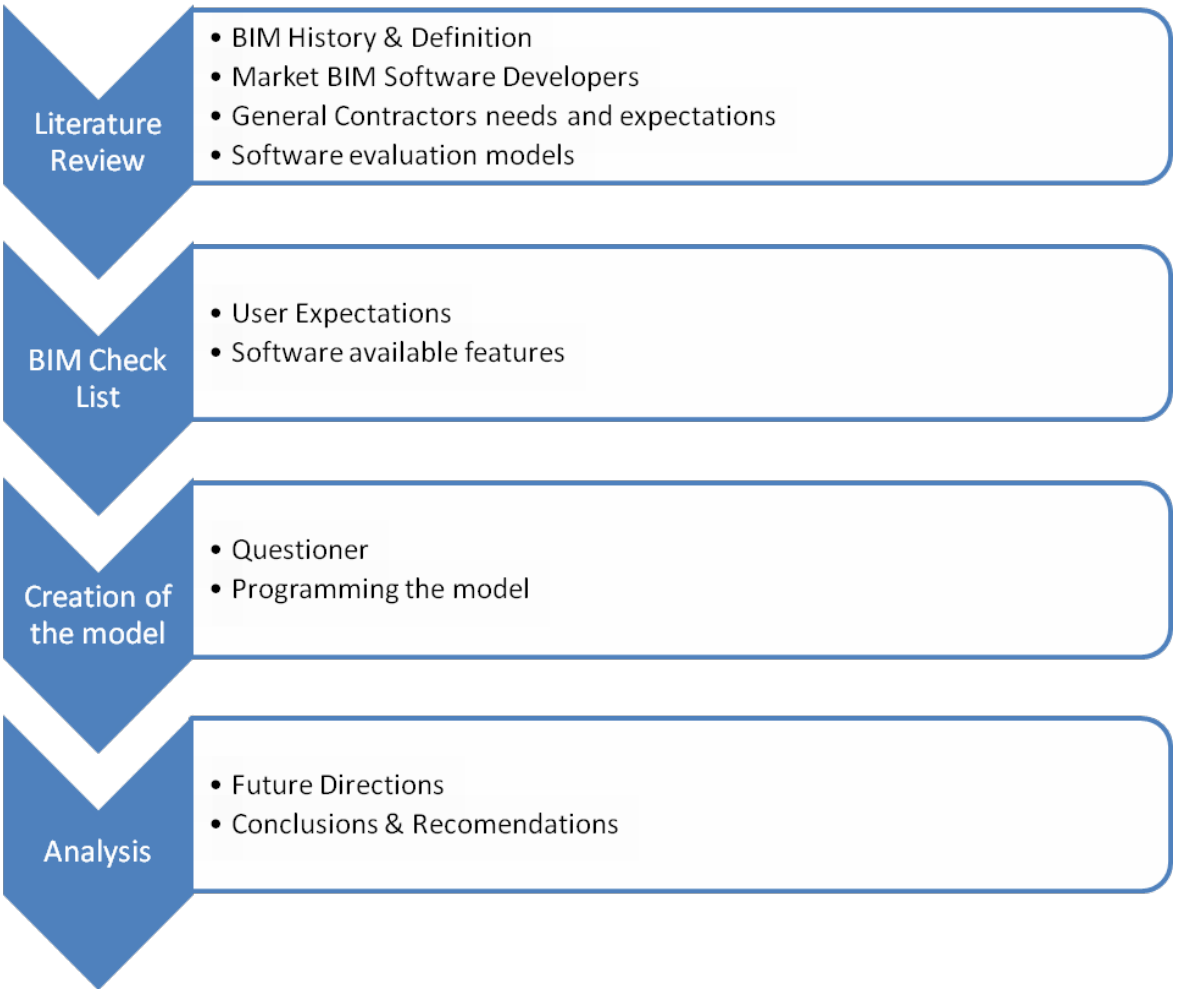


Figure 3-1. Methodology Process

CHAPTER 4
SOFTWARE PACKAGES KEY FEATURES AND USER NEEDS

Evaluating any kind of software is a complex process, as discussed in the literature review there is no formal evaluation model for BIM related software. Although, there is a list of major BIM software developers in the United States and a couple surveys trying to identify the needs and expectations from BIM users. Also from the literature review, a basic methodology that can be applied to the evaluate software in general was discovered. Using the concepts and methodologies discovered during the literature review the BIM Software Evaluation Model for General Contractors (BIMSEM-GC) was created.

This chapter covers the results from the analysis of the different software packages and the user needs and expectations regarding BIM. The final result of the analysis was the creation of a list of 40 different criteria to identify the company's needs during the preconstruction, construction, and post construction phases of the project as well as a list of 10 criteria to evaluate the general requirements of the company when acquiring any software. Also a scoring of the analyzed software packages was obtained during this phase to be used by the BIMSEM-GC.

Eleven BIM software developers were analyzed during the literature review. The major BIM software packages were considered for further analysis using two selection criteria: 1)it must be a software with BIM capabilities, and 2) those capabilities must help the general contractor in performing the basic needs of a building construction project for any of the preconstruction, construction and post construction phases.

A list of 33 software packages was identified from the previous selecting criteria. An analysis of the key features these solutions offered to the user was developed trying to identify the market available features, Table 4-1 shows a list of the different software packages and the basic key features found during the evaluation.

A similar analysis was done with the results from the AECbytes (2007) and Gilligan and Kunz (2007) surveys studied during the literature review, but in this case the results were categorized by the modeling capability, building analysis capability, functions for the estimating and project schedule, and finally functions for the project management. Table 4-2 shows the results from this categorization.

The same categorization done for the user needs and expectations was made for the 33 software packages key features that were identified in Table 4-1, Table 4-3 shows the categorization of these key features. To perform this categorization an in-depth analysis of the key features was done to make sure that all the different features available in the market were included and eliminating those features that were repeated from one software to other.

Once both lists were finished, one with the BIM user needs and expectations and another with the available features, a unified list was done including both criteria. This unified list showed 40 baseline questions than were adapted for the different phases of any construction project (preconstruction, construction, and post construction) where every phase should include the basic duties that the general contractors perform during any project; preconstruction refers to the bidding process and preparation process before the physical work starts, construction refers to the activity of building the project, and post construction to the analysis and deliverables that the general contractor does after the project is done. This adapted list of 120 questions including the three phases of the project and then 10 questions covering the general criteria for acquiring any software represented the foundation for the BIMSEM-GC as showed in Table 4-4.

With the evaluation criteria done, a description of every criteria was required to allow the company using the model to know the same considerations used during the creation of the

model. Tables 4-5 through 4-8 show the description of every criteria and the application of the concept for every phase during the following analysis.

The next step in the analysis was to score the 33 software packages with the BIM software evaluation criteria shown in Table 4-4. The software packages were scored according to the authors' knowledge and the analysis of the key features for every package. From the final scores for every phase for the different software an important set of results was obtained. The average score for the 33 software packages in the preconstruction phase was 119.4 point out of 200 (or 59.7%). The average score for the construction phase was 115.9 out of 200 (or 57.9%). For the post construction phase the average score was 113.2 out of 200 (or 56.6%) showing that there is still lots of room for improved the BIM technology and more important, that the user needs and expectations may not yet have been fulfilled.

Figures 4-1 through 4-3 show the scores for every software package considered during the evaluation process. It should be noted that more than half of the software packages evaluated are below the average line as shown in Figures 4-1 through 4-3. This may be due to the fact that some of the evaluated software is part of an integrated solution and the individual program performance is not as good when analyzing if for use on an entire construction project.

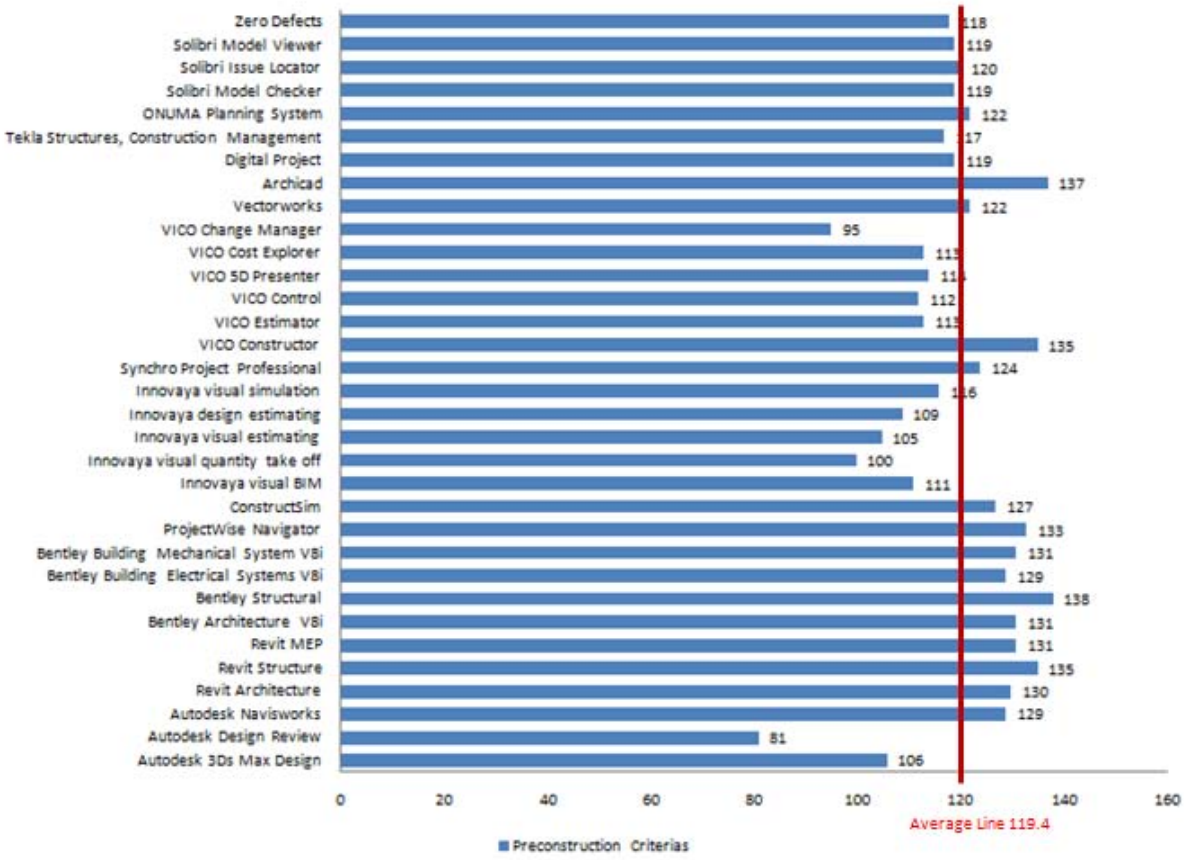


Figure 4-1. Evaluation Results for the software packages for the preconstruction phase

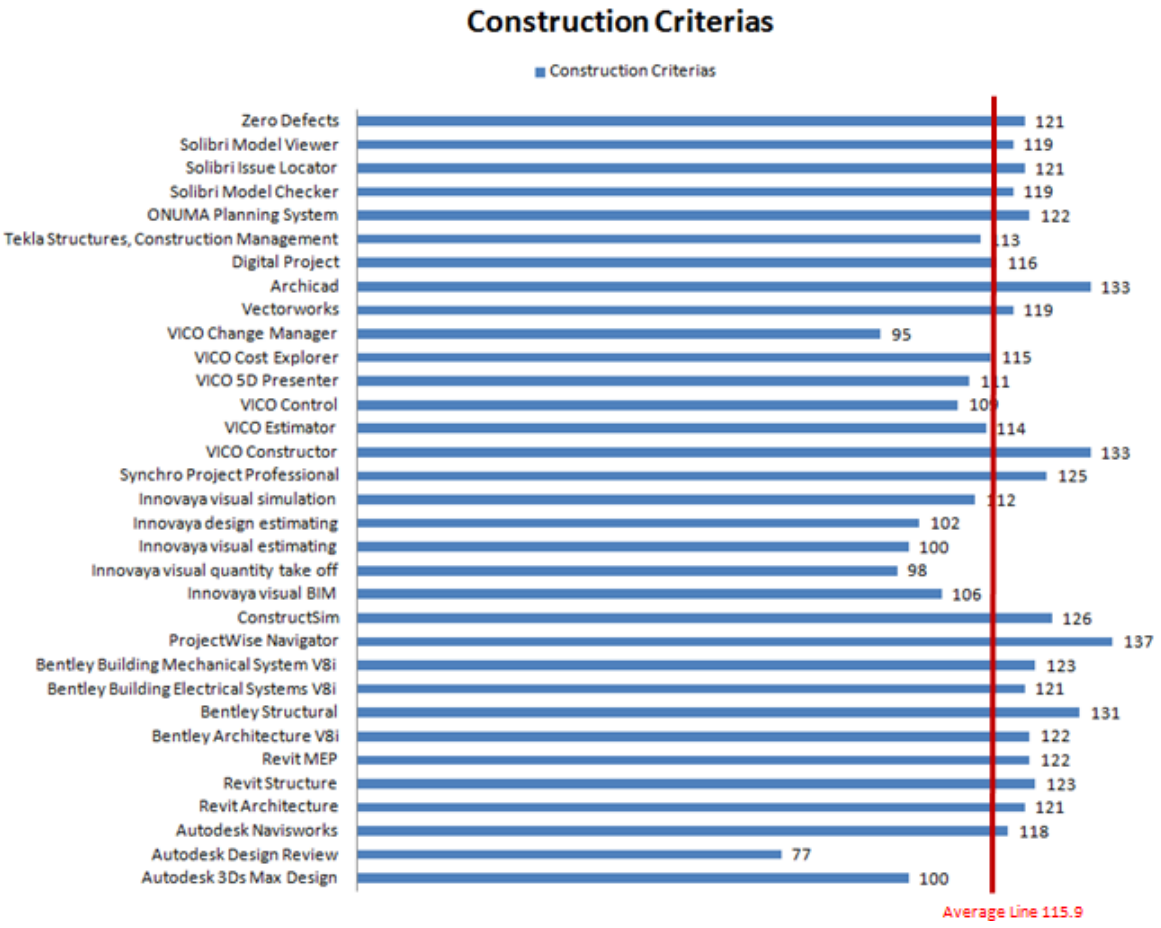


Figure 4-2. Evaluation Result of the BIM Software Packages for the Construction Phase

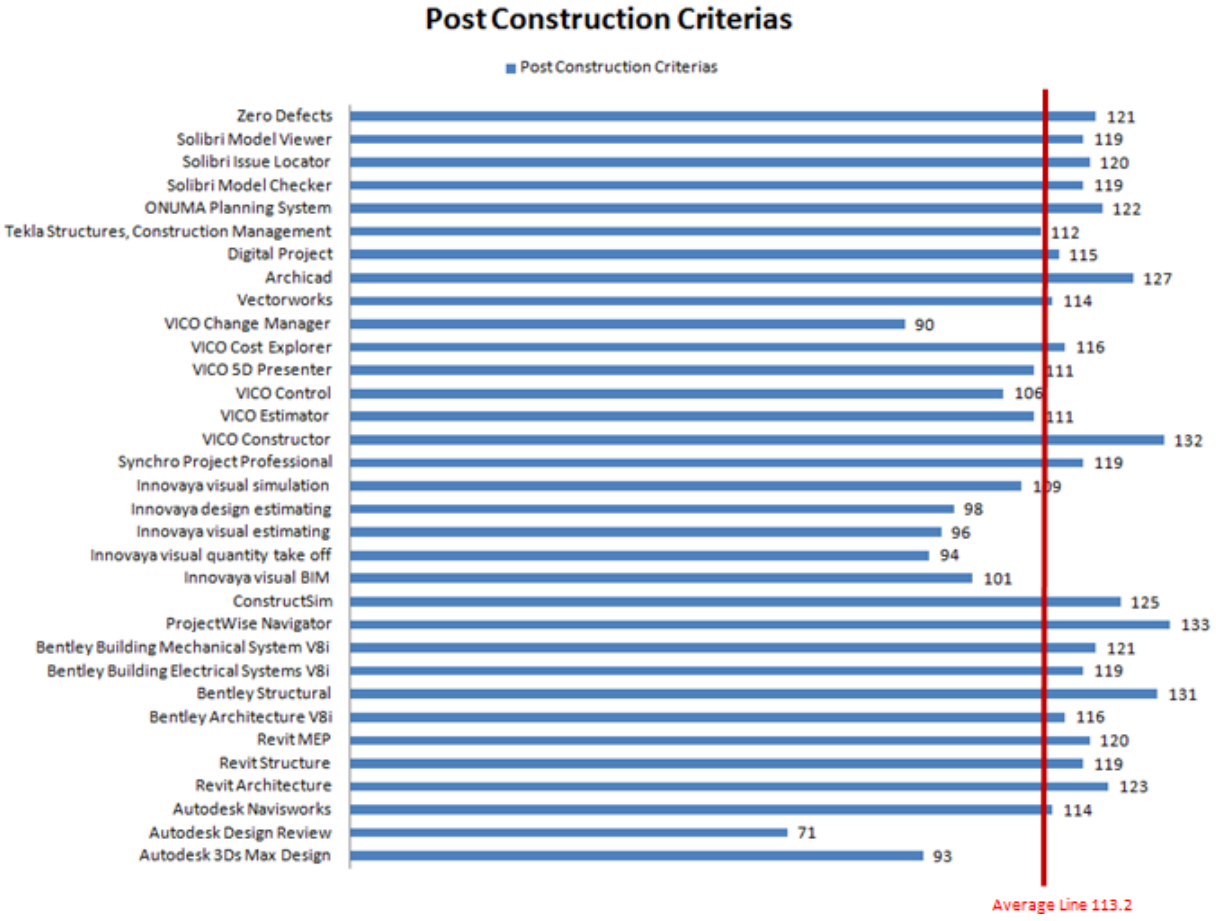


Figure 4-3. Evaluation Result of the BIM Software Packages for the Post Construction Phase

Table 4-1. BIM software packages and key feature

BIM software developers building construction				
Company	Products	Webpage	BIM key features	Cost per seat
Autodesk	Autodesk 3Ds Max Design	http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=10326929	Friendly User Interface	
			Drawing and Modeling Capability	
			File Management Utilities	
			Interoperability	
			Parametric Modeling in 2D or 3D	
			Ready to use geometry libraries	
			Polygon Modeling and Texturing	
			Subdivision Surfaces and Polygonal Smoothing	
			High rendering and animation features	$3,990
	Autodesk Design Review		Publish, Share, and view drawings and models from any Autodesk application	
			Mark Up and Annotate	
			Track and Import Changes	n/a
	Autodesk Navisworks		Interference detection	
			Point/Line Based Clashing Track status of clashes as they are found and resolved	
			Export Reports	
			XML import/export	
			4D Simulation	
			Schedule linking from other project management software	
			Set up planned and actual times to visualize deviations from the project schedule	
			Export 4D simulations into a prerecorded .AVI animation	
			Create project presentations	
			Rendering capability	
			Interoperability	$9,140

Table 4-1. Continued

Revit Architecture	Modeling Capability	
	Bidirectional Associability Schedules Creation Curtin Wall Modeling	
	Parametric Components Develop a study of multiple simultaneous design alternatives	
	Ready to use geometry libraries	
	Material Takeoff	
	Rendering capability	
	Interference detection	
	2D and 3D dwf Integration	
	Interoperability	$6,190
Revit Structure	Single model for Both structural analysis and documentation	
	Bidirectional Associability	
	Automates Construction documents	
	Create structural details	
	Interoperability	
	Bidirectional Links with structural packages	
	Ready to use material libraries	
	Parametric Components	
	Multiuser Work sharing	$5,990
Revit MEP	Integrated heating and cooling loads analysis tools to help perform energy analysis. Supports green building mark up language (gbXML)	
	Duct and Pipe Sizing/Pressure calculations	
	Duct and pipe System Modeling	
	HVAC/Electrical Space Design	
	System Inspector	
	Auto Route Duct	
	Lighting and Power Circuitry	
	Auto wire circuits	
	Create Panel Schedules	
	Lighting calculations	
	Voltage Drops and Derating Factors	
	Plumbing System Modeling	
	Sloped pipe and invert elevations	
	Fire protection system modeling	
	Interference detection	$6,420

Table 4-1. Continued

			Bidirectional Associability Parametric Components MEP Construction Documentation Work sharing Rendering capability Publish capability Interoperability	
Bentley Systems	Bentley Architecture V8i	http://www.bentley.com/en-US/	Friendly User Interface Drawing and Modeling Capability Ready to use material libraries Parametric Components Relationships and associability between architectural elements for rapid design changes Terrain modeling, roof and stair builder tools Support for international steel section tables Powerful solid modeling for easy creation of virtually any form 2D and 3D dwf Integration Export to SLT to support rapid model making and prototyping with 3D printers, laser cutters, and stereo lithography machines. Support of 3D with Adobe PDF Import export of IFC 2x Full integration with Bentley Systems gbXML export/import	$ 1495 $ 6290 w/Micro station
	Bentley Structural		User Friendly Interface Drawing and Modeling Capability Ready to use material libraries Parametric Components Structural design and construction documentation for structures in steel, concrete, and timber. Integrated analytical model with finite elements, nodes, boundary conditions and member releases, loads and load combinations. Support for a large variety of cross sections, straight, curved, B-Spline. Allow elements modifications. Dimension driven creation and modification of structural components	$ 2,750 $$7,545 w/Micro station

Table 4-1. Continued

	Support for all major metric and imperial steel section tables.	
	Multiple filtering options. Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x Integration with Bentley's STAAD.Pro and RAM International Products Integration with GT STRUDL, ROBOT, MIDAS/GENw and SFRAME Design history to review changes Export import of industry standards CIMsteel CIS/2 for analysis, steel detail and fabrication.	
Bentley Building Electrical Systems V8i	Professional electrical design solution	
	2D/3D design and modeling	
	Ready to use libraries	
	Bidirectional interfaces to power analysis (EDSA, AMTECH Prodesign, elcoPower)	
	Bidirectional links to third party Lighting Analysis programs (Lumen Designer, DIALux, Relux)	
	Electrical raceway design	$ 3,950
	Import/Export of IFC 2x	$ 8,745 w/Micros tation
	Support of 3D within Adobe PDF	
Bentley Building Mechanical System V8i	Design and construction documentation of air-handling piping/plumbing systems	
	Friendly User Interface	
	Drawing and Modeling Capability	
	Ready to use material libraries	
	Parametric Components Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x	
	gbXML export/import	$1,495
ConstructSim	Material Takeoff	
	Generation and sequencing of optimal weekly work plans at a crew level Visualization of project status against project schedule	
	Ability to create reports for: Bill-of-materials, work steps for construction, shortage lists, progress and status reports	n/a (more for industrial)
	Schedule simulation	

Table 4-1. Continued

			Simulation of different schedule scenarios to find the most efficient and effective schedules	
	ProjectWise Navigator	http://www.bentley.com/en-US/Products/ProjectWise+Navigator/	Design Review and manipulation	
			Photorealistic visualization	
			Schedule simulation	
			Clash detection	
			Export Reports Interoperability: IFC, DGN, DWG, DXF, SKP, PDF, IGES, STEP, etc	
			History tracking	
			Database repository	$360
Innovaya	Innovaya visual BIM	http://www.innovaya.com/	Interactive 3D visualization from architectural desktop or Revit Incorporated visibility controls to adjust transparency of the objects	
			Mark Up and Annotate	
			E-mail tools	
	Innovaya visual quantity take off		Material Takeoff	
			Visual review of the takeoff	
			Allow quantities organization in CSI or Uniformat	
			Color codes confirmation for quantity takeoff in the building	
			Associability with Sage Timberline Assembly	
			Intelligent change management	
			Export reports to MS Excel	
			E-mail tools	
	Innovaya visual estimating		Material Takeoff	
			Visual review of the takeoff	
			Allow quantities organization in CSI or Uniformat	
			Color codes confirmation for quantity takeoff in the building	
			Bidirectional link with Sage Timberline Assembly	
			Intelligent change management	
			Export reports to MS Excel	
			Allow the use of MC2 ICE or Timberline database	
	Innovaya design estimating		Automatic estimation with RS Means assemblies	
			Export reports in CSI, Uniformat or WBS	

Table 4-1. Continued

			Intelligent change management
			Color codes confirmation for quantity takeoff in the building
			Bidirectional link with Sage Timberline Assembly
			E-mail tools
	Innovaya visual simulation		Bidirectional link with MS Project and Primavera
			Schedule Simulation
			Color codes confirmation for schedule tracking
			Ability to simulate different schedule to develop "what if" analysis
			Mark Up and Annotate
			Export reports in MS Word
			E-mail tools
Synchro Ltd	Synchro Project Professional	http://www.synchroltd.com/	"What if" scenario with side by side comparative analysis
			Resource management
			Multiple baselines capability to compare actual performance against planned
			Progress tracking
			Rescheduling options
			Critical path planning and analysis
			Synchronization with MS Project and Primavera
			Ability to update the model
			Mark Up and Annotate
			E-mail tools
			Earn value analysis reports
			Resource and task usage reports
			Line of balance view
VICO Software	VICO Constructor	http://www.vicosoftware.com/	Modeling Capability
			Ready to use libraries
			Curtain Wall Modeling
			Ready to use libraries
			Structural and MEP modeling capability
	David: david.wilkinson@vicosoftware.com		Virtual trace capability to coordinate model with drawings
			Mark Up and Annotate
			Material Takeoff

Table 4-1. Continued

	Interactive model checker to identify missing quantities
	WBS of your project
	Estimating and scheduling integration
	Non-destructive element split (isolate zones and analyze quantities and schedule)
	Vico Control integration
	Data exchange with Primavera and MS Project
	Ability to place site surveying and benchmark
VICO Estimator	Recipe based estimating
	Cost variances tracking
	Customizable estimating and scheduling system
	Ability to split the project in phases
	Ability to input data manually
	Ability to separate bid packages
	Comparison functionality to compare subcontractors quotes
	History tracking
	Integration with VICO cost manager
	Cost tracking capability to perform earn value analysis
VICO Control	Ability to input schedule in Gantt or linear format
	Location breakdown structure
	Visual dependency network
	Ability to create quantity based schedules to see bill of quantities
	Resource histogram
	Control chart color coding
	Schedule forecast according to real progress inputs
	Link multiple projects
	Monte Carlo Risk analysis simulation
	Prerequisites check capability (For the procurement)
	Micromanagement capability
	Cost and cash flow capability
	Look ahead reporting capability
	Integration with MS Project and Primavera
VICO 5D Presenter	3D, 4D and 5D Views
	Ability to present isolated zones
	Constructability reviews
	EV analysis

Table 4-1. Continued

			Record simulation
			Filtering capability
			Movie recording capability
	VICO Cost Explorer		Graphical cost explorer
			Target costs capability, comparing actual cost with budget
			Costs changes tracking capability
			Side by side comparison
			What if scenarios
			Mark Up and Annotate
	VICO Change Manager		Full compatibility with DWG drawings
			DWG Comparison
			PDF Comparison
			Side by side comparison
			Comparison results panel
			RFI Management
			History tracking
			Highlighted changes
Nemetschek	Vectorworks	http://www.nemetschek.net/	Modeling Capability
			Bidirectional Database Associability
			HVAC, Plumbing and electrical modeling
			Parametric Components
			GSA compatible space planning object
			Ready to use geometry libraries
			Cost and Material tracking
			Rendering capability
			Digital terrain modeling
			2D and 3D dwf Integration
			Interoperability
	Archicad	http://www.graphisoft.com/	Modeling Capability
			Bidirectional Database Associability
			MEP modeling
			Parametric Components
			Clash detection
			Ready to use geometry libraries
			Cost and Material tracking
			Rendering capability
			Digital terrain modeling

Table 4-1. Continued

			2D and 3D dwf Integration
			Interoperability
Gehry Technologies	Digital Project	http://www.gehrytechnologies.com/	Design Review and manipulation
			4D Planning and coordination
			Photorealistic visualization
			3D 2D viewer
			Primavera integration
			Modeling Capability
			MEP system routing
			Knowledgeware integration (capture, reuse, and share organizational knowledge and skills)
			Project team collaboration tools
			Clash detection
			RFI Management
Tekla Corporation	Tekla Structures, Construction Management	http://www.tekla.com/international/solutions/building-construction/Pages/Default.aspx	View Tekla models
			Create erection sequences
			4D Simulation
			Assign and manage construction schedule
			Interoperability: IFC, DWG, DXF, DGN
			Clash detection
			Multiple reports
			Multiuser Work sharing
			Internet browser viewer
			Exchange data with MIS systems
			Material Takeoff
Onuma	ONUMA Planning System	http://www.onuma.com/	Internet database capability
			Update cost, bids, planned information in real time
			Collaboration in real time
			Model server capability
			Ability to divide the project in phases
			Ability to be use in facilities management
			GIS integration
			Interoperability
			IFC open standard

Table 4-1. Continued

			Each user can used their own tool
			Bobble diagramming of spaces
			Material Takeoff
			Estimating capability
			Multiuser Work sharing
			History tracking
			XML Export/Import
Solibri	Solibri Model Checker	http://www.solibri.com/	Integrity, quality and physical safety analysis
			Clash detection
			Code compliance analysis
			Material takeoff
			Integration with cost estimation systems
			Multiple reports
			IFC Support
			Best practices guide analysis
			Interoperability
	Solibri Issue Locator		Design issues locator in the BIM original tool
	Solibri Model Viewer		Open standard IFC viewer
Project Blueprint Ltd.	Zero Defects	http://www.projectblueprint.com/home.html	Single database updated in the internet
			History tracking
			Data base of onsite defects
			Defect costing reports
			List of most common defects

Table 4-2. Summary of User Needs and Expectations of BIM based in the Surveys

User needs and expectations of key features			
Model creation	Building analysis	Estimate and schedule	Project management
Automated Setup, management, and coordination, reducing traditional CAD management tasks	Direct integration with structural analysis applications	Direct integration with cost estimating applications	Direct integration with project management applications
Ability to work on large projects	Direct integration with energy analysis applications	Support for construction related task such as quantity take off, estimating, and 4D scheduling	
Ability to support distributed work processes, with multiple team members working on the same project	Safety analysis or management	4D Clash detection and interference management	IFC Compatibility
Multidisciplinary capability that serves architecture, structural engineering, and MEP	Energy analysis or management	Present schedule as 4D automation	Market share leadership position of the vendor offering the BIM solution
Ability to support preliminary conceptual design modeling	Structural Analysis		Extensibility and customization of the solution
Full support for producing construction documents so that another drafting application need not to be used			Quality of help and supporting documentation, tutorials and other learning resources
Built in ability to generate highly photorealistic renderings and animations			3D Clash detection and interference management
Smart objects, which maintain associability, connectivity, and relationships with other objects			Engage neighbors or users in understanding construction process
Availability of object libraries			Enhance submittal/shop drawings review
Extensibility and customization of the solution			Enhance shop fabrication process
High level of detail to model architectural design			Drive shop fabrication equipment
Ability to define space utilization			

Table 4-3. Summary of Available Key Features from software packages

Software packages summary of key features			
Model creation	Building analysis	Estimate and schedule	Project management
Drawing and Parametric Modeling Capability in 2D or 3D	Bidirectional Links with structural packages	4D Simulation	IFC Compliance
File Management Utilities	Integrated heating and cooling loads analysis tools to help perform energy analysis.	Schedule linking from other project management software	Publish, Share, and view drawings and models from different application
Ready to use geometry libraries	Duct and Pipe Sizing/Pressure calculations	Set up planned and actual times to visualize deviations from the project schedule	Mark Up and Annotate comments
High rendering and animation features	Lighting calculations	Material Takeoff	Track and Import Changes
Develop a study of multiple simultaneous design alternatives	Voltage Drops and Derating Factors	Generation and sequencing of optimal weekly work plans at a crew level	Clash detection
2D and 3D dwf Integration	Integration with Bentley's STAAD.Pro and RAM International Products	Ability to create reports for: Bill-of-materials, work steps for construction, shortage lists, progress and status reports	Track status of clashes as they are found and resolved
Multiapplications in Structural and MEP capabilities	Integration with GT STRUDL, ROBOT, MIDAS/GENw and SFRAME	Simulation of different schedule scenarios to find the most efficient and effective schedules	Export Reports and create presentations
Automates Construction documents	Bidirectional interfaces to power analysis (EDSA, AMTECH Prodesign, elcoPower)	Incorporated visibility controls to adjust transparency of the objects	XML import/export
Create structural details	Bidirectional links to third party Lighting Analysis programs (Lumen Designer, DIALux, Relux)	Visual review of the takeoff	Multiuser Work sharing
Ready to use material libraries		Allow quantities organization in CSI or Uniformat	Supports green building mark up language (gbXML)
Duct and pipe System Modeling		Intelligent change management	Data base of on site defects
HVAC/Electrical Space Design		Export reports to MS Excel	Defect costing reports
System Inspector		Bidirectional linking with other estimating software	List of most common defects
Auto Route Duct		Automatic estimation with RS Means assemblies	Best practices guide analysis
Lighting and Power Circuitry		Export reports in CSI, Uniformat or WBS	Design issues locator in the BIM original tool

Table 4-3. Continued

Auto wire circuits	Color codes confirmation for schedule tracking	Export to SLT to support rapid model making and prototyping with 3D printers, laser cutters, and stereo lithography machines.
Create Panel Schedules	Export reports in MS Word	Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x
Plumbing System Modeling	"What if" scenario with side by side comparative analysis	Design history to review changes
Sloped pipe and invert elevations	Resource management	Export import of industry standards CIMsteel CIS/2 for analysis, steel detail and fabrication.
Fire protection system modeling	Rescheduling options	Design Review and manipulation
Relationships and associability between architectural elements for rapid design changes	Critical path planning and analysis	Database repository
Terrain modeling, roof and stair builder tools	Ability to update the model	E-mail tools
Integrated analytical model with finite elements, nodes, boundary conditions and member releases, loads and load combinations.	Earn value analysis reports	Bidirectional Database Associability
Dimension driven creation and modification of structural components	Resource and task usage reports	GSA compatible space planning object
Support for all major metric and imperial steel section tables.	Line of balance view	Knowledgeware integration (capture, reuse, and share organizational knowledge and skills)
Multiple filtering options.	Non-destructive element split (isolate zones and analyze quantities and schedule)	Project team collaboration tools
Professional electrical design solution	Ability to place site surveying and benchmark	Internet browser viewer
Electrical raceway design	Cost variances tracking	Exchange data with Management Information Systems (MIS)
Design and construction documentation of air-handling piping/plumbing systems	Ability to split the project in phases	Internet database capability

Table 4-3. Continued

Curtain Wall Modeling	Ability to input data manually	Integrity, quality and physical safety analysis
Virtual trace capability to coordinate model with drawings	Ability to separate bid packages	Code compliance analysis
	Comparison functionality to compare subcontractors quotes	
	Ability to input schedule in Gantt or linear format	
	Location breakdown structure	
	Visual dependency network	
	Resource histogram	
	Control chart color coding	
	Schedule forecast according to real progress inputs	
	Link multiple projects	
	Monte Carlo Risk analysis simulation	
	Prerequisites check capability (For the procurement)	
	Look ahead reporting capability	
	Side by side geometric comparison	
	Comparison results panel	
	RFI Management	
	Create erection sequences	

Table 4-4. BIM Software Evaluation Criteria

	Software evaluation model for GC	
	Date:	26-Feb-09
	Company:	C1
	Criteria	Company's Needs
30%	Preconstruction criteria	
Model creation		
	Ability to Automated Setup, management, and coordination	
	Drawing and Modeling Capability	
	Parametric Modeling capability in 2D & 3D	
	Ready to use libraries	
	Built in ability to generate photorealistic renderings and animations	
	Smart objects, which maintain associability, connectivity, and relationships with other objects	
	Ability to publish, share and view drawings and models	
	Ability to track history to review changes	
	Multiuser work sharing capability	
	Ability to work on large projects	
	Multidisciplinary capability that serves architecture, structural engineering, and MEP	
	Ability to support preliminary conceptual design modeling	
	High level of detail to model architectural design	
	Full support for producing construction documents so that another drafting application need not to be used	
Building Analysis		
	Direct integration with structural analysis applications	
	Direct integration with energy analysis applications	
	Ability to define space utilization	
	Structural Analysis	
	Safety analysis or management	
	Energy analysis or management	
	3D Clash detection and interference management	
Estimate and schedule		
	Direct integration with cost estimating applications	
	Direct integration with project schedule applications	
	Ability to create quantity take off	
	Ability to create estimates	
	4D Clash detection and interference management	
	5D Analysis or management	

Table 4-4. Continued

	Present schedule as 4D automation	
Project management		
	"What if" analysis or management	
	Built in ability or direct integration with any team collaboration software.	
	Enhance submittal drawings preparation	
	Ability to develop temporary construction analysis	
	Enhance shop fabrication process	
	Resource Management Capability	
	XML Import/Export	
	IFC Compatibility	
	Bidirectional Associability with other software	
	Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x	
	Enhance precast elements coordination	
	Drive shop fabrication equipment	
	Subtotal:	0
30%	Construction Criteria	
Model creation		
	Ability to Automated Setup, management, and coordination	
	Capability to update drawings	
	Capability to update the Parametric Model in 2D & 3D	
	Ability to edit libraries	
	Ability to compare photorealistic renderings and animations with construction progress	
	Smart objects, which maintain associability, connectivity, and relationships with other objects	
	Ability to publish, share and view drawings and models as part of the construction reports	
	Ability to track construction history to review changes	
	Multiuser work sharing capability	
	Ability to work the project in phases	
	Multidisciplinary capability that serves architecture, structural engineering, and MEP	
	Ability to support temporary construction design modeling	
	Full support for producing as built documents so that another drafting application need not to be used	
	High level of detail to model architectural design	

Table 4-4. Continued

Building analysis		
	Direct integration with structural analysis applications	
	Direct integration with energy analysis applications	
	Ability to manage updates in the space utilization	
	Structural analysis or management	
	Energy analysis or management	
	Safety analysis or management	
	3D Clash detection and interference management with real progress	
Estimate and schedule		
	Direct integration with cost estimating applications	
	Direct integration with project schedule applications	
	Ability to update quantity take off	
	Ability to keep track of budget	
	4D Clash detection and interference management with real progress	
	5D Analysis or management with real progress	
	Update schedule as 4D automation	
Project management		
	"What if" analysis or management	
	Built in ability or direct integration with any team collaboration software.	
	Tracking of submittal drawings status	
	Ability to update temporary construction progress	
	Update shop fabrication process	
	Resource Tracking Capability	
	XML Import/Export	
	IFC Compatibility	
	Bidirectional Associability with other software	
	Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x	
	Enhance precast elements installation	
	Drive shop fabrication equipment	
	Sub Total:	0
30%	Post construction criteria	
Model creation		
	Ability to Automated Setup, management, and coordination	
	Capability to create as built drawings	
	Capability to create as built Parametric Model in 2D & 3D	

Table 4-4. Continued

Ability to add used or created libraries to the software for future reference	
Ability to compare photorealistic renderings and animations with final outcome as part of the post construction analysis	
Smart objects, which maintain associability, connectivity, and relationships with other objects	
Ability to publish, share and view drawings and models as part of the final construction report	
Ability to present construction history as part of the building manual to the owner	
Multiuser work sharing capability	
Ability to present the project phases as separated elements for future reference	
Multidisciplinary capability that serves architecture, structural engineering, and MEP	
Ability to analyze temporary construction for future improvements	
Full support for producing as built documents so that another drafting application need not to be used	
High level of detail to model architectural design	
Building analysis	
Direct integration with structural analysis applications	
Direct integration with energy analysis applications	
Ability to manage updates in the space utilization	
Structural analysis or management	
Energy analysis or management	
Safety analysis or management	
Ability to present history of 3D Clash detection and interference management for future references	
Estimate and schedule	
Direct integration with cost estimating applications	
Direct integration with project schedule applications	
Ability present final quantity take off report	
Ability to present final costs of the project	
4D projected schedule with final real schedule for future improvements	
Ability to compare 5D planned project with 5D final project	
Ability to present final 4D schedule for future improvements	

Table 4-4. Continued

Project management		
	Ability to compare all the "What if" analysis for future improvements	
	Built in ability or direct integration with any team collaboration software.	
	Ability to present final submittal to present as part of the owner report	
	Ability to present all real temporary construction progress for future improvements	
	Present as built shop fabrication process for future improvements	
	Ability to present Resource Utilization history for future improvements	
	XML Import/Export	
	IFC Compatibility	
	Bidirectional Associability with other software	
	Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x	
	Ability to analyze precast elements installation for future improvements	
	Ability to present shop fabrication equipment production rate for future improvements	
	Sub Total:	0
10%	General criteria	
	Market share leadership position of the vendor offering the BIM solution	
	Quality of help and supporting documentation, tutorials and other learning resources	
	Extensibility and customization of the solution	
	Engage neighbors or users in understanding construction process	
	Cost of the implementation	
	Recovery mechanism ensures data integrity to the business function level.	
	Operates in preferred operating environment (e.g., Windows, UNIX).	
	Necessary upgrades to the company's system	
	Ownership of components clearly define	
	Number of third party developers developing add on applications for the tool	
	Sub Total:	0

Table 4-5. Description of the BIM Software Evaluation Criteria for the preconstruction phase

Description of the software evaluation model for GC	
Preconstruction criteria	
Model Creation	Description
Ability to Automated Setup, management, and coordination	These criteria covers the ability to manage different files related to the preconstruction phase
Drawing and Modeling Capability	Includes the ability to create drawings and models of the building
Parametric Modeling capability in 2D & 3D	Includes the ability to work as the parametric model engine for 2D and 3D models
Ready to use libraries	These criteria included predetermine libraries with elements to create the model during the preconstruction phase. Elements like windows, doors, etc.
Built in ability to generate photorealistic renderings and animations	These criteria evaluated the built in capacity of the software to generate renderings, animations or avi. Movies.
Smart objects, which maintain associability, connectivity, and relationships with other objects	These criteria looked at the software ability to maintain associability, connectivity, and relationships for all the model objects.
Ability to publish, share and view drawings and models	The built in ability to produce reports.
Ability to track history to review changes	The ability to identify any changes in the drawings.
Multiuser work sharing capability	The ability to allow different people to work in the same model at the same time during the preconstruction phase.

Table 4-5. Continued

Ability to work on large projects	The software functionality on large projects and different types of projects.
Multidisciplinary capability that serves architecture, structural engineering, and MEP	The multi modeling capability of the model engine tool during the preconstruction phase.
Ability to support preliminary conceptual design modeling	The ability to analyze preliminary design allowing the general contractor an early involvement in the project.
High level of detail to model architectural design	The software ability to create models with high level of detail to be used in other phases.
Full support for producing construction documents so that another drafting application need not to be used	The software ability to generate all the necessary construction documents to built the facility.
Building analysis	**Description**
Direct integration with structural analysis applications	The software unidirectional link with other structural analysis packages to revise part of the bid documents.
Direct integration with energy analysis applications	The software unidirectional link with other energy analysis packages to revise any owner requirements with the proposed by the contractor.
Ability to define space utilization	The software ability to help in define site utilization layout.
Structural Analysis	The built in ability to perform structural analyses on any kind
Safety analysis or management	The built in ability to perform any kind of safety analysis.
Energy analysis or management	The built in ability to perform any kind of energy analysis.
3D Clash detection and interference management	The built in ability to perform 3D clash detections.

Table 4-5. Continued

Estimate and schedule	Description
Direct integration with cost estimating applications	The software unidirectional link with other estimating packages like Sage Timberline, MS Excel or MC2.
Direct integration with project schedule applications	The software unidirectional link with other project schedule packages like Primavera or MS Project.
Ability to create quantity take off	The built in ability to perform quantity take off.
Ability to create estimates	The built in ability to assign cost to the different quantities in the model.
4D Clash detection and interference management	The built in ability to show any clash detection during the simulation process.
5D Analysis or management	The ability to analysis cost expected cost during the simulation of the project.
Present schedule as 4D automation	The built in capability to perform schedule simulations

Project management	Description
"What if" analysis or management	The ability to perform "what if" analysis for design.
Built in ability or direct integration with any team collaboration software.	The ability to communicate any changes in the model with the rest of the team. Like email, internet server, etc.
Enhance submittal drawings preparation	The ability to facilitate submittals preparation.
Ability to develop temporary construction analysis	The ability to develop temporary construction analysis like cranes position, elevators position, etc.

Table 4-5. Continued

Enhance shop fabrication process	The ability to facilitate shop drawings preparation.
Resource Management Capability	The ability to perform resource management analyses.
XML Import/Export	The ability to import/export to any kind of XML format.
IFC Compatibility	The ability to work as an IFC standard
Bidirectional Associability with other software	The software bidirectional link with other software not mentioned before.
Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x	The ability to import several CAD formats into the software.
Enhance precast elements coordination	The ability to propose erection sequences.
Drive shop fabrication equipment	The ability to link the model with fabrication equipments.

Table 4-6. Description of the BIM Software Evaluation Criteria for the Construction Phase

Description of the software evaluation model for GC	
Construction criteria	
Model Creation	Description
Ability to Automated Setup, management, and coordination	These criteria covers the ability to manage different files related to the construction phase
Capability to update drawings	Includes the ability to update drawings and models with new information during the construction phase.
Capability to update the Parametric Model in 2D & 3D	Includes the ability to update not only the model and drawings but the parameters and smart data behind those.
Ability to edit libraries	These criteria looks for the ability to create new libraries or make changes to the existing ones. Bring manufactures libraries.
Ability to compare photorealistic renderings and animations with construction progress	Ability to create report comparing the updated rendering with real time pictures or avi. Movies.
Smart objects, which maintain associability, connectivity, and relationships with other objects	These criteria looked at the software ability to maintain associability, connectivity, and relationships for all the model objects.
Ability to publish, share and view drawings and models as part of the construction reports	The built in ability to produce reports from the model to be used on site by the superintendent and other parties.
Ability to track construction history to review changes	The ability to keep track of all the changes found and status of RFI.
Multiuser work sharing capability	The ability to allow different people to work in the same model at the same time during the construction phase.
Ability to work the project in phases	The software functionality on large projects and different types of projects.

Table 4-6. Continued

Multidisciplinary capability that serves architecture, structural engineering, and MEP	The multi modeling capability of the model engine tool during the construction phase.
Ability to support temporary construction design modeling	The ability to input temporary construction elements into the model to optimize construction process.
Full support for producing as built documents so that another drafting application need not to be used	The software ability to keep updated all the necessary construction documents.
High level of detail to model architectural design	The software ability to create models with high level of detail to be use in other phases.
Building analysis	**Description**
Direct integration with structural analysis applications	The software bidirectional link with other structural analysis packages to revise part of the construction documents.
Direct integration with energy analysis applications	The software bidirectional link with other energy analysis packages to revise any owner requirements with the proposed by the contractor.
Ability to manage updates in the space utilization	The software ability to keep the site utilization layout updated allowing the contractor to visualize available areas.
Structural analysis or management	The built in ability to perform structural analyses of any changes during the project
Energy analysis or management	The built in ability to perform any kind of energy analysis.
Safety analysis or management	The built in ability to perform any kind of safety analysis.
3D Clash detection and interference management with real progress	The built in ability to perform 3D clash detections comparing the real process.
Estimate and schedule	**Description**
Direct integration with cost estimating applications	The software bidirectional link with other estimating packages like Sage Timberline, MS Excel or MC2.
Direct integration with project schedule applications	The software bidirectional link with other project schedule packages like Primavera or MS Project.

Table 4-6. Continued

Ability to update quantity take off	The built in ability up date quantity take offs automatically from any update made to the model.
Ability to keep track of budget	The built in ability to keep track of the cost of the project with bill of materials, or any other control tool.
4D Clash detection and interference management with real progress	The built in ability to show alarms by clash detected from changes made to the model during the construction process.
5D Analysis or management with real progress	The ability to perform earn value analysis.
Update schedule as 4D automation	The built in ability to simulate the planned performance with the real performance to analyze any variation to come.
Project management	**Description**
"What if" analysis or management	Ability to perform "what if" analysis to propose value engineering.
Built in ability or direct integration with any team collaboration software.	The ability to communicate any changes in the model with the rest of the team. Like email, internet server, etc.
Tracking of submittal drawings status	The ability to track submittals status.
Ability to update temporary construction progress	The ability to develop update any temporary construction analysis with changes during the construction.
Update shop fabrication process	The ability to track shop drawings status.
Resource Tracking Capability	The ability to track resource utilization, and present look ahead reports.
XML Import/Export	The ability to import/export to any kind of XML format.
IFC Compatibility	The ability to work as an IFC standard

Table 4-6. Continued

Bidirectional Associability with other software	The software bidirectional link with other software not mentioned before.
Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x	The ability to import several CAD formats into the software.
Enhance precast elements installation	The ability to optimize erection sequences.
Drive shop fabrication equipment	The ability to change any fabrication order during the construction process as a change order.

Table 4-7. Description of the BIM Software Evaluation Criteria for the Post Construction Phase

Description of the software evaluation model for GC	
Post construction criteria	
Model creation	Description
Ability to Automated Setup, management, and coordination	These criteria covers the ability to manage different files related to the post construction phase
Capability to create as built drawings	Includes the ability to keep a set of the different updates to create the as built drawings and model.
Capability to create as built Parametric Model in 2D & 3D	Includes the ability to keep all the smart data of the model updated to deliver an us built set of parameters to the owner.
Ability to add used or created libraries to the software for future reference	The ability to store the created elements during the project to be used as part of the libraries in future projects.
Ability to compare photorealistic renderings and animations with final outcome as part of the post construction analysis	Ability to create a final report comparing the initial renders with the final product.
Smart objects, which maintain associability, connectivity, and relationships with other objects	These criteria looked at the software ability to maintain associability, connectivity, and relationships for all the model objects.
Ability to publish, share and view drawings and models as part of the final construction report	The ability to store all the reports and present a summary at the end of the project.
Ability to present construction history as part of the building manual to the owner	The ability to keep a history schema of the changes and RFI found in the project for future reference.
Multiuser work sharing capability	The ability to allow different people to work in the same model at the same time during the post construction phase.
Ability to present the project phases as separated elements for future reference	The software functionality on large projects and different types of projects.
Multidisciplinary capability that serves architecture, structural engineering, and MEP	The multi modeling capability of the model engine tool during the post construction phase.

Table 4-7. Continued

Ability to analyze temporary construction for future improvements	The ability to analyze the performance of temporary construction for future improvements.
Full support for producing as built documents so that another drafting application need not to be used	The software ability to generate all the as built documents of the facility.
High level of detail to model architectural design	The software ability to create models with high level of detail to be use in other phases.
Building analysis	**Description**
Direct integration with structural analysis applications	The software bidirectional link with other structural analysis packages present a final report of the evolution of the project.
Direct integration with energy analysis applications	The software bidirectional link with other energy analysis packages to present a final report to be use as part of any further certification for the building.
Ability to manage updates in the space utilization	The ability to present the final site utilization process for review and improvements in future projects.
Structural analysis or management	The ability to present a report of the structural analyses during the project.
Energy analysis or management	The built in ability to perform any kind of energy analysis.
Safety analysis or management	The built in ability to perform any kind of safety analysis.
Ability to present history of 3D Clash detection and interference management for future references	The ability to create a histogram of the evolution for the different 3D clash detections made during the project.
Estimate and schedule	**Description**
Direct integration with cost estimating applications	The software bidirectional link with other estimating packages like Sage Timberline, MS Excel or MC2 to present final cost reports.
Direct integration with project schedule applications	The software bidirectional link with other project schedule packages like Primavera or MS Project to present final schedule analysis.
Ability present final quantity take off report	The built in ability present an analysis comparing the estimated quantities with the used quantities.
Ability to present final costs of the project	The built in ability to present a comparison analysis of the estimated budget and final cost of the project.

Table 4-7. Continued

4D projected schedule with final real schedule for future improvements	The built in ability to compare planned schedule with final real schedule to perform a lessons learned analysis
Ability to compare 5D planned project with 5D final project	The ability to present a cost histogram to analyze where the variations occurred.
Ability to present final 4D schedule for future improvements	The built in ability to simulate the planned performance with the real performance to correct any variation in future projects.
Project management	Description
Ability to compare all the "What if" analysis for future improvements	Ability to compare all the proposed "what if" scenarios with final product for future improvements.
Built in ability or direct integration with any team collaboration software.	The ability to communicate any changes in the model with the rest of the team. Like email, Internet server, etc.
Ability to present final submittal to present as part of the owner report	The ability to present a final submittals report to present to the owner as part of the operations manual.
Ability to present all real temporary construction progress for future improvements	The ability to present a final real temporary construction process for future improvements.
Present as built shop fabrication process for future improvements	The ability to present a final shop drawings report to present to the owner as part of the operations manual.
Ability to present Resource Utilization history for future improvements	The ability to create a resource histogram to analyze future improvements.
XML Import/Export	The ability to import/export to any kind of XML format.
IFC Compatibility	The ability to work as an IFC standard
Bidirectional Associability with other software	The software bidirectional link with other software not mentioned before.
Supports DGN, DWG, DXF, PDF, STEP, IGES, IFC 2x	The ability to import several CAD formats into the software.
Ability to analyze precast elements installation for future improvements	The ability to analyze real erection sequences for future improvements.
Ability to present shop fabrication equipment production rate for future improvements	The ability to keep track of off site fabrication production rate equipment for future improvements.

Table 4-8. Description of the BIM Software Evaluation Criteria for the General Requirements

Description of the software evaluation model for GC	
General criteria	
Description	
Market share leadership position of the vendor offering the BIM solution	These criteria looked at the software vendor experience and how the rest of the market perceived its history in BIM.
Quality of help and supporting documentation, tutorials and other learning resources	These criteria looked at the quality of the supporting documentation that the software developer offers to accelerate the learning period.
Extensibility and customization of the solution	These criteria looked at the ability to request custom made applications.
Engage neighbors or users in understanding construction process	The software ability to present the result in a manner that not technical people could understand and get involved in the process.
Cost of the implementation	The cost to buy the software with the required license.
Recovery mechanism ensures data integrity to the business function level.	The built in ability in the software to maintain a recovery mechanism in to prevent loss of information.
Operates in preferred operating environment (e.g., Windows, UNIX).	The software ability to function in different operating environments or just one.
Necessary upgrades to the company's system	The maturity of the software in the market. It compared if the software is in a beta or a finish version.
Ownership of components clearly define	These criteria looked at the software ability to assigned ownership to the different models and areas of the model.
Number of third party developers developing add on applications for the tool	The number of companies beside the software developer, designing add on applications for the main package.

CHAPTER 5
BIM SOFTWARE EVALUATION MODEL

Once the baseline of the model was created the next step was to create the evaluation criteria to recommend the top five software packages according to the company's responses to the created criteria. This chapter presents a detailed explanation of how the BIM Software Evaluation Model for General Contractors (BIMSEM-GC) works taking into consideration the steps involved in using the model and the required programming language to make the model work.

The model needed to be a simple and easy to use and also take into consideration that when a contractor is using the BIMSEM-GC as part of the implementation process, the contractor is starting to acquire knowledge in the subject. This is why MS Excel was selected as the platform to develop the BIMSEM-GC and also the fact that almost every contractor uses MS Excel nowadays as part of their operations was taken into consideration.

The BIMSEM-GC consists of one main spread sheet called "model" where the selection criteria questions will appear in blank to be filled out by the contractor. The questions are filled out using the same 5-point Likert scale that was used to score the 33 software packages as shown in Figure 5-1. By clicking in the cell the 5-point Likert scale will appear for every question of the evaluation criteria for every phase. The BIMSEM-GC will only display the specified values from 1 to 5 with 1 being the least important and 5 the most important. The model will also display a warning message if the user inputs a value out of the range and will not allow the user to continue with the evaluation until the value is changed.

Once the contractor has answered every question for the preconstruction, construction, post construction, and general criteria the next step is to click the button called "Recommendation" shown in Figure 5-2. By clicking that button the model will start with the

calculation process analyzing the company responses and trying to match those responses with the most appropriate software for those needs.

The BIMSEM-GC will display the top five solutions for every phase, preconstruction, construction, post construction, and general criteria. Figures 5-3 through 5-6 show the name of the most appropriate software package and the given scores for all criteria used by the author, therefore the user will be able to compare every individual score for every recommendation. The recommended software packages for every phase are listed from left to right, with the first one being the one that best fits the company's needs and the last one is the fifth recommendation form the 33 software packages that the model evaluated.

Additionally, the BIMSEM will also display a graph showing the company's performance according to the responses for the criteria and its performance on the combination of the recommendations as shown in Figure 5-7. This will allow the user to determine how well the recommendation is adapted to the company's needs, supporting even more the final selection of the BIM software.

Figure 5-8, shows company's BIM software needs according to the user of the model responses. The BIM model will compare the company's results with the maximum possible scores, also showing if there is a deficiency in any area when implementing BIM. The model should be as balanced as possible, assuming that the company is trying to implement BIM in all the phases of the project. If the company is only implementing BIM in one specific area then the model graph should bias the results to that area, allowing the company to see if any effort is being wasted in any other area where the implementation is not desired.

The final results (See Figures 5-9 to 5-12) shows the recommended software packages and the company's assessment of its level of need by the subtotal score for every evaluation

phase. At this point the user will be able to compare the subtotal score of every package with the subtotal score for the company, supporting one more time the final decision when implementing the software.

The results from testing the BIMSEM-GC model for different possible scenarios determines that there is no single software package that satisfies the needs of a random company for every phase of the project. Most of the times the results will vary from phase to phase and no software package will completely satisfy all the company's needs, there is always a deficiency for some area or some phase of the project. This supports the idea that the best option when implementing BIM in all the project processes is it to consider the implementation of a suite of products that together will cover the most areas of the project workflow.

How does the Model Work? : Thus far the data required to develop the model and to use the model have been explained. Next the description of the process of how the BIMSEM-GC is able to recommend the most appropriate software for every phase while trying to consider every company needs is discussed. The evaluation process for in the model is as follows:

- First the individual software packages scores and the company's needs score are compiled by looking at the subtotal for every phase. The software packages and the company's subtotal are listed in column to then calculate the difference between every software subtotal to the company subtotal for every phase.
- The next step is to calculate the absolute value of every difference and sort the software packages list by the smallest to the largest difference allowing to identify the closest software packages to the company's needs.
- The coefficient of variation at the 95% confidence level is then calculated for every software package and then the company's coefficient of variation is also calculated. Then the difference between the company's needs coefficient of variation and every software package's coefficient of variation is calculated. This will allow the model to select the solution with the most similar behavior according to the company's needs.
- The final process was to sort the software packages listed by the smallest to the largest absolute difference for the coefficient of variation. Then the top five names for every phase are recommended in the "model" spread sheet.

This whole process was programmed by using MS Visual Basic to facilitate the use of the BIMSEM-GC and the program coding is shown in Appendix A.

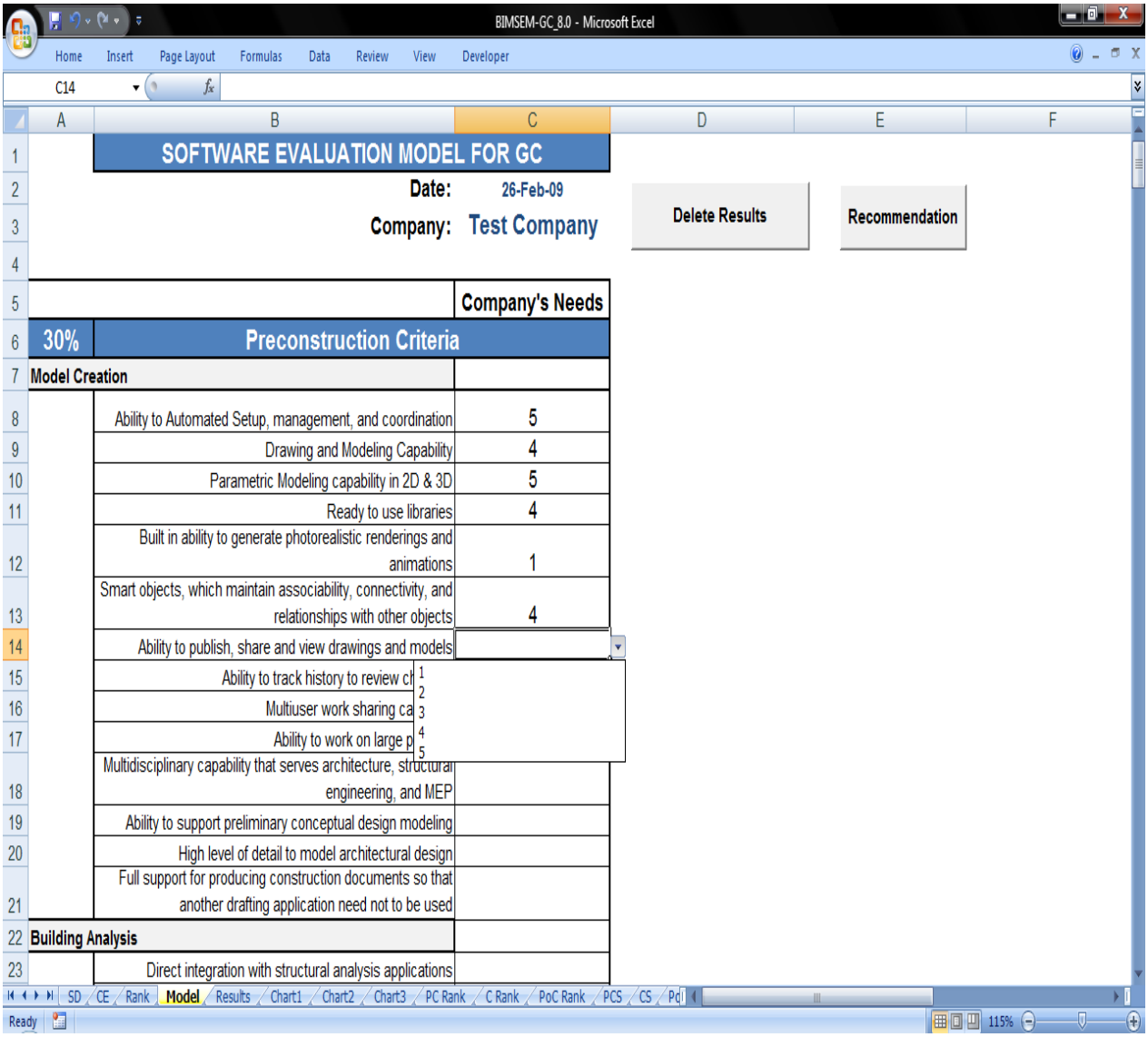


Figure 5-1. BIMSEM-GC Screen capture: Importance selection of the different criteria.

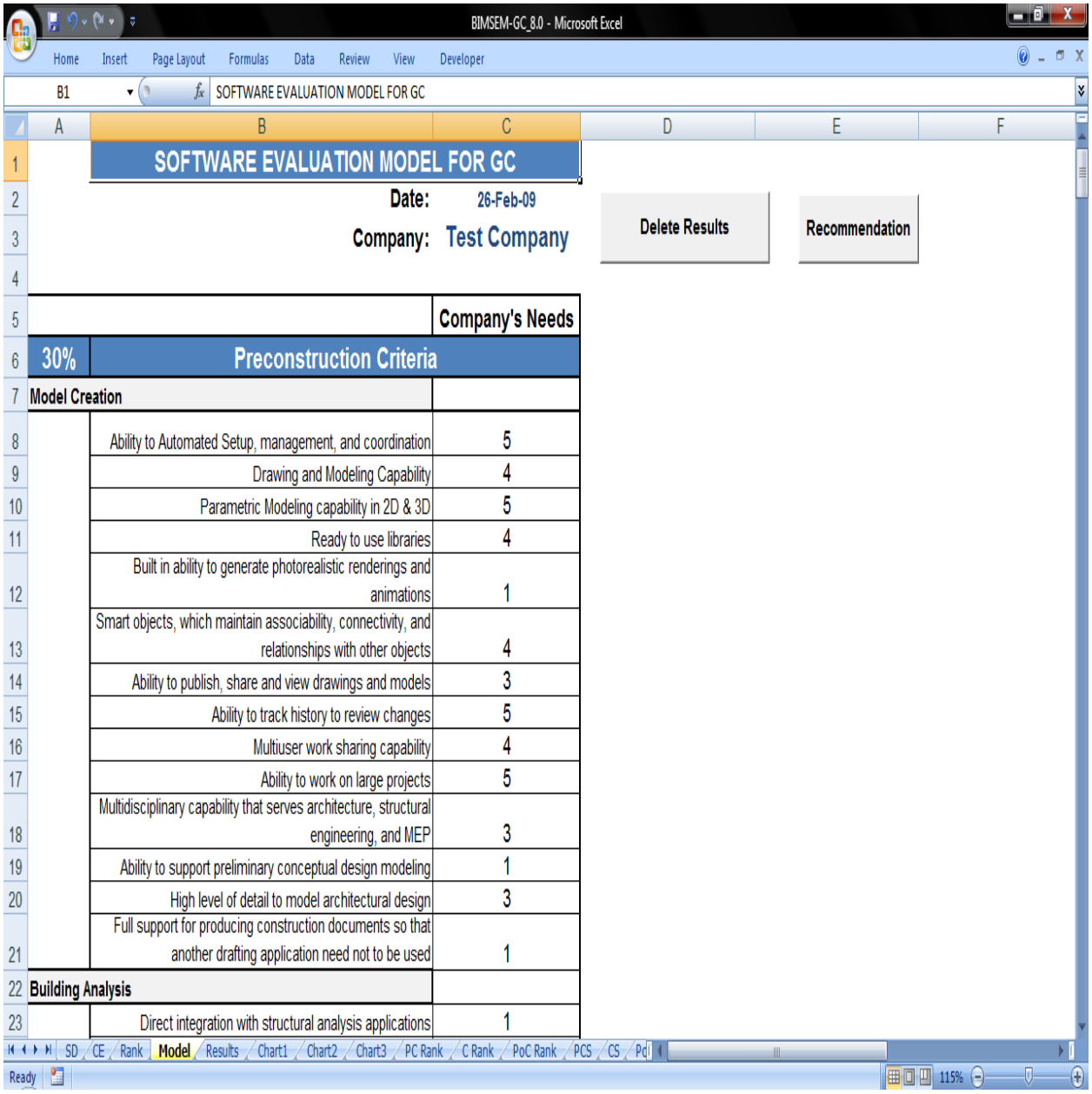
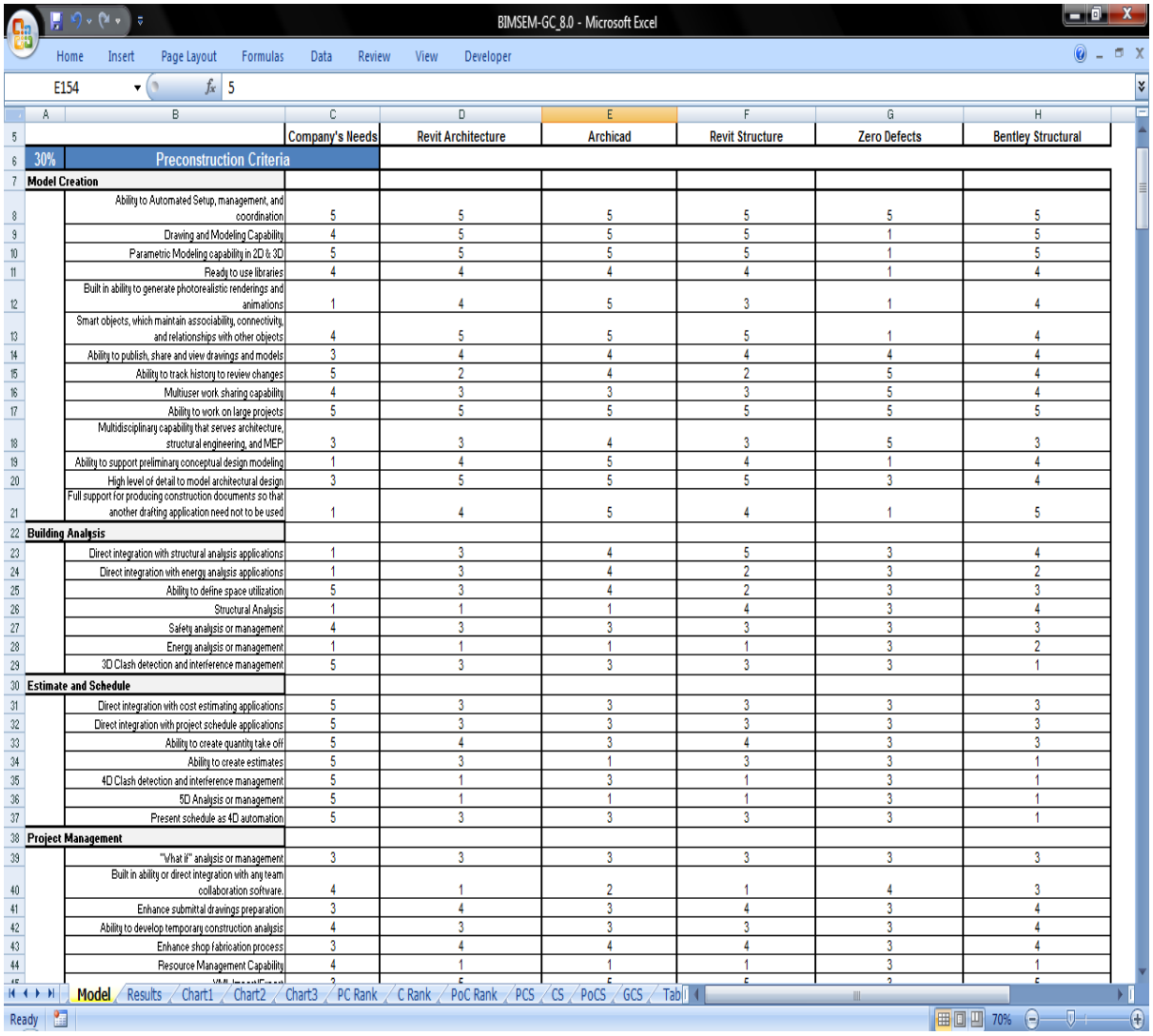


Figure 5-2. BIMSEM-GC Screen capture: Before clicking the recommendation button



BIMSEM-GC_8.0 - Microsoft Excel

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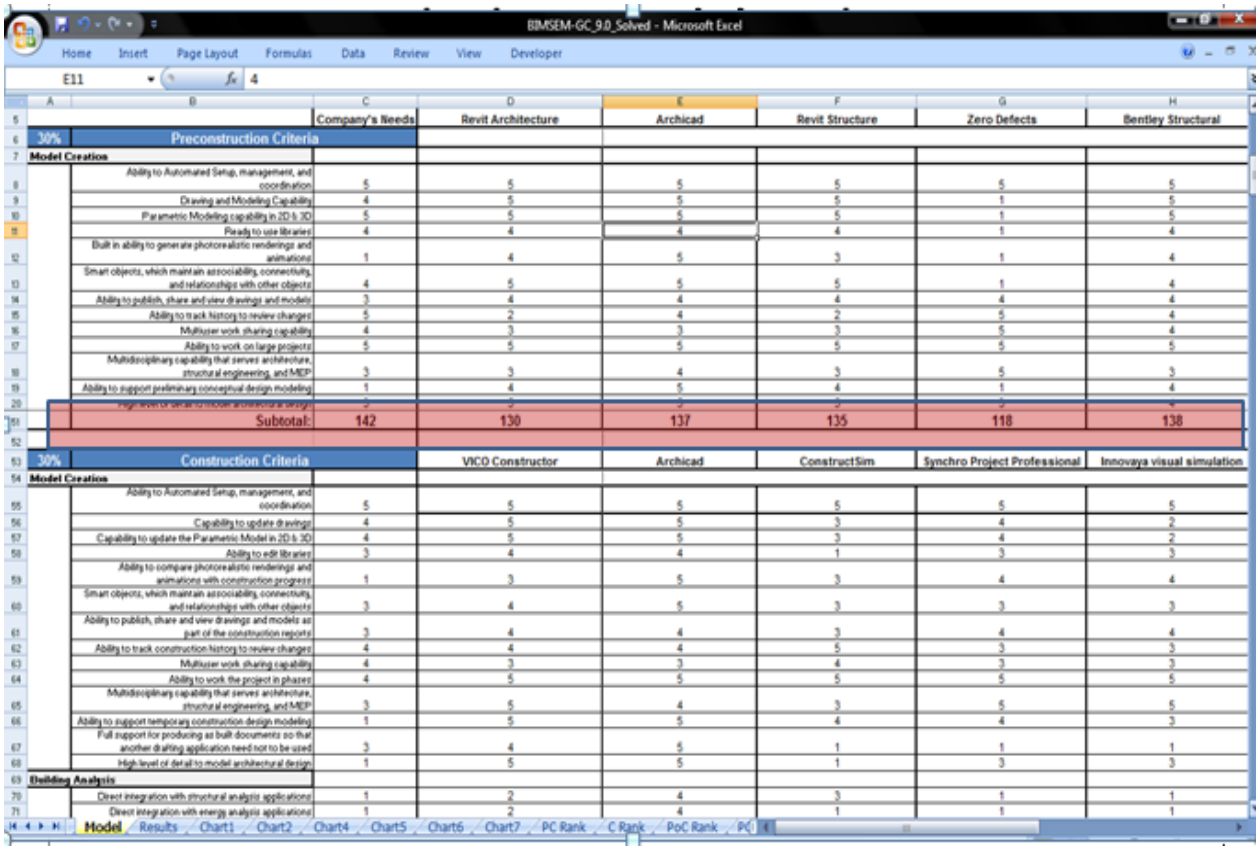
		Company's Needs	Revit Architecture	Archicad	Revit Structure	Zero Defects	Bentley Structural
30%	Preconstruction Criteria						
Model Creation							
	Ability to Automated Setup, management, and coordination	5	5	5	5	5	5
	Draving and Modeling Capability	4	5	5	5	1	5
	Parametric Modeling capability in 2D & 3D	5	5	5	5	1	5
	Ready to use libraries	4	4	4	4	1	4
	Built in ability to generate photorealistic renderings and animations	1	4	5	3	1	4
	Smart objects, which maintain associability, connectivity, and relationships with other objects	4	5	5	5	1	4
	Ability to publish, share and view dravings and models	3	4	4	4	4	4
	Ability to track history to review changes	5	2	4	2	5	4
	Multiuser work sharing capability	4	3	3	3	5	4
	Ability to work on large projects	5	5	5	5	5	5
	Multidisciplinary capability that serves architecture, structural engineering, and MEP	3	3	4	3	5	3
	Ability to support preliminary conceptual design modeling	1	4	5	4	1	4
	High level of detail to model architectural design	3	5	5	5	3	4
	Full support for producing construction documents so that another drafting application need not to be used	1	4	5	4	1	5
Building Analysis							
	Direct integration with structural analysis applications	1	3	4	5	3	4
	Direct integration with energy analysis applications	1	3	4	2	3	2
	Ability to define space utilization	5	3	4	2	3	3
	Structural Analysis	1	1	1	4	3	4
	Safety analysis or management	4	3	3	3	3	3
	Energy analysis or management	1	1	1	1	3	2
	3D Clash detection and interference management	5	3	3	3	3	1
Estimate and Schedule							
	Direct integration with cost estimating applications	5	3	3	3	3	3
	Direct integration with project schedule applications	5	3	3	3	3	3
	Ability to create quantity take off	5	4	3	4	3	3
	Ability to create estimates	5	3	1	3	3	1
	4D Clash detection and interference management	5	1	3	1	3	1
	5D Analysis or management	5	1	1	1	3	1
	Present schedule as 4D automation	5	3	3	3	3	1
Project Management							
	"What if" analysis or management	3	3	3	3	3	3
	Built in ability or direct integration with any team collaboration software.	4	1	2	1	4	3
	Enhance submittal dravings preparation	3	4	3	4	3	4
	Ability to develop temporary construction analysis	4	3	3	3	3	4
	Enhance shop fabrication process	3	4	4	4	3	4
	Resource Management Capability	4	1	1	1	3	1

Model | Results | Chart1 | Chart2 | Chart3 | PC Rank | C Rank | PoC Rank | PCS | CS | PoCS | GCS | Tab

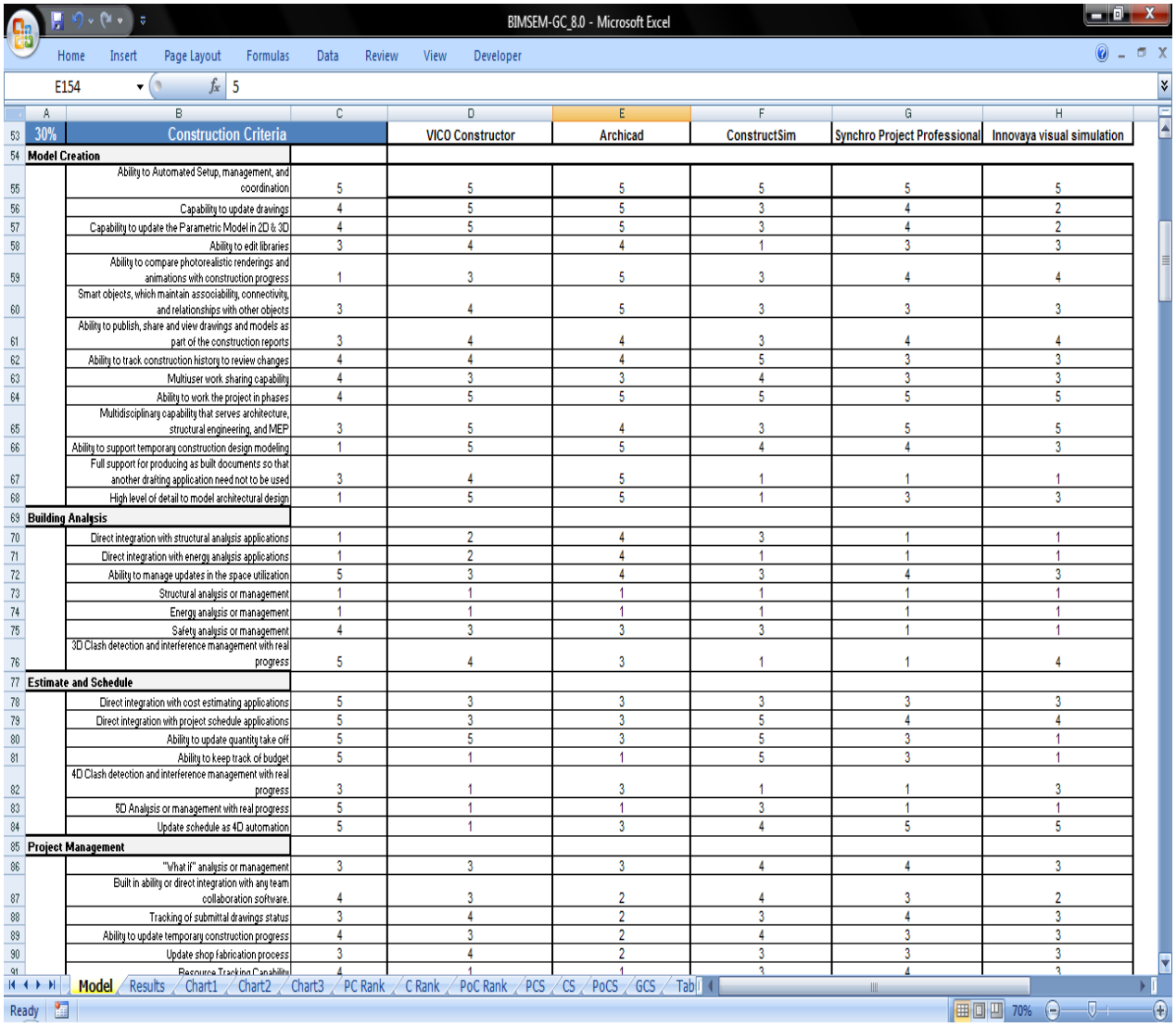
Ready 70%

Figure 5-3. BIMSEM-GC Screen capture: Preconstruction top five recommendations



		Company's Needs	Revit Architecture	Archicad	Revit Structure	Zero Defects	Bentley Structural
30%	Preconstruction Criteria						
Model Creation							
	Ability to Automated Setup, management, and coordination	5	5	5	5	5	5
	Drawing and Modeling Capability	4	5	5	5	1	5
	Parametric Modeling capability in 2D & 3D	5	5	5	5	1	5
	Ready to use libraries	4	4	4	4	1	4
	Built in ability to generate photorealistic renderings and animations	1	4	5	3	1	4
	Smart objects, which maintain associability, connectivity, and relationships with other objects	4	5	5	5	1	4
	Ability to publish, share and view drawings and models	3	4	4	4	4	4
	Ability to track history to review changes	5	2	4	2	5	4
	Multiuser work sharing capability	4	3	3	3	5	4
	Ability to work on large projects	5	5	5	5	5	5
	Multidisciplinary capability that serves architecture, structural engineering, and MEP	3	3	4	3	5	3
	Ability to support preliminary conceptual design modeling	1	4	5	4	1	4
	High level of detail to model architectural design	5	5	5	5	5	4
	Subtotal:	142	130	137	135	118	138
30%	Construction Criteria		VICO Constructor	Archicad	ConstructSim	Synchro Project Professional	Innovaya visual simulation
Model Creation							
	Ability to Automated Setup, management, and coordination	5	5	5	5	5	5
	Capability to update drawings	4	5	5	3	4	2
	Capability to update the Parametric Model in 2D & 3D	4	5	5	3	4	2
	Ability to edit libraries	3	4	4	1	3	3
	Ability to compare photorealistic renderings and animations with construction progress	1	3	5	3	4	4
	Smart objects, which maintain associability, connectivity, and relationships with other objects	3	4	5	3	3	3
	Ability to publish, share and view drawings and models as part of the construction reports	3	4	4	3	4	4
	Ability to track construction history to review changes	4	4	4	5	3	3
	Multiuser work sharing capability	4	3	3	4	3	3
	Ability to work the project in phases	4	5	5	5	5	5
	Multidisciplinary capability that serves architecture, structural engineering, and MEP	3	5	4	3	5	5
	Ability to support temporary construction design modeling	1	5	5	4	4	3
	Full support for producing as built documents so that another drafting application need not to be used	3	4	5	1	1	1
	High level of detail to model architectural design	1	5	5	1	3	3
Building Analysis							
	Direct integration with structural analysis applications	1	2	4	3	1	1
	Direct integration with energy analysis applications	1	2	4	1	1	1

Figure 5-4. BIMSEM-GC Screen capture: Preconstruction subtotal scores



BIMSEM-GC_8.0 - Microsoft Excel

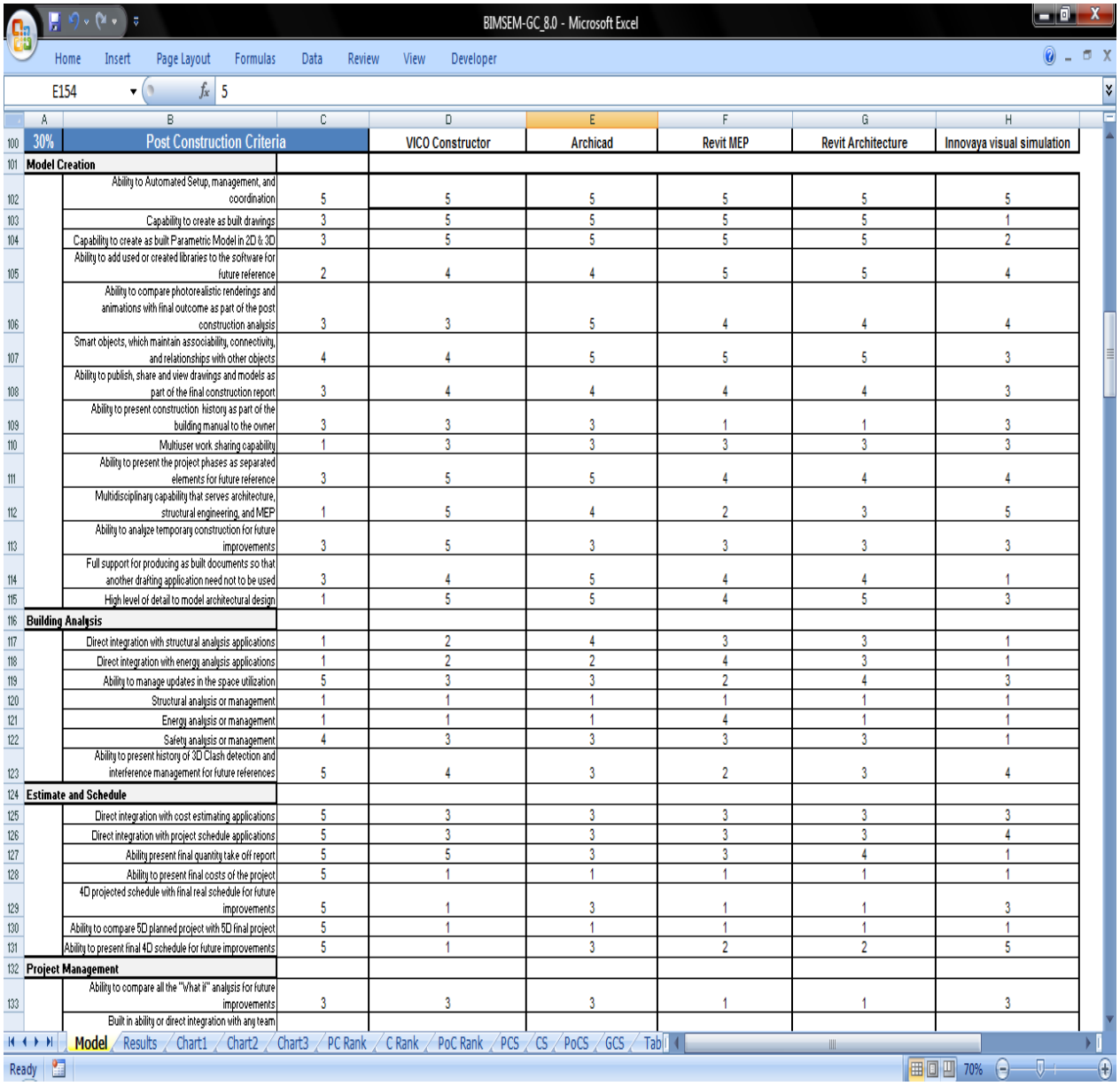
E154 | 5

30%	Construction Criteria	VICO Constructor	Archicad	ConstructSim	Synchro Project Professional	Innovaya visual simulation
Model Creation						
	Ability to Automated Setup, management, and coordination	5	5	5	5	5
	Capability to update drawings	4	5	5	3	4	2
	Capability to update the Parametric Model in 2D & 3D	4	5	5	3	4	2
	Ability to edit libraries	3	4	4	1	3	3
	Ability to compare photorealistic renderings and animations with construction progress	1	3	5	3	4	4
	Smart objects, which maintain associability, connectivity, and relationships with other objects	3	4	5	3	3	3
	Ability to publish, share and view drawings and models as part of the construction reports	3	4	4	3	4	4
	Ability to track construction history to review changes	4	4	4	5	3	3
	Multiuser work sharing capability	4	3	3	4	3	3
	Ability to work the project in phases	4	5	5	5	5	5
	Multidisciplinary capability that serves architecture, structural engineering, and MEP	3	5	4	3	5	5
	Ability to support temporary construction design modeling	1	5	5	4	4	3
	Full support for producing as built documents so that another drafting application need not to be used	3	4	5	1	1	1
	High level of detail to model architectural design	1	5	5	1	3	3
Building Analysis						
	Direct integration with structural analysis applications	1	2	4	3	1	1
	Direct integration with energy analysis applications	1	2	4	1	1	1
	Ability to manage updates in the space utilization	5	3	4	3	4	3
	Structural analysis or management	1	1	1	1	1	1
	Energy analysis or management	1	1	1	1	1	1
	Safety analysis or management	4	3	3	3	1	1
	3D Clash detection and interference management with real progress	5	4	3	1	1	4
Estimate and Schedule						
	Direct integration with cost estimating applications	5	3	3	3	3	3
	Direct integration with project schedule applications	5	3	3	5	4	4
	Ability to update quantity take off	5	5	3	5	3	1
	Ability to keep track of budget	5	1	1	5	3	1
	4D Clash detection and interference management with real progress	3	1	3	1	1	3
	5D Analysis or management with real progress	5	1	1	3	1	1
	Update schedule as 4D automation	5	1	3	4	5	5
Project Management						
	"What if" analysis or management	3	3	3	4	4	3
	Built in ability or direct integration with any team collaboration software.	4	3	2	4	3	2
	Tracking of submittal drawings status	3	4	2	3	4	3
	Ability to update temporary construction progress	4	3	2	4	3	3
	Update shop fabrication process	3	4	2	3	3	3
	Resource Tracking Capability	4	1	1	3	4	3

Model | Results | Chart1 | Chart2 | Chart3 | PC Rank | C Rank | PoC Rank | PCS | CS | PoCS | GCS | Tabl

Ready | 70%

Figure 5-5. BIMSEM-GC Screen capture: Construction top five recommendations

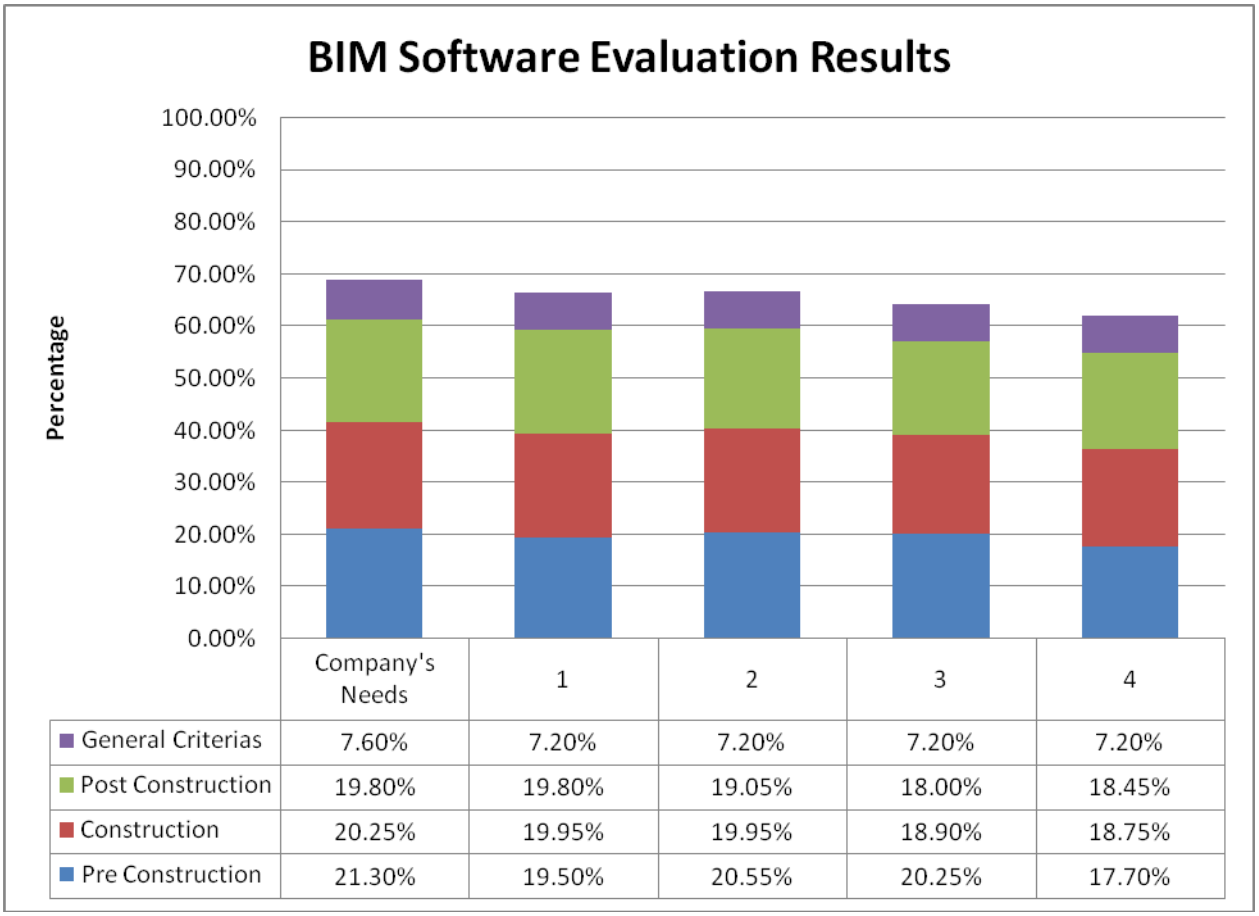


BIMSEM-GC_8.0 - Microsoft Excel

E154 | 5

30%	Post Construction Criteria	VICO Constructor	Archicad	Revit MEP	Revit Architecture	Innovaya visual simulation
Model Creation						
Ability to Automated Setup, management, and coordination	5	5	5	5	5	5
Capability to create as built drawings	3	5	5	5	5	1
Capability to create as built Parametric Model in 2D & 3D	3	5	5	5	5	2
Ability to add used or created libraries to the software for future reference	2	4	4	5	5	4
Ability to compare photorealistic renderings and animations with final outcome as part of the post construction analysis	3	3	5	4	4	4
Smart objects, which maintain associability, connectivity, and relationships with other objects	4	4	5	5	5	3
Ability to publish, share and view drawings and models as part of the final construction report	3	4	4	4	4	3
Ability to present construction history as part of the building manual to the owner	3	3	3	1	1	3
Multiuser work sharing capability	1	3	3	3	3	3
Ability to present the project phases as separated elements for future reference	3	5	5	4	4	4
Multidisciplinary capability that serves architecture, structural engineering, and MEP	1	5	4	2	3	5
Ability to analyze temporary construction for future improvements	3	5	3	3	3	3
Full support for producing as built documents so that another drafting application need not to be used	3	4	5	4	4	1
High level of detail to model architectural design	1	5	5	4	5	3
Building Analysis						
Direct integration with structural analysis applications	1	2	4	3	3	1
Direct integration with energy analysis applications	1	2	2	4	3	1
Ability to manage updates in the space utilization	5	3	3	2	4	3
Structural analysis or management	1	1	1	1	1	1
Energy analysis or management	1	1	1	4	1	1
Safety analysis or management	4	3	3	3	3	1
Ability to present history of 3D Clash detection and interference management for future references	5	4	3	2	3	4
Estimate and Schedule						
Direct integration with cost estimating applications	5	3	3	3	3	3
Direct integration with project schedule applications	5	3	3	3	3	4
Ability present final quantity take off report	5	5	3	3	4	1
Ability to present final costs of the project	5	1	1	1	1	1
4D projected schedule with final real schedule for future improvements	5	1	3	1	1	3
Ability to compare 5D planned project with 5D final project	5	1	1	1	1	1
Ability to present final 4D schedule for future improvements	5	1	3	2	2	5
Project Management						
Ability to compare all the "What if" analysis for future improvements	3	3	3	1	1	3
Built in ability or direct integration with any team						

Figure 5-6. BIMSEM-GC Screen capture: Post Construction top five recommendations



	Company's Needs	1	2	3	4
General Criterias	7.60%	7.20%	7.20%	7.20%	7.20%
Post Construction	19.80%	19.80%	19.05%	18.00%	18.45%
Construction	20.25%	19.95%	19.95%	18.90%	18.75%
Pre Construction	21.30%	19.50%	20.55%	20.25%	17.70%

Figure 5-7. Combination performance of the different top recommended software

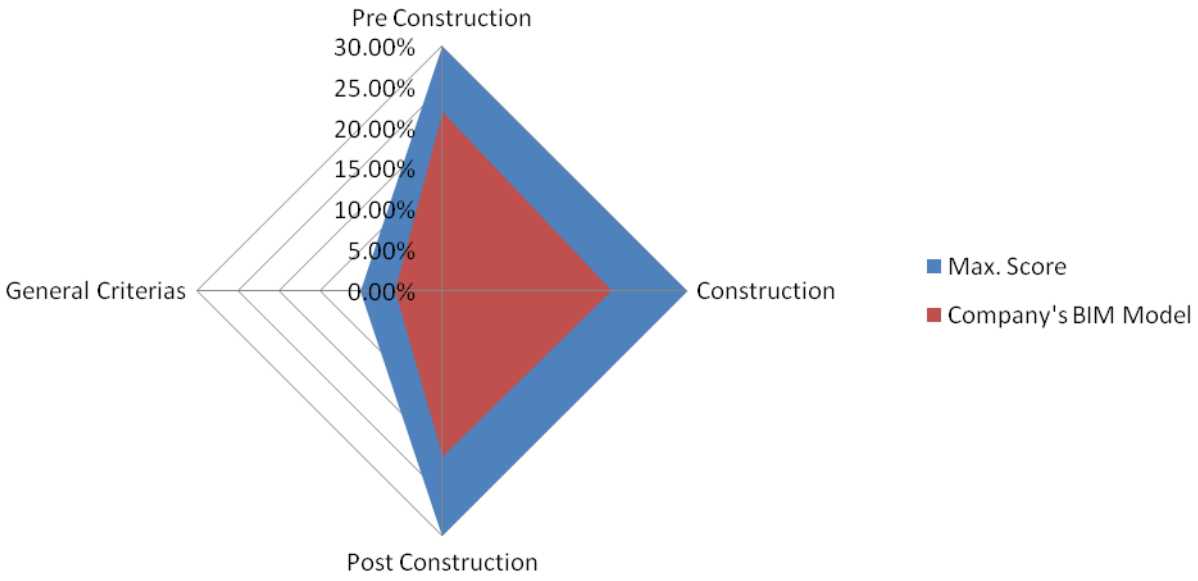


Figure 5-8. Company’s Real BIM model compared with perceived BIM model

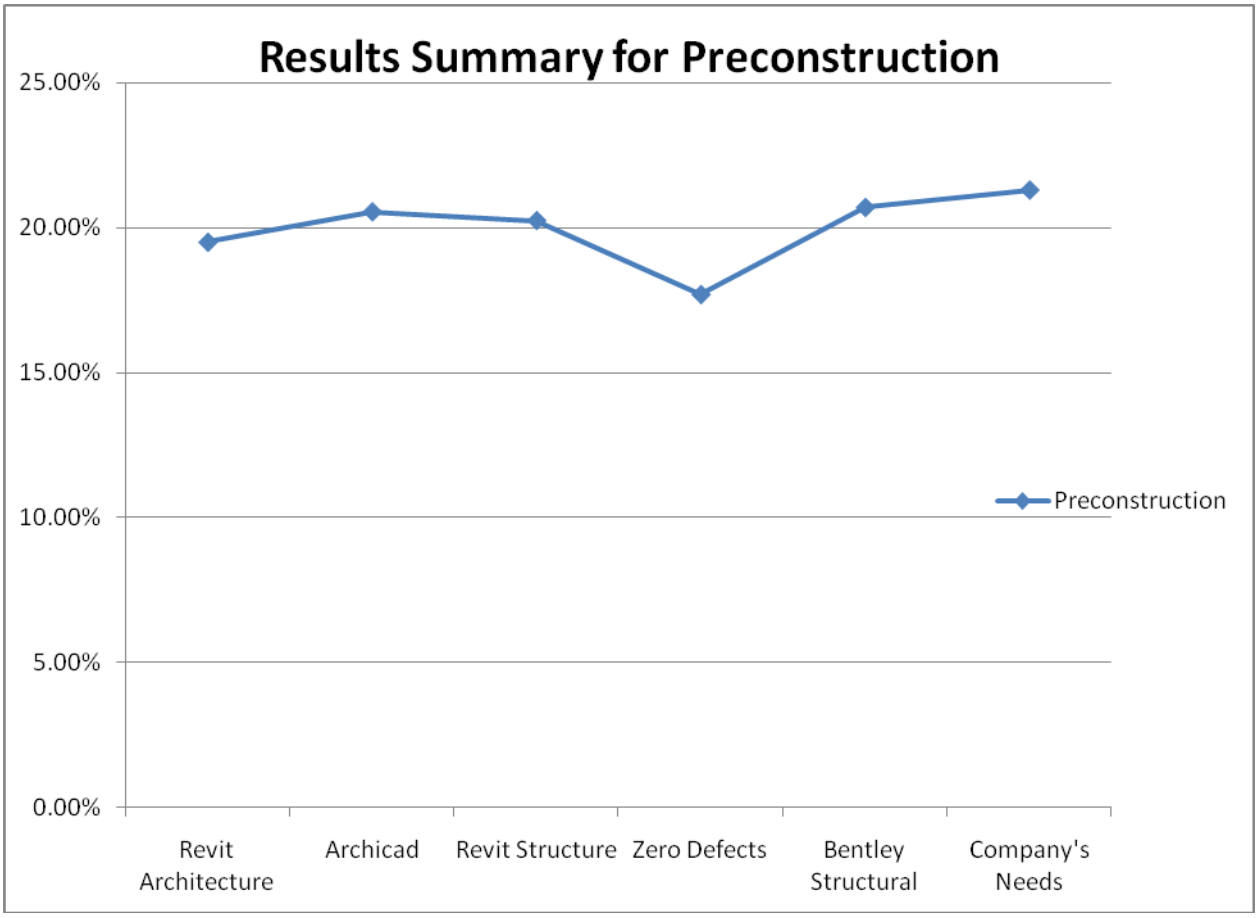


Figure 5-9. Recommended and Company's subtotal behavior for Preconstruction

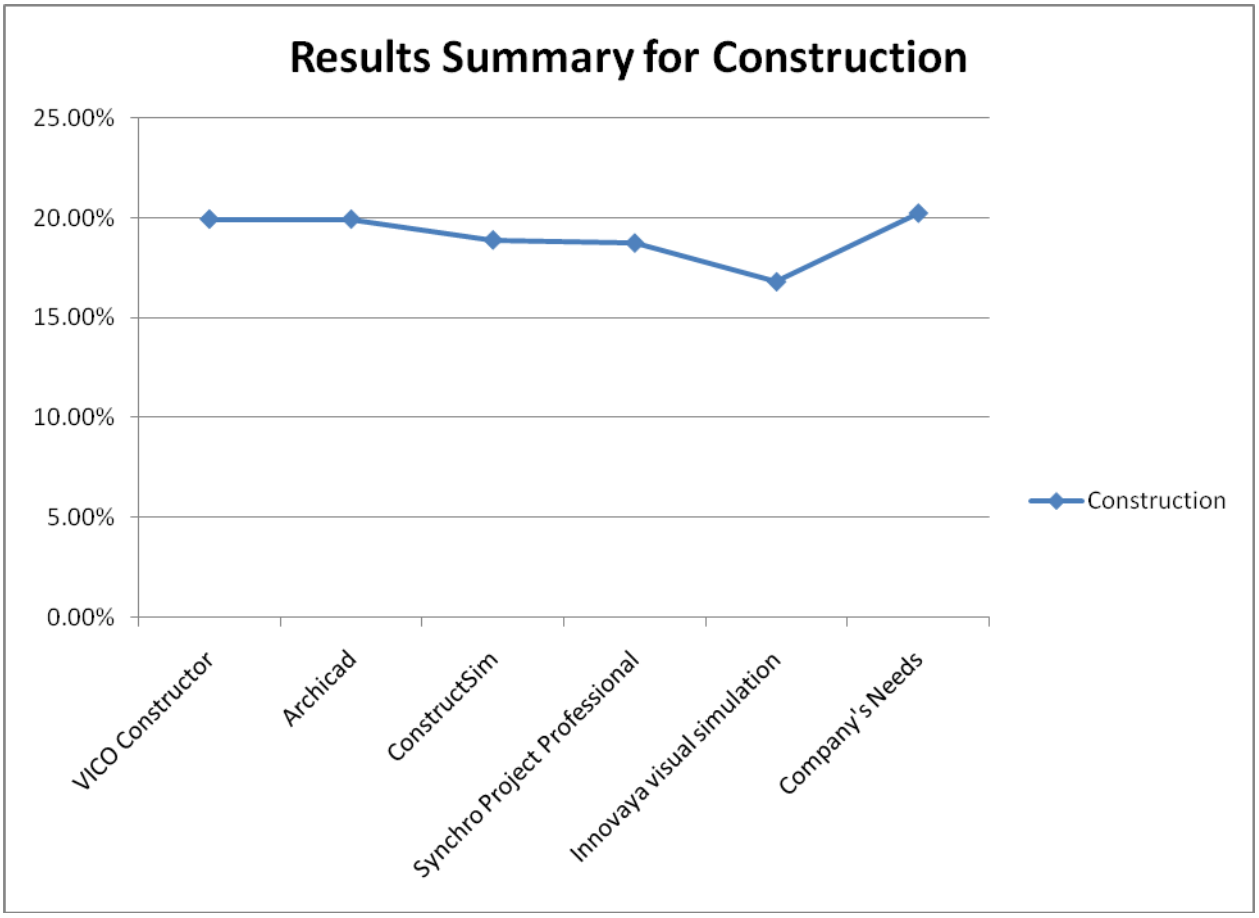


Figure 5-10. Recommended and Company's subtotal behavior for Construction

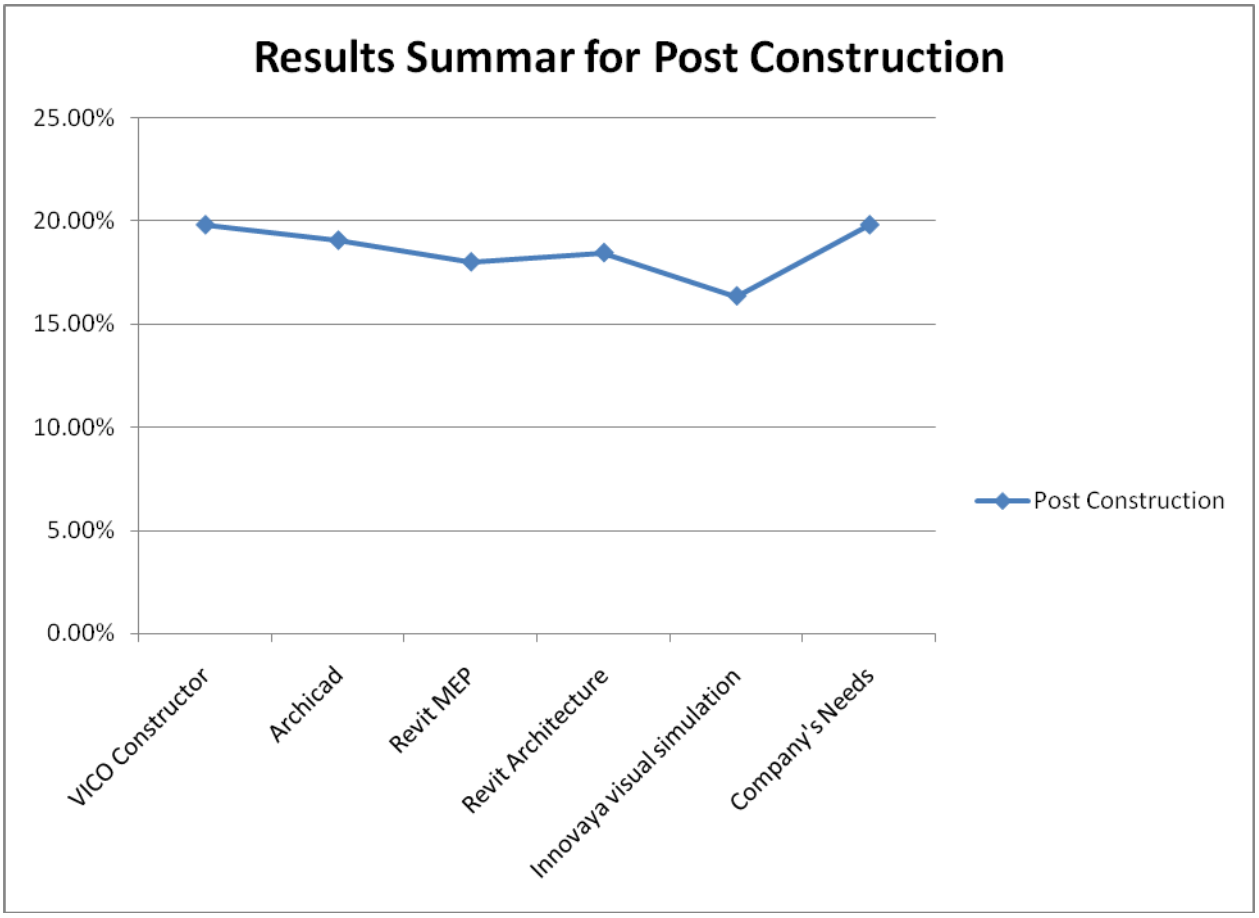


Figure 5-11. Recommended and Company's subtotal behavior for Post Construction

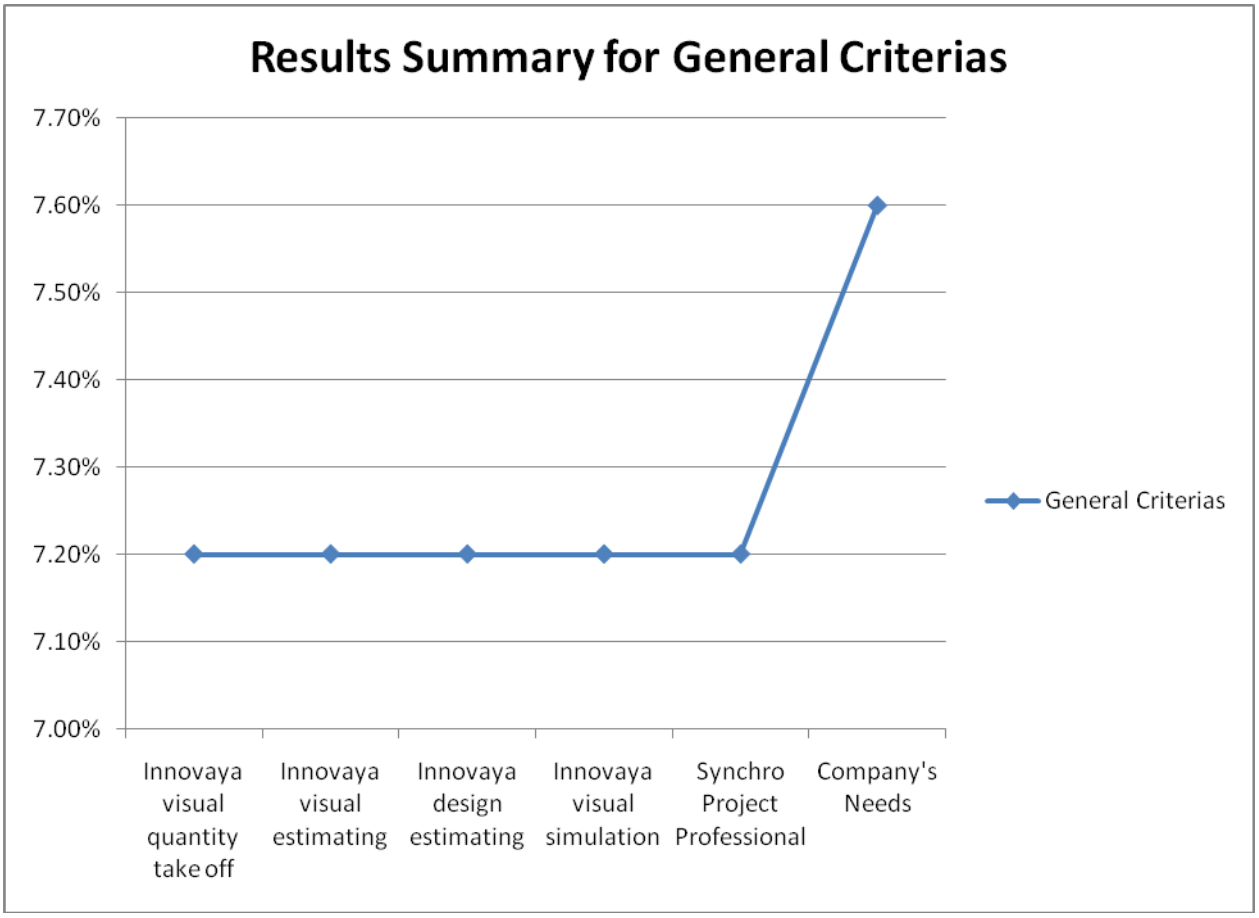


Figure 5-12. Recommended and Company's subtotal behavior for the General Criteria

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Building Information Modeling technology is being used more and more by general contractors, the need to optimize processes, cost, quality, and safety in the industry creates the perfect conditions to guarantee that BIM is going to be around from this point on. BIM technology will continue to evolve offering unthinkable solutions nowadays for the construction industry and bringing more applications to a market that today seems to be full of applications. This study looked at 33 different software packages ranking them by the authors' criteria and acquired knowledge during the preparation of the study, creating the baseline for an interactive evaluation model. The proposed model should be continuously updated and fed constantly with other BIM Packages and new solutions from companies, perhaps incorporating more evaluation criteria or changing some of them according to their needs.

The model created during this study looked at the company's needs to recommend the five software packages that come closest to satisfying those needs. The model will not recommend the best software in the market, but the software packages that fit the best the company's needs. It is recommended for future models to consider suggesting not only the software that comes closest to meeting the GC needs but also those that exceed them in order to allow the company to consider any future grow.

From the initial evaluation of the 33 software packages it was noticed that the average performance was not as good as expected when looking at the individual solution, but is can be expected that the performance will be improved when using a suit of solutions for certain project.

Also from the evaluation of the 33 software solutions looked at in this research, one conclusion was that there is no individual package that satisfies all the possible company's needs looked at as part of this study. The sum or the combination of different packages for different

phases of the project would be the best option for a company looking to implement BIM technology during all the construction process.

The proposed use of different software packages for every phase of construction highlights the importance of interoperable programs, where no matter what software is being used during the project, the product of that particular software will be recognize entirely by the rest of the software packages. An analysis of the integration of different software packages would be recommended to determine which combination fulfills the most company's needs when applied to the different phases of the project for a general contractor.

Looking at the study of the individual solutions, a set of common applications were found. Applications like parametric modeling, quantity take off, clash detections, 4D simulations and interoperable application can be consider the minimum standard for a BIM implementation from a general contractor. Considering the great number of software developers that offer this in one or all of their software packages.

Also a number of more specific applications were identified; applications that in most of the cases applied more for the general contractor needs, but are still in the development phase and which are not standard in every software package. These solutions were: 5D analyses, bill-of materials, earned value analysis, collaboration tools, bidirectional links with fabrication equipment, micromanagement capabilities, resource management, Monte Carlo risk analysis, code compliance, etc.

It is important to remember that this study should be used as a complement to a structured implementation process from the general contractor. Once the model is used and the preferred software is selected, a trial period of the preferred software should be implemented to optimize the benefits at the time of the full implementation.

CHAPTER 7
FUTURE DIRECTION

Building Information Modeling (BIM) is going to continue evolving and new software packages will appear with more solutions for contractors. These new software packages will add to the already great number of choices that general contractors already have increasing the importance of having a software evaluation model tool, but not only that, it will also require a tool that monitors how well the implemented software is being used.

The following section was divided in 2 parts, the first one discusses the evolution that the BIM software packages may have and new opportunities on the horizon and the second part discusses the necessary improvements to software evaluation techniques.

BIM software developers are going to start selling integrated solution considering that the performance of every individual package is limited. Nowadays the industry is looking for more integration of processes forcing the software developers to evolve and offer packages with a group of solutions that satisfy more areas of the entire project than a solution that will only fulfill the needs of one area.

Another application that the software developers may put to work in their packages is the ability to check required codes. These codes can go from building codes, environmental codes, structural codes, or a set of best design criteria, so far only Solibri Model Checker offers a limited capacity to develop code checking, but is it is an application that the market will start asking more and more for.

Laser scanning is an application that none of the studied software offered, but it may bring big advantages to the contractor to be able to maintain a laser scan working during the construction process to be able to track the process in real time and to automatically update the model.

It is important to analyze the legal procedure once the selection decision is done; there are some baselines for the legal requirements to look at when buying BIM software, specifically requirements for the software vendors. These requirements can go from minimum performance standards to maintenance and technical support expectations.

Another area where software evaluation needs to pay more attention is in keeping a performance score of the software analyzed to monitor whether the selected software was the best decision and to allow the user to understand much better their real needs.

APPENDIX

PROGRAMMING OF THE BIM SOFTWARE EVALUATION MODEL FOR GENERAL CONTRACTORS IN MS VISUAL BASIC

```
Sub Delete()
'
' Delete Macro
'
    Range("D5:H521").Select
    Selection.ClearContents
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    Selection.Borders(xlEdgeLeft).LineStyle = xlNone
    Selection.Borders(xlEdgeTop).LineStyle = xlNone
    Selection.Borders(xlEdgeBottom).LineStyle = xlNone
    Selection.Borders(xlEdgeRight).LineStyle = xlNone
    Selection.Borders(xlInsideVertical).LineStyle = xlNone
    Selection.Borders(xlInsideHorizontal).LineStyle = xlNone
    Range("A5:C158").Select
    Range("C5").Activate
    Selection.Borders(xlDiagonalDown).LineStyle = xlNone
    Selection.Borders(xlDiagonalUp).LineStyle = xlNone
    With Selection.Borders(xlEdgeLeft)
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlMedium
    End With
    With Selection.Borders(xlEdgeTop)
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlMedium
    End With
    With Selection.Borders(xlEdgeBottom)
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlMedium
    End With
    With Selection.Borders(xlEdgeRight)
        .LineStyle = xlContinuous
        .ColorIndex = 0
        .TintAndShade = 0
        .Weight = xlMedium
    End With
    Range("C8:C50").Select
```

```
Selection.ClearContents
ActiveWindow.SmallScroll Down:=45
Range("C55:C97").Select
Selection.ClearContents
ActiveWindow.SmallScroll Down:=48
Range("C102:C144").Select
Selection.ClearContents
ActiveWindow.SmallScroll Down:=54
Range("C148:C157").Select
Selection.ClearContents
Range("D153").Select
ActiveWindow.SmallScroll Down:=-183
Sheets("PCS").Select
Range("A3:D35").Select
ActiveWindow.SmallScroll Down:=-60
Range("B3:B36").Select
Range("B36").Activate
ActiveWindow.SmallScroll Down:=18
Range("C27").Select
ActiveWindow.SmallScroll Down:=-81
Range("A3").Select
ActiveCell.FormulaR1C1 = "Rank  "
With ActiveCell.Characters(Start:=1, Length:=6).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("B3").Select
ActiveCell.FormulaR1C1 = "Software"
With ActiveCell.Characters(Start:=1, Length:=8).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
```

```
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("C3").Select
ActiveCell.FormulaR1C1 = "Company Score"
With ActiveCell.Characters(Start:=1, Length:=13).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("D3").Select
ActiveCell.FormulaR1C1 = "Software Score"
With ActiveCell.Characters(Start:=1, Length:=14).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("E3").Select
ActiveCell.FormulaR1C1 = "Dif."
With ActiveCell.Characters(Start:=1, Length:=4).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
```

```
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("F3").Select
ActiveCell.FormulaR1C1 = "Abs"
With ActiveCell.Characters(Start:=1, Length:=3).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("G3").Select
ActiveCell.FormulaR1C1 = "Comp. C.V 95%"
With ActiveCell.Characters(Start:=1, Length:=13).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("H3").Select
ActiveCell.FormulaR1C1 = "Soft. C.V 95%"
With ActiveCell.Characters(Start:=1, Length:=13).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
```

```
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("I3").Select
ActiveCell.FormulaR1C1 = "Dif."
With ActiveCell.Characters(Start:=1, Length:=4).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("J3").Select
ActiveCell.FormulaR1C1 = "Abs"
With ActiveCell.Characters(Start:=1, Length:=3).Font
    .Name = "Arial"
    .FontStyle = "Regular"
    .Size = 10
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlUnderlineStyleNone
    .ColorIndex = xlAutomatic
    .TintAndShade = 0
    .ThemeFont = xlThemeFontNone
End With
Range("A4:D36").Select
Selection.ClearContents
Range("E4:F4").Select
Selection.Copy
```

```
    Range("E5:F36").Select
    ActiveSheet.Paste
    Application.CutCopyMode = False
    Range("G4:H36").Select
    Selection.ClearContents
    Range("I4:J4").Select
    Selection.Copy
    Range("I5:J36").Select
    ActiveSheet.Paste
    Application.CutCopyMode = False
    Range("A3:J36").Select
    Range("J36").Activate
    Selection.Copy
    Sheets("CS").Select
    Range("A3").Select
    ActiveSheet.Paste
    ActiveWindow.SmallScroll Down:=-48
    Sheets("PoCS").Select
    Range("A3").Select
    ActiveSheet.Paste
    Sheets("GCS").Select
    Range("A3").Select
    ActiveSheet.Paste
    Range("E14:J36").Select
    Application.CutCopyMode = False
    Range("A1").Select
    Sheets("Model").Select
End Sub
Sub Recommend()
'
' Recommend Macro
'

'
    Sheets("Rank").Select
    ActiveWindow.SmallScroll Down:=-879
    Range("C4:AI4").Select
    Selection.Copy
    Sheets("PCS").Select
    Range("B4").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=True
    ActiveWindow.SmallScroll Down:=-6
    Sheets("CS").Select
    Range("B4").Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
```

```
    :=False, Transpose:=True
Sheets("PoCS").Select
Range("B4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
Sheets("GCS").Select
Range("B4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
Sheets("Rank").Select
ActiveWindow.SmallScroll ToRight:=-20
ActiveWindow.LargeScroll ToRight:=-3
ActiveWindow.SmallScroll ToRight:=-2
ActiveWindow.SmallScroll Down:=36
Range("C50:AI50").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PCS").Select
Range("D4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
ActiveWindow.SmallScroll Down:=-15
Sheets("Rank").Select
ActiveWindow.SmallScroll ToRight:=-30
ActiveWindow.SmallScroll Down:=48
Range("C97:AI97").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("CS").Select
Range("D4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
ActiveWindow.SmallScroll Down:=-54
Sheets("Rank").Select
ActiveWindow.SmallScroll ToRight:=-30
ActiveWindow.SmallScroll Down:=51
Range("C144:AI144").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PoCS").Select
Range("D4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
Sheets("Rank").Select
ActiveWindow.SmallScroll ToRight:=-29
ActiveWindow.SmallScroll Down:=9
```

```
Range("C157:AI157").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("GCS").Select
Range("D4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
ActiveWindow.SmallScroll Down:=-33
Sheets("Rank").Select
ActiveWindow.SmallScroll Down:=-3
ActiveWindow.SmallScroll ToRight:=-30
ActiveWindow.SmallScroll Down:=9
Range("C169:AI169").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PCS").Select
Range("H4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
ActiveWindow.SmallScroll Down:=-6
Sheets("Rank").Select
ActiveWindow.SmallScroll ToRight:=-2
ActiveWindow.SmallScroll Down:=-3
ActiveWindow.SmallScroll ToRight:=-28
ActiveWindow.SmallScroll Down:=12
Range("C180:AI180").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("CS").Select
Range("H4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
Sheets("Rank").Select
ActiveWindow.SmallScroll ToRight:=-29
ActiveWindow.SmallScroll Down:=12
Range("C191:AI191").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PoCS").Select
Range("H4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
Sheets("Rank").Select
ActiveWindow.SmallScroll ToRight:=-29
ActiveWindow.SmallScroll Down:=6
Range("C202:AI202").Select
```

```
Application.CutCopyMode = False
Selection.Copy
Sheets("GCS").Select
Range("H4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
ActiveWindow.SmallScroll Down:=-15
Sheets("PCS").Select
Range("C4").Select
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=30
Range("C51").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PCS").Select
Range("C4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Application.CutCopyMode = False
Selection.Copy
Range("C5:C36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=51
Range("C98").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("CS").Select
Range("C4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Application.CutCopyMode = False
Selection.Copy
Range("C5:C36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=57
Range("C145").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PoCS").Select
Range("C4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
```

```
Application.CutCopyMode = False
Selection.Copy
Range("C5:C36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=12
Range("C158").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("GCS").Select
Range("C4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Application.CutCopyMode = False
Selection.Copy
Range("C5:C36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("Model").Select
Range("C170").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PCS").Select
Range("G4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Application.CutCopyMode = False
Selection.Copy
Range("G5:G36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=12
Range("C181").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("CS").Select
Range("G4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Application.CutCopyMode = False
Selection.Copy
Range("G5:G36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
```

```
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=15
Range("C192").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("PoCS").Select
Range("G4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Application.CutCopyMode = False
Selection.Copy
Range("G5:G36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=9
Range("C203").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("GCS").Select
Range("G4").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Application.CutCopyMode = False
Selection.Copy
Range("G5:G36").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Sheets("PCS").Select
Range("A5").Select
Application.CutCopyMode = False
ActiveWorkbook.Worksheets("PCS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("PCS").Sort.SortFields.Add Key:=Range("F3:F36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("PCS").Sort
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
ActiveWorkbook.Worksheets("PCS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("PCS").Sort.SortFields.Add Key:=Range("J3:J36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("PCS").Sort
```

```
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
ActiveWindow.SmallScroll Down:=-21
Range("A3").Select
ActiveCell.FormulaR1C1 = "1"
Range("A4").Select
ActiveCell.FormulaR1C1 = "2"
Range("A5").Select
ActiveCell.FormulaR1C1 = "3"
Range("A6").Select
ActiveCell.FormulaR1C1 = "4"
Range("A7").Select
ActiveCell.FormulaR1C1 = "5"
Range("B4:B8").Select
Selection.Copy
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=-372
Range("D5").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
Columns("D:D").EntireColumn.AutoFit
Columns("E:E").EntireColumn.AutoFit
Columns("F:F").EntireColumn.AutoFit
ActiveWindow.SmallScroll ToRight:=2
Columns("G:G").EntireColumn.AutoFit
Columns("H:H").EntireColumn.AutoFit
ActiveWindow.SmallScroll ToRight:=-2
Range("C7:C51").Select
Application.CutCopyMode = False
Selection.Copy
ActiveWindow.SmallScroll Down:=-42
Range("D7:H51").Select
Selection.PasteSpecial Paste:=xlPasteFormats, Operation:=xlNone, _
    SkipBlanks:=False, Transpose:=False
Application.CutCopyMode = False
Range("C5").Select
Selection.Copy
Range("D5:H5").Select
Selection.PasteSpecial Paste:=xlPasteFormats, Operation:=xlNone, _
    SkipBlanks:=False, Transpose:=False
Application.CutCopyMode = False
```

```
Columns("D:D").EntireColumn.AutoFit
Columns("E:E").EntireColumn.AutoFit
Columns("F:F").ColumnWidth = 9.29
Columns("F:F").EntireColumn.AutoFit
Columns("G:G").EntireColumn.AutoFit
ActiveWindow.SmallScroll ToRight:=2
Columns("H:H").EntireColumn.AutoFit
ActiveWindow.SmallScroll Down:=-3
ActiveWindow.SmallScroll ToRight:=-2
Sheets("CS").Select
Range("B4").Select
ActiveWorkbook.Worksheets("CS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("CS").Sort.SortFields.Add Key:=Range("F3:F36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("CS").Sort
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
ActiveWorkbook.Worksheets("CS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("CS").Sort.SortFields.Add Key:=Range("J3:J36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("CS").Sort
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
Range("A3").Select
ActiveCell.FormulaR1C1 = "1"
Range("A4").Select
ActiveCell.FormulaR1C1 = "2"
Range("A5").Select
ActiveCell.FormulaR1C1 = "3"
Range("A6").Select
ActiveCell.FormulaR1C1 = "4"
Range("A7").Select
ActiveCell.FormulaR1C1 = "5"
Range("B4:B8").Select
Selection.Copy
Sheets("Model").Select
```

```
ActiveWindow.SmallScroll Down:=45
Range("D53").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
Range("D5:H51").Select
Range("D51").Activate
Application.CutCopyMode = False
Selection.Copy
ActiveWindow.SmallScroll ToRight:=-3
ActiveWindow.SmallScroll Down:=42
Range("D53:H98").Select
Selection.PasteSpecial Paste:=xlPasteFormats, Operation:=xlNone, _
    SkipBlanks:=False, Transpose:=False
Application.CutCopyMode = False
ActiveWindow.SmallScroll Down:=48
Sheets("PoCS").Select
Range("F4").Select
ActiveWorkbook.Worksheets("PoCS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("PoCS").Sort.SortFields.Add Key:=Range("F3:F36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("PoCS").Sort
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
ActiveWorkbook.Worksheets("PoCS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("PoCS").Sort.SortFields.Add Key:=Range("J3:J36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("PoCS").Sort
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
ActiveWindow.SmallScroll Down:=-42
Range("A3").Select
ActiveCell.FormulaR1C1 = "1"
Range("A4").Select
ActiveCell.FormulaR1C1 = "2"
Range("A5").Select
ActiveCell.FormulaR1C1 = "3"
```

```
Range("A6").Select
ActiveCell.FormulaR1C1 = "4"
Range("A7").Select
ActiveCell.FormulaR1C1 = "5"
Range("B4:B8").Select
Selection.Copy
Sheets("Model").Select
ActiveWindow.SmallScroll Down:=-3
ActiveWindow.SmallScroll ToRight:=-2
Range("D98:H98").Select
Application.CutCopyMode = False
Selection.Borders(xlDiagonalDown).LineStyle = xlNone
Selection.Borders(xlDiagonalUp).LineStyle = xlNone
With Selection.Borders(xlEdgeLeft)
    .LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlMedium
End With
With Selection.Borders(xlEdgeTop)
    .LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlMedium
End With
With Selection.Borders(xlEdgeBottom)
    .LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlMedium
End With
With Selection.Borders(xlEdgeRight)
    .LineStyle = xlContinuous
    .ColorIndex = 0
    .TintAndShade = 0
    .Weight = xlMedium
End With
Selection.Borders(xlInsideHorizontal).LineStyle = xlNone
ActiveWindow.SmallScroll ToRight:=-2
Range("D100").Select
Sheets("PoCS").Select
Selection.Copy
Sheets("Model").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
ActiveWindow.SmallScroll Down:=-39
```

```
Range("D53:H98").Select
Application.CutCopyMode = False
Selection.Copy
ActiveWindow.SmallScroll Down:=15
Range("D100:H145").Select
Selection.PasteSpecial Paste:=xlPasteFormats, Operation:=xlNone, _
    SkipBlanks:=False, Transpose:=False
Application.CutCopyMode = False
ActiveWindow.SmallScroll Down:=48
Range("H148").Select
ActiveWindow.SmallScroll ToRight:=-2
Sheets("GCS").Select
Range("D5").Select
ActiveWorkbook.Worksheets("GCS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("GCS").Sort.SortFields.Add Key:=Range("F3:F36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("GCS").Sort
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
ActiveWorkbook.Worksheets("GCS").Sort.SortFields.Clear
ActiveWorkbook.Worksheets("GCS").Sort.SortFields.Add Key:=Range("J3:J36"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets("GCS").Sort
    .SetRange Range("A2:J36")
    .Header = xlYes
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
End With
Range("A3").Select
ActiveCell.FormulaR1C1 = "1"
Range("A4").Select
ActiveCell.FormulaR1C1 = "2"
Range("A5").Select
ActiveCell.FormulaR1C1 = "3"
Range("A6").Select
ActiveCell.FormulaR1C1 = "4"
Range("A7").Select
ActiveCell.FormulaR1C1 = "5"
Range("B4:B8").Select
```

```
Selection.Copy
Sheets("Model").Select
Range("D147").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=True
ActiveWindow.SmallScroll Down:=-45
Range("D100:H100").Select
Application.CutCopyMode = False
Selection.Copy
ActiveWindow.SmallScroll Down:=51
Range("D147:H147").Select
Selection.PasteSpecial Paste:=xlPasteFormats, Operation:=xlNone, _
    SkipBlanks:=False, Transpose:=False
Application.CutCopyMode = False
Range("C148:C158").Select
Selection.Copy
Range("D148:H158").Select
Selection.PasteSpecial Paste:=xlPasteFormats, Operation:=xlNone, _
    SkipBlanks:=False, Transpose:=False
Application.CutCopyMode = False
Range("E154").Select
Columns("D:D").EntireColumn.AutoFit
Columns("E:E").EntireColumn.AutoFit
ActiveWindow.SmallScroll ToRight:=3
Columns("E:E").EntireColumn.AutoFit
Columns("F:F").EntireColumn.AutoFit
Columns("G:G").EntireColumn.AutoFit
Columns("H:H").EntireColumn.AutoFit
ActiveWindow.SmallScroll Down:=-336
ActiveWindow.SmallScroll ToRight:=-1
ActiveWindow.SmallScroll Down:=-3
ActiveWindow.SmallScroll ToRight:=-2
Sheets("Results").Select
Range("C5").Select
Sheets("Model").Select
Dim i, j, n, c As Integer
c = 3
j = 1
For n = 1 To 5
Do While j = 1
If Sheet4.Cells(5, n + 3) = Sheet3.Cells(4, c) Then
For i = 7 To 51
Sheet4.Cells(i, n + 3) = Sheet3.Cells(i - 1, c)
Next i
j = 0
Else: c = c + 1
```

```
End If
Loop
j = 1
c = 3
Next n
Dim o, p, q, r As Integer
r = 3
p = 1
For q = 1 To 5
Do While p = 1
If Sheet4.Cells(53, q + 3) = Sheet3.Cells(4, r) Then
For o = 54 To 98
Sheet4.Cells(o, q + 3) = Sheet3.Cells(o - 1, r)
Next o
p = 0
Else: r = r + 1
End If
Loop
p = 1
r = 3
Next q
Dim s, t, u, v As Integer
v = 3
t = 1
For u = 1 To 5
Do While t = 1
If Sheet4.Cells(100, u + 3) = Sheet3.Cells(4, v) Then
For s = 101 To 145
Sheet4.Cells(s, u + 3) = Sheet3.Cells(s - 1, v)
Next s
t = 0
Else: v = v + 1
End If
Loop
t = 1
v = 3
Next u
Dim w, x, y, z As Integer
z = 3
x = 1
For y = 1 To 5
Do While x = 1
If Sheet4.Cells(147, y + 3) = Sheet3.Cells(4, z) Then
For w = 148 To 158
Sheet4.Cells(w, y + 3) = Sheet3.Cells(w - 1, z)
Next w
```

```
    x = 0
    Else: z = z + 1
    End If
    Loop
    x = 1
    z = 3
    Next y

End Sub
```

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BIOGRAPHICAL SKETCH

Jose Mauricio Ruiz earned his master's degree from the M.E. Rinker, Sr. School of Building Construction at the University of Florida in Gainesville. While pursuing his master's degree in building construction, he worked for the Shimberg Center for Housing Studies as a data analyst. Prior to earning his master's degree, he attended the Instituto Tecnologico de Costa Rica, where he earned a bachelor's of construction engineering. During this time, he worked as an assistant project manager at a construction management firm in Costa Rica, working for international and national clients, where he gained the background and experience with various large-scale urban projects.

Mauricio's research interests are in the areas of design and construction technology, with emphasis on the implementation of technologies in the building industry. He is also interested in data management technology and virtual design and construction.