BUILDING INFORMATION MODELING IN SUPPORT OF SUSTAINABLE DESIGN AND CONSTRUCTION

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN BUILDING CONSTRUCTION

UNIVERSITY OF FLORIDA

2010

To my family and friends

Vigilando, agendo, bene consulendo, prospera omnia cedunt

ACKNOWLEDGMENTS

First and foremost, I would like to thank my thesis committee members, Dr. Raymond Issa, Dr. Svetlana Olbina, and Dr. Ian Flood for their continual guidance through the process of this research. Their expertise in the field of building information modeling as well as sustainability helped provide the framework for this investigation and for their advice and direction I am grateful.

I would like to thank the University of Virginia School of Architecture and its faculty for establishing the foundation of my education in both digital modeling and sustainable design. Without my education at UVA I would not be the student or individual that I am today, and for that I am entirely grateful.

Finally, I would like to thank my family and friends for their support in everything I have accomplished so far. Without you I would not be able to achieve the goals I set forth so early in my lifetime. Through your patience and eternal guidance I know that I will forever be able to depend on you for support.

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LIST OF ABBREVIATIONS

AEC	Architecture/Engineer/Construction
ARCH	Architect
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer Aided Design
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CM	Construction Management
CM-R	Construction Management at Risk
CNC	Computer Numerically Controlled
DB	Design-Build
DBD	Design-Bid-Build
DBIA	Design-Build Institute of America
DOE	Department of Energy
ENG	Engineer
GBI	Green Building Initiative
GC	General Contractor
IAI	International Alliance for Interoperability
IPD	Integrated Project Delivery
LEED AP	Leadership in Energy and Environmental Design Accredited Professional
NURBS	Non-uniform B-splines
SUB	Subcontractor
USGBC	United State Green Building Council

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science in Building Construction

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May 2010

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Major: Building Construction

The use of building information modeling (BIM) has provided a means of increasing total project quality, providing accurate scheduling timetables, yielding quantity take-offs, and diminishing total project costs. However, there has not been significant analysis performed with regards to the impact BIM has on sustainable construction practices. This research is intended to evaluate the current trends in BIM usage within the architecture / engineering / construction (AEC) industry in its support for sustainable design and construction. An introduction of several BIM software and various green rating systems is provided exploring the relationships seen between each in support for sustainable design and construction. A survey was developed based on information gathered through a review of literature and analysis was performed on the participant's responses in order to gain insight on the AEC perspective of the use of BIM and sustainability within the AEC industry.

Currently, the majority of the AEC industry is utilizing BIM in some form or another due to its ability to support collaborative and distributed work processes which facilitates

project delivery. Although the majority of the AEC industry believes that sustainable design and construction practices are of importance within their company's structure, most still believe that it is not a primary application for BIM, that, project coordination and visualization instead are more important. Additionally, as owners become more aware of the potential benefits provided by BIM, the AEC industry will begin to utilize BIM regularly as a standard process. Due to the relative high costs of obtaining licenses for BIM software, many companies within the AEC industry view it as not cost-effective. While BIM is perceived as a multidisciplinary tool, problems with interoperability continue to persist among the various sectors of the industry. In terms of project delivery, the majority of the survey respondents believe that the move towards Design-Build and Integrated Project Delivery is the optimal method to provide for BIM as a sustainability tool. Although BIM is still a recent development, as more AEC professionals understand the potential benefits offered through its use, BIM will become a vital tool for sustainable design and construction within the industry.

CHAPTER 1
INTRODUCTION

1.1 Purpose of Study

Building information modeling (BIM) has been a growing development within the past decade in the construction industry, paving the way towards a future in the virtually built environment. The use of BIM today has provided a means of increasing total project quality, providing accurate scheduling timetables, yielding quantity take-offs, and diminishing total project costs. Although BIM is a recent development, an abundance of research has been conducted in order to further enhance the capabilities of BIM in design and construction. However, there has not been a significant amount of analysis performed on the impact BIM has on sustainable construction practices. This research is intended to identify the potential capabilities of BIM software in relation to sustainable construction practices.

The ability to utilize the virtual world in construction provides the necessary means to build three-dimensionally within a computer simulation prior to construction of the actual building. This allows for more efficient, better designed structures that limits waste of resources, optimizes energy usage, and promotes passive design strategies. A literature review discussing the potential capabilities of BIM and sustainable design is found in Chapter 2. Following the completion of the literature review it was determined that there was a lack of studies exploring the use of BIM in accomplishing sustainable design. The focus of this study therefore is to attempt to uncover the potential relationships between BIM and sustainable construction practices as they relate to the built environment.

1.2 Objective of the Study

The goal of this study is to investigate the current state in which BIM operates and functions with respect to sustainable design practices. The following statements list the objectives of the study: 1) to analyze the current trends and future developments with BIM and sustainable practices within the AEC industry; 2) to assess how BIM is being used as a mechanism for sustainable practices; 3) to understand how BIM is being used today in order to analyze the building performance of a built project; 4) to determine what difficulties with interoperability are seen as potential problems with BIM software, and; 5) to determine at what stage in the design development process BIM is thought of as a useful tool in facilitating sustainable design and/or construction practices.

In order to obtain the necessary information an extensive survey questionnaire was distributed to numerous professionals in the AEC industry as a means to collect data regarding BIM systems and their impact on sustainable construction practices. Through the use of descriptive statistical analysis the data was used as a way of rating the various BIM systems and determining trends among various sectors of the AEC industry.

1.3 Research Methodology

A survey was generated as a means of gathering information regarding BIM and sustainable construction practices. The survey was distributed to various companies in the AEC industry. The survey was divided into five major sections in order to generate data concerning various companies' use of BIM and their involvement in sustainable design and construction practices. The collected data resulted in the necessary quantitative data to analyze different BIM software and find trends within the AEC

industry. Comparisons of the results to the literature review findings were made, and conclusions and recommendations were presented.

1.4 Structure of Research

Chapter 2 provides a literature review on BIM and its potential impact on sustainable construction. The literature review directly defines sustainable design in terms of the applications of various techniques and strategies with design and construction. BIM is thoroughly defined by way of its potential abilities as well as its shortcomings. In order to discuss the various types of BIM software, the literature review examines examples of actual BIM software available that will be used in order to form comparisons among the most effective BIM software.

Chapter 3 describes the methodology followed in conducting this research. The survey consisted of twenty-eight questions broken into five major sections, varying in type and complexity. The survey was distributed across the United States to firms in the AEC industry varying in size, type, and structure.

Chapter 4 provides the overall analysis of the results stemming from the investigations seen within the survey of the population sampled. Comparisons of the results to the findings in the literature review are made and several hypotheses were tested and discussed.

Chapter 5 provides a detailed analysis based on results found from responses gathered from Chapter 5's analysis of specific information regarding the participant. The results found within this evaluation process will provide an enhanced examination of the respondent's views on specific survey questions in order to answer the objectives of the study.

Chapter 6 produces the final chapter and explains the conclusions and recommendations derived from the analyses conducted. In addition, recommendations for future research studies are presented.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

This literature review consists of four sections relating to the trends in both building information modeling (BIM) and sustainable design and construction practices. Each section addresses the current knowledge of both applications within the AEC industry, by looking at: 1) BIM and its development over time; 2) current trends for sustainable design and construction practices within the AEC industry; 3) recent developments to unite BIM and sustainability; and, 4) the future of BIM within the AEC industry as it concerns sustainable design and construction practices.

The first section of this literature review briefly follows a history of the development of BIM as used in the AEC industry. A summary of current available BIM software and auxiliary BIM software is provided as well as descriptions of each in order to determine any variations found among the software. The second section examines the concept of sustainability within the built environment understanding what means and methods are currently practiced in order to mitigate negative impacts on the environment. An analysis of various green building assessment systems is presented to determine the current sustainable strategies used within the design and construction industry. The third section is used to determine what current trends are utilized in order to stitch together the use of BIM technology and sustainable design and building practices in order to facilitate the development of environmentally ‘green buildings.’ The final section of the literature review concludes with a brief explanation of future developments with respect to BIM use in sustainable design and construction practices.

2.2 Building Information Modeling

2.2.1 Historical Outline

Building information modeling (BIM) has seen a dramatic increase in use in the design and construction industry over the last few years due to its ability to foster collaborations among many disciplines. BIM can be used to accelerate the extraction of knowledge accumulated in a number of simulations that can be used to define product development standards and recommendations. Essentially, this means that throughout the modeling of a project the model itself can demonstrate a number of effective solutions and can offer a range of potential applications in nearly every phase of development.

The BIM process has grown to become a completely different system than Computer Aided Design (CAD), as operations now have developed into an almost internalized system of integrated information whereas CAD obtains information through external sources. As Krygiel and Nies (2008) noted, "a BIM model contains the building's actual constructions and assemblies rather than a two-dimensional representation of the building that is commonly found in CAD-based drawings." BIM provides a number of advantages over CAD by being able to manage information, not just graphics, and supporting a controlled environment which eliminates data redundancy seen most commonly in miscommunication. Popov et al. (2008) describes the main concepts of BIM as the capability:

- To develop the strategy of building project design, construction, and maintenance management;
- To ensure integration management of graphical and informational data flows, combining the graphical interface with the information flows and process descriptions;

- To transform individual executors into teams and decentralized tools into complex solutions, this leading to individual tasks being implemented as complex processes, and;
- To performing life cycle operations of a construction project faster, more effective, and with lower costs.

As BIM provides the capability to perform rigorous functions simultaneously, it allows for a number of potential benefits with its use in the AEC industry.

2.2.2 Potential Benefits to the AEC Industry

The capabilities of BIM allow for a far better transition from design to construction, where information and decision making becomes a bigger task than documentation and processing of materials. BIM allows for the work, processes, and information to be collected from multiple disciplines, multiple companies, and multiple project phases. The result of all this becomes evident with the savings in time and resources, improved quality, and overall more efficient buildings. Khemlani (2007) lists the following as features of BIM used by AEC professionals:

- The ability to support distributed work processes, with multiple team members working on the same project;
- The ability to support preliminary conceptual design modeling;
- The ability to work on large projects;
- Automated setup, management, and coordination, reducing traditional CAD management tasks;
- The availability of object libraries;
- Built-in ability to generate highly photorealistic renderings and animations;
- Direct integration with cost estimating applications;
- Direct integration with energy analysis applications;
- Direct integration with project management applications;

- Direct integration with structural analysis applications;
- Full support for producing construction documents so that another drafting application need not be used;
- Multidisciplinary capability that serves architecture, structural engineering, and MEP;
- Support for construction-related tasks such as quantity take-off, estimating, and 4D scheduling.

As shown in Figure 2-1, BIM has the ability to integrate and incorporate many of the facets of the AEC industry typically regarded as individual building tasks. Figure 2-1 displays an example of the integration seen within BIM in relation to the multiple functions necessary to complete a built project. For AEC professionals, this ultimately allows for a combination of functionalities which as a result provide endless possibilities with its use.

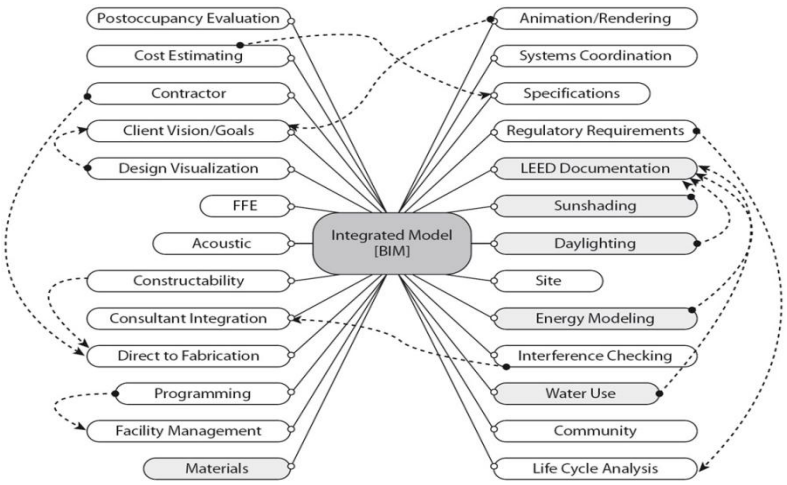


Figure 2-1. Integrated BIM model (source: Krygiel 2008).

From the perspective of the owners, the utilization of BIM on a project can provide the potential benefits of:

- Increased building value;
- Shortening project schedule;

- Obtaining reliable and accurate cost estimates;
- Assuring program compliance;
- Produce market ready facilities, and;
- Optimizing facility management and maintenance (Eastman, Teicholz, Sack, and Liston 2008).

As a result of these benefits, the owner experiences high return on investments. Figure 2-2 shows that the more involved the use of BIM is within the initial phases of the project (i.e. conceptual and programming phases) the more influence it can have on costs. Because BIM facilitates the ability to communicate through collaborative efforts, the construction process is streamlined, reducing the amount of time it takes to process information externally. Therefore, the owner is provided with a project that is completed and fully operational on a shortened schedule. Additionally, as the BIM is made through the virtual modeling of assemblies, the owner is provided with a database for rooms, spaces, and equipment used in order to catalog information regarding facility operations and maintenance (Eastman et al. 2008).

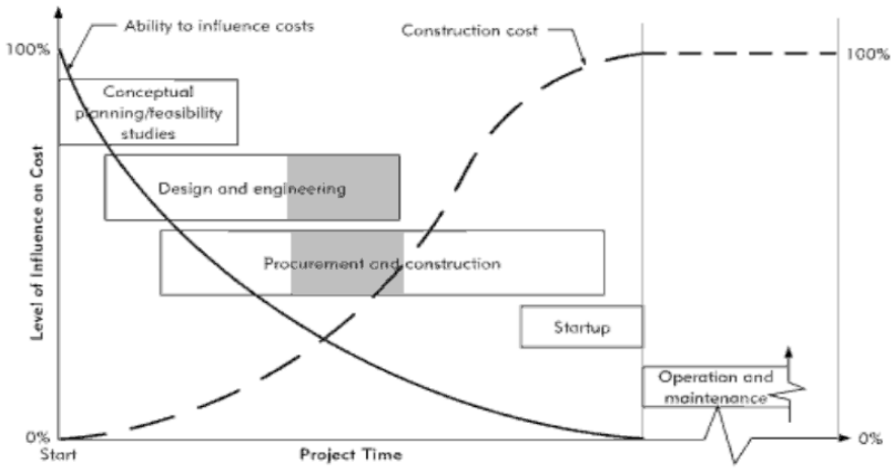


Figure 2-2. BIM's influence on overall project cost over project life cycle (source: Eastman et al. 2008)

2.2.3 Problems with BIM

Although the utilization of BIM provides a number of benefits to all parties of a project team, there are drawbacks to implementing its use in the AEC industry. Until recently, contractual agreements provided by professional organizations such as the American Institute of Architects (AIA) and the Association of General Contractors (AGC) were based on traditional paper-based methods, therefore providing little if any legal guidelines on the use of BIM in the AEC industry. As BIM is intended to be used as a collaborative effort among multiple disciplines legal concerns are presented in the form of liability over the model. Who is at fault for complications arising over errors found in the modeling of the project? Who claims ownership of the information within the model? These questions are continually being addressed by BIM users. In 2008, the AIA released the E202™-2008 document concerning the management of BIM across the entire project.

The application of BIM into a multidisciplinary network results in a higher demand for collaboration and transfer of information. As the move to implement BIM into the AEC industry is seen as a recent endeavor the transformation of work processes in the industry requires significant amounts of time and education. However, as professionals in the field begin to use BIM as part of their work practices, BIM's prevalence in the industry will increase. Additionally, through the efforts of software organizations, extensive learning modules are provided on basic and advanced functions of BIM increasing the knowledge and know-how of its use within the AEC industry (Eastman et al. 2008).

The greatest issue concerning the use of BIM in the industry is the interoperability of information between various software platforms. Because BIM is intended to act as the sole database of information regarding a project, information must translate from software to software seamlessly. Currently, software providers have not established an ideal file exchange format to achieve seamless translations of data; however, significant strides have been made in order to prevent data loss. Organizations such as building-SMART and the International Alliance for Interoperability (IAI) lead these critical efforts. In one such effort, the Industry Foundation Classes (IFC) was developed to create a large set of consistent data representations of building information for file exchange between AEC software applications (Eastman et al. 2008). Currently, the IFC is the most optimal file exchange format available to provide seamless translation of data and many BIM software platforms have offered it as a file extension. The future of interoperability within BIM fares well as software companies continually enhance and improve previous versions. Hardin (2009) remarked about the future of interoperability:

> Although it's difficult to speculate as technology moves so fast, in 10 years we should see a reduction in the relative number of software tools available as they will be integrated into existing software or available on an as needed basis via the Internet. Additionally, the disparity between how systems work together will be significantly reduced, as well as the costs associated with the purchase of multiple pieces of software to accomplish some of the tasks associated with construction management.

Therefore, as software platforms become integrated the standardization of file exchange formats will result in the prevention of translation errors. Until then current file exchange formats must be utilized carefully so that data loss is at a minimum.

2.2.4 BIM Software Platforms

Currently, in the market there is a wide variety of BIM software platforms utilized by AEC firms, each with their own take on how to represent the virtual environment. In order to understand the differences between BIM software this section offers a description of the various aspects of each software platform. In order to provide a fair comparison of each, the capabilities of individual BIM software will be discussed based on the specifications of its user interface; 2D CAD and drawing generations; interoperability and extensibility; multiuser/multidisciplinary environment; and, its capability of handling robust and complicated geometry. Through this assessment of current BIM software platforms an understanding of the advantages and disadvantages of each individual product as well as an evaluation of the BIM industry as a whole will be presented.

2.2.4.1 Autodesk Revit 2010

Currently, the market leader in BIM is Revit provided by Autodesk. Revit originated through the smaller Massachusetts-based company, Revit Technology Corporations, before being purchased by Autodesk 2002, the same year it was introduced under their franchise name. Autodesk Revit contains a series of integrated programs consisting of Revit Architecture, Revit Structure, and Revit MEP, all of which run independent of one another but are however linked through a common RVT file extension. The version reviewed here is the 2010 edition released in April of 2009.

Revit by definition is a design and documentation system that delivers information about project design, scope, quantities, and phases whenever needed. Revit provides a central database for storing information on a project. As Revit is defined by

parametric modeling, all information is interrelated through the database where relationships are created among each element. This allows for any change made within the project to be coordinated throughout the entire project. The database is accessible to any user with access to the server; therefore, as a project is updated any team member is able to view the change (Autodesk 2009c). Because of its ability to provide quick access to information it allows for better communication among members in the AEC industry.

The software utilizes a structured hierarchy in order to define the elements within its program. Each element is further broken down into categories, then families, and finally types as a way to differentiate between components (Figure 2-3). The nature of the hierarchy is designed to be flexible such that the user has the ability to modify and create elements. Additionally, elements are designed to be contingent on their context within the project as defined by the constraints established with other components by which the user controls.

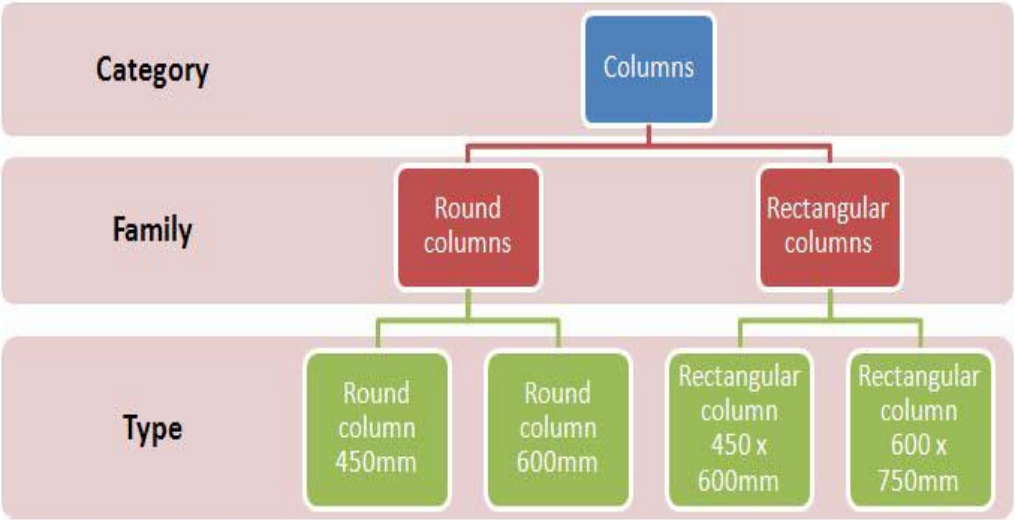


Figure 2-3. Revit element hierarchy within parametric modeling (source: Autodesk 2010c).

In order to make Revit more interoperable among various software suppliers, Autodesk provided the software with multiple file exchange interfaces. In order to import files from commonly used CAD systems, Revit supports DGN, DWG, DWF, DXF, SAT, and SKP file extensions. Any renderings, image, and video views generated through Revit can be exported through common file types such as JPG, TIF, BMP, PNG, TGA, or AVI. Additionally, in order to facilitate interoperability in the building industry, Revit offers the building-SMART object oriented file format, IFC, as it is in the process of becoming an international standard. Finally, in order to execute building performance analysis Revit offers support for both RISA and ROBOT to perform structural analysis and gbXML to provide energy simulation and load calculations (Eastman et al. 2008).

Although Revit is the leading BIM provider for the AEC industry there are limitations and drawbacks that can be seen as a disadvantage within its software platform. Because the program is highly dependent on the performance capabilities of the computer it is operating on, this can cause the systems to run at a substantially slower speed. Additionally, although recent developments with Revit 2010 have increased its capabilities, the software does not fluidly support complex curved surfaces, such as non-uniform rational B-splines (NURBS). Yet with Revit's easy to learn interface, broad object libraries, and support for multi-user operation it allows the software to remain ahead of the others in terms of its performance.

2.2.4.2 Bentley Architecture V8i

Bentley Systems introduced its BIM based software, Bentley Architecture, in 2004 as part of a package that included: Bentley Structural; Bentley Building Mechanical

Systems; Bentley Building Electrical Systems; Bentley Facilities; Bentley PowerCivil; and, Bentley Generative Components. The current version, Bentley Architecture V8i, includes ProjectWise Navigator as part of its package to enhance collaboration among multiple parties. Bentley Architecture V8i was designed as an evolutionary descendant from Microstation and TriForma (i.e. Bentley's CAD programs), thus, it inherited the full range of sophisticated solid and surface modeling tools allowing it to create complex geometry more fluidly than other software platforms. Additionally, Bentley Architecture V8i uses a file-based system to store information therefore the software is able to run robust files without substantially slowing down the operating system (Khemlani 2009b). Similar to Revit, Bentley Architecture V8i utilizes a structured hierarchy in its parametric modeling scheme, using families as a method of creating or modifying components.

Bentley Architecture V8i was designed to integrate its capabilities with other Bentley-related programs in order to provide seamless integration between design, engineering, analysis, construction, and operations through the life cycle of the project as illustrated in Figure 2-4. Included within this method to provide the most effective means of interoperability are a number of available file extensions supported by the software. Bentley Architecture V8i supports DGN, DWG, and DXF file extensions for its interface with common CAD software. Any graphical data is available to be exported through the following file extensions JPG, BMP, TIF, PNG, STP, IGES, STL, and PDF. Similar to Revit, Bentley Architecture V8i offers the building-SMART object oriented file format, IFC. Additionally, the software offers STAAD and RAM file extensions for structural analysis as well as support for gbXML in order to perform energy analysis. However, Bentley offers its own energy application tools, Hevacomp Simulator and Tas

Simulator, in efforts to maintain a seamless integration of programs (Eastman et al. 2008).

Although Bentley Architecture V8i offers a number of products as a package suite, unless the user is familiar with the software platform it is quite difficult to learn. Additionally, the object library is less extensive than other BIM product available. However, because many of the software packages are seamlessly integrated Bentley Architecture V8i does offer a competitive advantage over its competitors.

Figure 2-4. Extensive product map of Bentley's building package solutions (source: Bentley Systems, Inc. 2009)

2.2.4.3 Graphisoft ArchiCAD 13

Founded in Hungary in 1982, Graphisoft claims to be the first software platform able to be used on personal computers to create both 2D and 3D drawings. Its newest BIM software, ArchiCAD 13, is a data-enhanced parametric object modeling system utilizing the ability to create smart objects in order to define modeling inputs. The introduction of ArchiCAD 13 in September of 2009 included the first ever client-based BIM utility created to enhance collaboration among multiple users. Similar to other BIM platforms, ArchiCAD 13 offers an extensive object library to which users are able to

create or modify elements as necessary for individual projects. Its ability to perform with a 64-bit processor allows for faster operation and the capability to work on larger projects, which is a major improvement on the software from previous versions. More importantly, ArchiCAD 13 provides the add-ons Virtual Building Explorer, MEP Modeler, and EcoDesigner which streamlines building performance analysis as well as through clash detection (Khemlani 2009a).

In order to provide for better interoperability ArchiCAD 13 includes a larger database of structural elements as a means to facilitating recognition of elements in structural analysis software. Additionally, ArchiCAD like other BIM software maintains the ability to import CAD files in the DWG and DXF file extensions. Similar to Revit, with built-in rendering and animation programs ArchiCAD 13 has the ability to export to JPG, TIF, BMP, PNG, PDF, TGA, or AVI file extensions (Eastman et al. 2008).

However, ArchiCAD 13 still remains a single disciplinary software instead of a multi-disciplinary BIM platform. Compared to its competitors, the software has limitations on its parametric modeling capabilities which make it difficult to guarantee integrity of a model as well as provide accurate downstream analysis with other applications. Though with the innovation of the first client-based BIM server ArchiCAD stand as one of the giants in the BIM industry.

2.2.4.4 Beck-Technology DProfiler

Beck Technology's DProfiler is a 'macro' BIM software parametric modeling platform that is used for conceptual design of certain building types in order to provide feedback on construction costs and scheduling. DProfiler integrates Sage Timberline estimating applications and RSMeans costing within the software as a way of providing

an interactive cost estimate as a project is modeled. This software differentiates from other BIM platforms in that it is used to assess the feasibility of a project early on during conceptual stages, whereas other software platforms are used for their capabilities with design development and generation of construction documents throughout the duration of a project.

DProfiler's interface is similar to that of SketchUp, where geometries are created through a massing of solids, however, the software lacks many of the intuitive operations other BIM software platforms utilize. In terms of operability DProfiler is limited to only DWG and DXF file extension for imports, and IGES, DWG, DXF, and STL for export file extensions. Generated BIM models are capable to be exported to an IFC format, thus, models built in DProfiler are able to be imported in other BIM software platforms. Additionally, DProfiler is directly integrated with eQuest, a DOE-2 based energy simulation tool, which provides for quick energy calculations of conceptual design strategies (Khemlani 2008b).

DProfiler is primarily used as a quick modeling service to determine the economic feasibility of a project before design begins. It is not considered a general purpose BIM tool; however, its ability to generate on-the-fly cost estimates as well as energy assessments makes it a useful tool during the early conceptual phases of a project.

2.2.4.5 Gehry Technologies Digital Project V1,R4

Developed by Gehry Technologies through the evolutionary descendent of Dassault's CATIA software platform, Digital Project V1,R4 is another form of parametric object modeling to which it is capable of modeling any type of complex geometry. The software itself is an integration of Gehry Technologies Architecture and Structures

programs combined into a BIM Workbench enabling better connections between modeled components. The following add-on products are available as a means to enhance the capabilities within Digital Project:

- *Digital Project Viewer* – provides quick access to visualization and navigation of robust models as well as a means for collaboration and management;
- *Digital Project Primavera Integration* – provides scheduling simulation by linking construction scheduling information with the model data;
- *Digital Project MEP/Systems Routing* – provides an interface for designers to optimize MEP virtually to avoid conflicts;
- *Digital Project Imagine & Shape* – provides a mechanism to create complex forms of geometry;
- *Digital Project Knowledgeware* – provides an extensive object library to select, create, or modify different forms of geometry;
- *Digital Project Specialized Translators* – provides for an additional file extension in STL and STEP formats, and;
- *Digital Project Photo Studio* – provides for an advanced rendering output system (Gehry Technologies 2010).

As part of its efforts to provide better interoperable features, Digital Project offers the following exchange formats: CIS/2, SDNF, STEP AP203 and AP214, DWG, DXF, VRML, STL, HSF, SAT, 3DXML, IGES, and HCG. This version of Digital Project also offers enhanced IFC interoperability especially within the Architecture and Structures Workbench. Both Uniformat and Masterformat are embedded within the software platform in order to provide direct integration with cost estimating applications. The interface allows analytical studies through the use of Ecotect, a type of building analysis software (Eastman et al. 2008).

Digital Project is a powerful BIM software able to model large assemblies, however, its learning curve is steep and the upfront cost of the software is high making

it a tough product to implement into practice. The object library of the software is not as extensive as other BIM software platforms and it must rely on external 2D programs for drafting purposes.

2.2.4.6 Nemetschek Vectorworks Architect 2010

Nemetschek Vectorworks Architect 2010 is a parametric 2D/3D CAD and BIM software program utilizing its unique core modeling engine, developed from Siemens Parasolid geometric modeling kernel, which allows for better functionality when modeling complex components. Vectorworks Architect 2010 provides the capability to generate NURBS and other complicated geometry. Similar to most BIM software platforms, construction drawings are linked so that changes update automatically throughout the model. Integrated within Vectorworks 2010 are automated schedules and material takeoffs.

Vectorworks Architect 2010 offers a number of exchange file types within its platform, primarily due to the inclusion of the Parasolid modeling kernel. The following import/export file extensions are available within the program: DXF, DWG, EPSF, WMF, PICT, PDF, SHP, 3DS, IGES, SAT, SKP, X_T, JPG, GIF, TIFF, PICT, PNGT, and PNG. Vectorworks Architect 2010 offers the IFC file extension as well in order to perform analysis on external programs involved with building performance assessment (Vectorworks Inc. 2009).

Though the Parasolid modeling kernel gives Vectorworks Architect 2010 an advantage in terms of its ability to handle complex geometry, its inability to provide multidisciplinary BIM tools (i.e. structural and MEP) forces the program to become one dimensional instead of encompassing all facets of the AEC industry as many

comparable BIM programs offer. However, as a strictly architectural design program Vectorworks Architect 2010 offers a high level product at an affordable cost.

2.2.4.7 Tekla Structures 14

Tekla Structures 14 is a BIM application for structural engineers that use comprehensive tools for fabricators, manufacturers, and constructors. Similar to Revit Structures, Tekla Structures 14 offers the ability to create a complete digital model that simulates a real life structure in order to evaluate the system through several structural analyses. The software operates on a central database therefore all drawings and reports are linked within the model. However, by placing the files in separate folders as opposed to within the model itself, Tekla Structures 14 is able to run large complex projects without significantly slowing down the processor speed. The program contains an extensive library of parametric components that is capable of automating the tasks of creating details and connection drawings, thus, reducing the amount of drafting necessary. Its ability for fluid viewing and model navigation allows for enhanced clash detection and its transaction-based model sharing concept provides support for multiple users. The integration of the Construction Management module as part of the platform provides a means to perform scheduling tasks and quantity takeoffs (Khemlani 2009e).

Tekla Structures 14 allows for various options in its ability to support different interfaces such as: SDNF, CIS/2, DGN, DWG, DXF, XML, 3DD, IGES, STEP, VRML, and STL. The primary format for Tekla Structures however is the IFC file exchange format since it relies on interoperability with other BIM applications. Additionally, export capabilities to CNC fabrication equipment is provided as a means to foster the construction of building systems (Eastman et al. 2008).

As a structural engineering software, Tekla Structures 14 is a powerful tool; however, it is quite complex to learn. It is not fully integrated with architectural and MEP programs, which makes it one dimensional compared to other BIM platforms.

2.2.4.8 Vico Software Constructor 2009

Vico Constructor 2009 is a BIM modeling platform as part of an entire suite devoted to building construction planning and management. Within its framework, the BIM software contains integrated architecture, structural, and MEP modeling capabilities using parametric object modeling. Additionally, the software is fully integrated with the following Vico programs found within the suite in order to provide for all aspects of building construction:

- *Vico Estimator 2009* – a program to perform model-based estimating;
- *Vico Control 2009* – a program for location-based scheduling and linking time and space in new views;
- *Vico 5D Presenter 2009* – a program to see the model (3D), schedule (4D), and cost (5D) in one view;
- *Vico Cost Explorer 2009* – a program to monitor and control changes to a project's cost , and;
- *Vico Change Manager 2009* – a program to track revisions for consistency across all representations (Vico Construction Services 2009).

Vico Constructor 2009's modeling interface is similar to ArchiCAD in terms of its underlying data and representation; however, it differentiates in that it includes the integration of the six separate software packages in order to enhance total project management (see Figure 2-5). Vico Constructor 2009 is highly compatible with IFC file extensions which allows for users to create or modify data from BIM models made through other software. Additionally, Vico Constructor 2009 allows the BIM to be built

virtually as if it were constructed in the physical sense. However, because of this the user must have an extensive knowledge of construction in order to effectively utilize all the BIM capabilities.

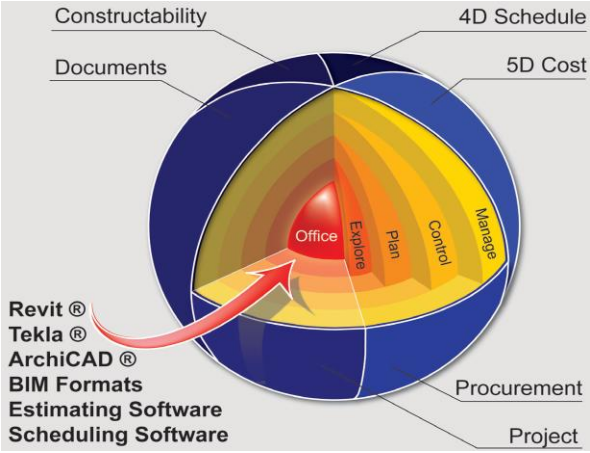


Figure 2-5. Vico Office Suite functional diagram on project management and construction (source: Vico Software, Inc. 2009)

2.2.5 BIM Software Supplemental Applications

Though the majority of BIM software platforms attempt to provide most functionalities within the framework of their interface, multiple subsidiary software applications are available to enhance the capabilities and performance of BIM. Similar to major BIM platforms, each auxiliary BIM application adheres to its own style and performance abilities, therefore, there are discriminating characteristics among each that allows for comparison.

2.2.5.1 NavisWorks Manage 2010

Another Autodesk product, NavisWorks Manage 2010 is designed to facilitate collaboration and project visualization during or just before the construction phase of a project. The software offers a method of networking multiple parties together in order to implement an integrated workflow. NavisWorks Manage 2010 provides optimal viewing

programs to deliver smooth real time walk-through visualizations as well as clash detection software to improve the integrity of a BIM model. Additionally, NavisWorks Manage 2010 provides scheduling simulation in association with Primavera Project Planner via links within the 3D model data and the project schedules.

NavisWorks Manage 2010 operates on a NWD file extension however it has the ability to support DWG, DXF, DGN, 3DS, and IGES formats. In order to provide alternative interoperability functions NavisWorks Manage 2010 provides file exporters so that selective BIM software is able to support the NWD file format (Autodesk 2009b).

2.2.5.2 Solibri Model Checker

The Solibri Model Checker is a relatively new application used to analyze potential problems, conflicts, or design code violations. Integrated within the software are visualization tools, walkthrough capabilities, interference detection, model comparison, and quantity takeoff. The program's visual interface is simple and well organized allowing the user relative ease to learn the software. Similar to Autodesk Navisworks Manage 2010, Solibri Model Checker is viewed as primarily a quality inspection utility for BIM model integrity, along with its other capabilities. The software runs entirely through the IFC file extension which limits its ability to work in a seamless environment with major BIM applications; however, as IFC is becoming the international standard Solibri Model Checker is on par in terms of its interoperability capabilities (Khemlani 2009d).

2.2.5.3 Innovaya Visual Software

Innovaya provides a number of software options for the AEC industry with the intent on maximizing the potential of computer tools in design and construction

processes. Innovaya offers five products that primarily target the construction aspect of the building process with integrated software involved in visualization, quantity takeoffs, estimating via Sage Timberline, and simulation through Primavera Project Planner:

- Innovaya Visual BIM;
- Innovaya Visual Quantity Takeoff;
- Innovaya Visual Estimating;
- Innovaya Design Estimating, and;
- Innovaya Visual Simulation.

Currently, Innovaya products work directly with only Autodesk Revit, Autodesk Architectural Desktop (ADT), and Autodesk Building Systems (ABS) through an add-on INV file extension; therefore, it is not interoperable with different BIM software. However, due to its ability to offer numerous construction related programs it is a viable product in the market for BIM users to invest in (Khemlani 2006).

2.3 Sustainability

With the growing threats of global warming many industrial sectors are beginning to address the need for energy efficiency in residential and commercial buildings. Consuming approximately 70 percent of the electricity in the United States as of 2005, the energy used from the building sector has steadily increased since the early 1980's (Torcellini 2006). Although there have been attempts in reducing the demands of energy use and carbon emissions within residential buildings, previous developments have yet to meet their fullest potential in creating new generations of high performance green buildings.

On a global scale, with nearly 72 percent of all greenhouse gases related to household consumption there is a definite necessity to invest in developments to reduce the global warming potential (GWP) within the built environment (Hertwich and Peters 2009). Through the proper application of innovative strategies in design, construction, and facility operations development of sustainable communities will continue to increase. By applying sustainable techniques and methods over a period of time there should be a considerable amount of change resulting in reduced environmental impacts, not only within the built environment but on a grander ecological scale.

2.3.1 Green Building Assessment

As a means to mitigating the substantial stress buildings place on the environment, numerous green building assessment organizations have been established with the goal of analyzing and evaluating the current construction projects and their building performance. The main function of these building assessment organizations is to promote high performance buildings through responsible design, construction, and operations maintenance practices. As defined by Cam and Ong (2005), the main roles of green building assessment organizations are: 1) acting as an institutional setting to raise awareness of building environmental issues to different players in the design and construction sectors and encourage them in delivering environmentally friendly housing; 2) setting benchmarks for building environmental practice to safeguard the minimum performances standards, and in evaluating architectural design against these benchmarks; and, 3) providing a platform for inspiring new designs, ideas and technical solutions.

The following sections examine the evaluation means and methods behind the LEED, Green Globes, BREEAM, and other rating systems in terms of their ability to promote, assess, and provide innovation for high performance green buildings.

2.3.1.1 LEED

Developed by the United States Green Building Council (USGBC) in 1998, the Leadership in Energy and Environmental Design (LEED) rating systems provide a system of standards for sustainable design and construction operations. Within the overarching framework of its ratings suite are included the following sub-rating systems:

- LEED for New Construction
- LEED for Existing Buildings: Operations and Maintenance
- LEED for Core and Shell Development
- LEED for Schools
- LEED for Commercial Interiors
- LEED for Neighborhood Development
- LEED for Homes
- LEED for Healthcare
- LEED for Retail New Construction (pilot)
- LEED for Retail Interiors (pilot)

The intention behind of the development of LEED was to promote the construction of environmentally friendly, high performance green buildings. According to LEED-NC v3.0, in order to achieve certification, projects must undergo a third-party evaluation based on a 110 point scale. Table 2-1 lists the breakdown of the points into their respective categories. As indicated in Table 2-1, the five major categories that make up the composition of its rating system include sustainable sites; water efficiency; energy

and atmosphere; materials and resources; and, indoor environmental quality. Additionally, LEED provides the opportunity to earn points for achievements in innovations and, most recently with the current changes to version 3.0, the ability to earn points for regional priorities.

Table 2-1. LEED Rating System v3.0 New Construction

	LEED Category	Points	Percent
A	Sustainable Sites	26	24%
B	Water Efficiency	10	9%
C	Energy + Atmosphere	35	32%
D	Materials + Resource	14	13%
E	Indoor Environmental Quality	15	14%
F	Innovation and Design	6	5%
G	Regional Priority	4	4%
Column Totals		110	100%

Evaluations of the criteria are made via web-based documentation by the project team showing how points were attempted to be earned. Upon completion of the project the building undergoes a cursory review process by which time the building is awarded certification. The four levels of certification and required points are shown in Table 2-2.

Table 2-2. Points required for LEED certification (LEED-NC v3.0)

	LEED Certification Level	Required Points
A	LEED Certified	40-49
B	LEED Silver	50-59
C	LEED Gold	60-79
D	LEED Platinum	80 and above

2.3.1.2 Green Globes

The Green Globes environmental assessment and rating systems is evolutionary descendent of the United Kingdom's BREEAM system. Began by the Green Building Initiative (GBI) in 2004, Green Globes provides an effective and practical way to advance the overall environmental performance and sustainability of commercial

buildings. The framework of the Green Globes system is composed of the following elements:

- Comprehensive environmental assessment protocol;
- Software tools that speed and simplify online assessment;
- Best practices guidance for green construction and operations;
- Qualified assessors with green building expertise, and;
- Rating/certification system.

Table 2-3 provides the structure for the Green Globes assessment protocol. Though similar to the LEED-NC v3.0 structure, Green Globes addresses additional issues such as project management; emergency response planning; durability; adaptability; deconstruction; life-cycle assessment; and, noise control (Kibert 2008). In order for project to become certified the project team must complete a web-based questionnaire during various stages of the project duration and attain at least 35 percent of the possible points (i.e. 350 points). Following completion of the project a third-party verifier with expertise in green building design, engineering, construction, and facility operations is responsible for personal assessment of the project team and the project, at which point their recommendation is sent to the GBI concerning the appropriate certification level.

Table 2-3. Green Globes Rating System v1

	Green Globes Rating Category	Points	Percent
A	Project Management	50	5%
B	Site	115	12%
C	Energy	360	36%
D	Water	100	10%
E	Resources, Building Materials, + Solid Waste	100	10%
F	Emissions + Other Impacts	75	8%
G	Indoor Environment	200	20%
Column Totals		1000	100%

2.3.1.3 BREEAM

BRE Environmental Assessment Method (BREEAM) is an environment assessment method for buildings began in the United Kingdom in 1988, now adopted by many European and Asian countries as well as Canada. BREEAM assesses building under guidelines of the following environmental impacts: management; health and well-being; energy; transport; water; material and waste; land use and ecology; and, pollution. Assessments are carried out by independent assessors who are trained and licensed by BRE Global. Credits are awarded in each of the criteria listed according to performance based on a rated scale of Pass, Good, Very Good, Excellent, or Outstanding with a certificate awarded to the development. BREEAM currently assesses a number of building types including: offices; retail; education; prisons; courts; healthcare; industrial and, EcoHomes (Kibert 2008).

2.3.1.4 Other green building assessments

There are several additional building assessment systems available worth mentioning such as the CASBEE (Japan) system, the Green Star (Australia) system, and the SBTool. CASBEE is a Japanese green building rating system developed in 2001. Its distinguishing characteristic is that it is founded on the principle of Building Environment Efficiency (BEE) as the major indicator, which is based on the following formula:

$$\text{BEE}=\frac{\text{Building Environmental Quality and Performance (Q)}}{\text{Building Environment Loadings (L)}}$$

where Q defines indoor environment, quality of service and outdoor environment on site issues; and, L defines energy, resources and materials, and off-site environment issues. Each area within the category is scored on a scale from 1 to 5. Once calculated, points

are plotted on a designed performance chart where an overall score is generated. The scores are graded from C (poor) through B-, B+, A, and S (excellent) (Kibert 2008; Krygiel 2008).

Green Star is an Australian based environmental rating system launched in 2003. Within the structure of its rating system, nine categories are assessed with its tools: management; indoor environmental quality; energy; transportation; water; materials; land use and ecology; emissions; and, innovation. Certification is earned through evaluation of each of these categories based on a point system. Awarded to buildings that achieve high standards of environmental awareness are various levels of stars indicative of the level of performance the building has attained. Green Star has developed its toolkit to include analysis over facilities within the education; healthcare; multiunit residential; office; and, retail sectors, and currently is under pilot programs for facilities within the industrial; mixed use; and, convention center sectors (Kibert 2008).

The SBTool is a framework designed for the assessment of buildings based on environmental performance. The structure to its evaluation criteria involves 116 parameters found within seven main categories. The main categories include:

- Site selection, project planning, and development
- Energy and resource consumption
- Environmental loadings
- Indoor environmental quality
- Service quality
- Social and economic aspects
- Cultural and perceptual aspects

The tool is broken down into three parts: 1) tool for weighting the appropriate standards for a region; 2) tool for the project team to describe all the project information; and, 3) tool for assessment. Because of its ability to be adaptable to certain local conditions, building performance is related to nationally established baselines or benchmarks (Krygiel 2008).

2.3.2 Future Development of Green Building Assessments

In terms of its ability to promote high performance green buildings, the majority of green building assessment programs have significantly impacted the perceptions of sustainability within the design and construction industry. Within the United States, 22 states and 75 municipalities have instituted or encouraged buildings to become LEED certified. Therefore, as the trend towards sustainability continues to grow the use of LEED and other green building assessment programs will be a primary factor in its development. However, as the future of sustainability continues to see improvements and innovation there must be the same within green building assessment programs, continually raising the bar to achieve greater goals. Additionally, the AEC industry itself must mandate its practices to abide by the goals set within the rating systems in order to fully compliment the targeting aspirations desired collectively. The future of green building assessments remains to be seen, however, current initiatives are making steps into the right direction.

2.4 The Interoperability between BIM and Sustainability

2.4.1 Environmental Analysis Software

In order to provide tools for environmental analysis, software companies offer different packages of applications as a means of evaluating design and construction

practices and their environmental impact. These environmental analysis software applications are intended to be joined with BIM in order to assess the performance of proposed projects. Until recently, these applications were seen as separate elements from BIM, based on different platforms and interfaces. Today, in order to maintain interoperability, building performance analysis software and BIM are connected through a common exchange file extension, gbXML. The green building extensible markup language (gbXML) is an open, non-proprietary schema that was developed to facilitate intelligent information exchange, enabling integrated interoperability between building design models and a wide variety of engineering analysis tools available today (Eastman et al. 2008). Additionally, with more advanced integrated software, IFC file extensions are used so that projects may be created or modified within the analytical software. The following section describes various building performance and environmental analysis software in terms of the types of analysis, interface, and interoperability with BIM.

2.4.1.1 Autodesk Ecotect Analysis 2010

A new member of the Autodesk family since summer 2008, Ecotect is a green building software designed to provide information regarding projects throughout the design and preconstruction phases of development. Its comprehensive 3D platform allows for multiple sustainable design tools to provide for simulations and analysis to gain insight into building performance beginning with the conceptualization of a project. It provides functions for whole building analysis based on the solar energy, daylighting, acoustical, and thermal, among others. Ecotect provides the ability to build a massing of a structure within its interface in order to determine specific criteria such as optimal

location, shape, and building orientation to create more sustainable constructs. Simulations and analysis are carried through the use of Green Building Studio web-based technology using the gbXML schema. In addition to whole building analysis, Ecotect provides tools for the following analyses (Autodesk 2009a):

- Carbon-emissions estimates
- Water use and cost estimates
- ENERGY STAR scoring
- LEED daylighting credit potential
- Natural ventilation
- Wind energy
- Photovoltaic collection
- Thermal performance
- Solar radiation
- Visual impact
- Daylighting
- Shading design
- Acoustic analysis

The use of gbXML and IFC file extensions provide the ability for information to be translated seamlessly. With its enhanced capability to apply sustainable design criteria within its platform, Ecotect is a major product in terms of its service towards BIM and sustainable design and construction.

2.4.1.2 IES <Virtual Environment>

Virtual Environment (VE) is software offered by Integrated Environmental Solutions (IES) that virtualizes the entire process of designing buildings specifically for

environmental purposes. The software provides a full building modeler, similar to BIM, where a user may import extensible files or start from the beginning within the interface. VE contains a number of modules within its program in order to provide for analytical assessments. The following is the list of the available tools in the analytical toolkit:

- VE/Mechanical
- VE/Electrical
- VE/Lighting
- VE/Thermal
- VE/Solar
- VE/CFD
- VE/Costs
- VE/Value

These tools include options for analyzing energy consumption; carbon emissions; LEED daylighting; solar shading; and, artificial lighting. In order to enhance its capabilities within interoperability, VE is organized around a central 3D model that is able to directly connect with SketchUp, Autodesk Revit, Graphisoft ArchiCAD, or any other 3D modeler through the gbXML/DXF import file extensions (see Figure 2-6).

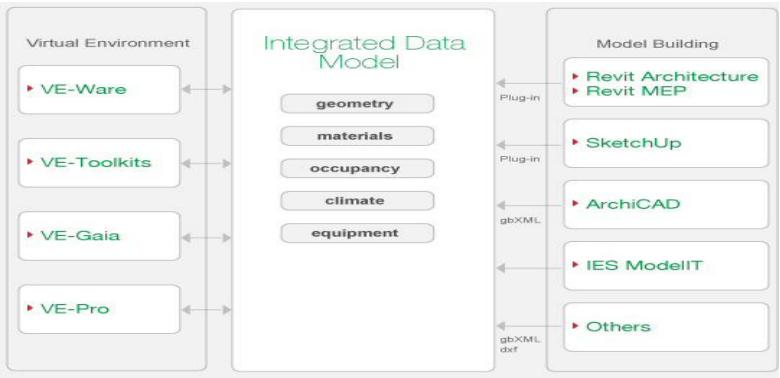


Figure 2-6. IES Virtual Environment integrated data model (source: Khemlani 2009).

2.4.1.3 Graphisoft EcoDesigner

A plug-in provided by Graphisoft, EcoDesigner is a program that allows for modeling and analysis of the energy efficiency performance of a building early on during the design phase of a project. Because it is a plug-in for the Graphisoft ArchiCAD software platforms, it runs seamlessly enhancing its interoperability. Though not regarded as a complete detailed analysis tool, it does provide a number of features to quickly analyze and assess various aspects of a project (Thoo 2010).

2.4.1.4 eQUEST

An acronym for "Quick Energy Simulation Tool," eQUEST is a building energy simulation tool provided by the US Department of Energy as part of the DOE-2 software packages. It is a tool that is free online offered for whole building energy analysis. eQUEST is designed so that it may be used during the early schematic phases of design, with modeling capabilities built within its software platform. Using the Energy-Efficiency Measures (EEM) Wizard provides design alternatives through base building descriptions. eQUEST's energy analysis engine provides tabulated data in terms of annual energy use and gas consumption so that comparison may be made among different design alternatives. Although the software is seen as completely internalized, eQUEST offers the ability to import DWG files into its interface (Energy Design Resources 2009).

2.5 Future Developments

As relatively new concepts within the AEC industry, the relationship between BIM and sustainability is only beginning to touch the surface of its potential. However, as the demand of each subject is increasing annually the development of more sophisticated

robust platforms is necessary to maintain the level of achievement reached so far. Sustainable measures must be enhanced in order to improve upon established goals set forth through green building assessments. BIM must increase its capacity to integrate environmental analysis and improve interoperability. The advancement of technology will assist both in establishing standards of excellence in the future, however, and most importantly, the AEC industry and owners must be willing to implement these tools of performance into their standards of practice. Additionally, each party must be willing to cooperate with one another so that an optimal collaborative effort will be provided for sustainably built projects.

CHAPTER 3
RESEARCH DESIGN AND METHODOLOGY

3.1 Overview

This investigatory report looks at the available possibilities for BIM usage in the design and construction industry. The primary focus of this thesis concerns the ability to incorporate BIM into the concepts of sustainable design and construction practices throughout the development of a built project (i.e. from conceptual design through project closeout). In order to obtain the necessary data to carry on this research a survey was developed and distributed in the AEC industry. The purpose of the survey was to understand how professionals consider BIM as a tool in the fields of design and construction in terms of its application towards enhancing sustainably built projects. Accordingly, the objectives of the survey were established as: 1) to analyze the current trends and future developments in BIM and sustainable practices within the AEC industry; 2) to assess how BIM is being used as a mechanism to foster sustainable practices; 3) to understand how BIM is being used today in order to analyze the building performance of a built project; 4) to determine what difficulties with interoperability are seen as potential problems with BIM software, and; 5) to find out at what stage in the development of a BIM project is thought of as a useful tool in providing sustainable design and/or construction practices.

The second phase of this research was to distribute the survey to a sample population of the AEC industry. The third phase involved collecting the survey data in order to conduct an analysis of the results using descriptive statistics. Upon analysis of the data, the fourth and final phase of the research was to determine trends within the AEC industry and provide a summary of the collected results (see Figure 3-1).

3.2 Survey Questionnaire Design

The survey questionnaire can be found in its entirety in Appendix C. The survey questionnaire, consisted of five major sections, specifically: 1) personal information; 2) company information; 3) BIM and its relationship to design and building practices; 4) sustainability and its relationship to design and building practices; and, 5) BIM and its use to support sustainable design and building practices. In compliance with the University of Florida Institutional Review Board (UFIRB-02) the survey contained a confidentiality statement indicating that all responses to the survey questionnaire would be held in complete confidentiality. An optional section was included at the end detailing instruction on how the participant would be able to acquire the final results of the survey upon completion of the study. The following section provides a more comprehensive description of each section in the questionnaire as it relates to the overall objectives of this study.

3.2.1 Personal Information

Section 1 of the survey questionnaire was designed for the purpose of individually classifying the responses of the participants individually. Since the AEC industry is comprised of many different entities it is important to identify where the responses to the survey originate. Therefore, the questions within this section concerned the participant as an individual, distinguishing certain relevant characteristics which were later on used to determine relevance when analyzing Sections 3 through 5.

Question 1.1: Occupational role – The purpose of this question was to define the position role (e.g. architect, engineer, general contractor) of the individual participant in order to identify which employment category within the AEC industry the respondent

belonged to. The use of this question during analysis of the data as a whole provided relevance within Sections 3 through 5 in terms of their categorical response (i.e. analysis of results through a stratification of the data).

Question 1.2: Are you a LEED AP? – The responses to this question provided another means of distinguishing participants from one another. Determining the relationship between the LEED AP status of the respondent and their opinion on sustainability was deemed valuable and provided insight into the other participant responses.

Question 1.3: Number of years working as a professional? – This question was posed in order to determine if there was any relevance between the numbers of years a professional has worked in the industry compared to other survey responses in respect to their opinions found within Sections 3 through 5.

3.2.2 Company/Organization Information

Similar to Section 1 of the survey questionnaire, Section 2 was designed to classify the responses of the participant in terms of the characteristics of their corresponding company. Again, due to the nature of the AEC industry and the heterogeneous composition of companies in terms of size, annual revenue, locality, and methods of business, it is important to identify those characteristics in order to assess the results against other survey responses, specifically in Sections 3 through 5.

Question 2.1: Company project types – The responses to this question provided relevance when compared to other survey responses. The relationship between a company's project type (e.g. commercial, residential, and industrial) and their

involvement with BIM and sustainability is quite significant. Respondents had the option to select as many categories as applied to their company.

Question 2.2: Annual company revenue – This question provided a means for analyzing the size of the participant's company size in terms of annual revenue. The responses were used to understand the potential relationships between a company's annual revenue and their involvement in BIM and sustainability.

Question 2.3: Number of company employees – Similar to Question 2.2, the responses to this question was used to determine the participant's company size. The question provided a means to analyze the relationships between a company's size and their involvement in BIM and sustainable design and construction practices.

Question 2.4: Number of company LEED AP employees – Similar to Question 1.2, this question was provided to determine the number of employees within a company affiliated with the LEED AP accreditation. The responses to this question were used to analyze any relevance of a company's involvement in sustainable design and construction practices against other participant responses.

Question 2.5: Regional location of company – The responses to this question were used to determine relevance between the locality of a participant's company (i.e. region within the United States) and their involvement with BIM and sustainable design and building practices. The regions identified in this question were defined as the designated areas provided by the United States Census Bureau.

Question 2.6: Primary company project delivery method – This question was posed in order to identify what project delivery method was used within the respondent's company practices. The responses to this question were used to determine any

significant relevance between the participant's company project delivery methods and their involvement with BIM and sustainable design and construction practices.

3.2.3 Building Information Modeling (BIM)

Section 3 of the survey questionnaire was designed to understand the respondent's company use of BIM as part of its current practices. The primary goal of this section was to answer the investigation objectives through a series of different styles of questions. The questions in this section specifically targeted what types of BIM software platforms had been used as well as to what extent the software was utilized within the structure of the company's business practices. Additionally, the participants were asked questions based on their opinion on the use of BIM within the AEC industry as a whole in order to provide feedback concerning specific aspects of BIM.

Question 3.1: Which of the following BIM software packages does you company utilize? – This question was used as a means to understand what types of BIM software were being used by companies in the AEC industry both collectively and categorically. The list of platforms provided in the question stemmed from a product list of the most frequently used platforms currently available on the market. The respondents were given the option to select multiple software platforms as utilized through their company practices.

Question 3.2: How long has your company implemented BIM into its practice? – The responses to this question were used in order to develop an understanding of how recent companies have implemented BIM into their business practices. The information collected regarding this question allows for further analysis in combination with the other questions found in Section 3.

Question 3.3: Approximately what percentage of projects completed by this company has utilized some form of software within the past 5 years? – This question allows for an understanding of how frequently BIM is being used on projects within a company's practice. Similar to Question 3.2, the information collected regarding this question allows for further analysis in combination with the other questions found in Section 3.

Question 3.4: Approximately what percentage of projects completed by this company has been required by owners/stakeholders to utilize some form of software within the past 5 years? – Similar to Question 3.3, this question provides a means of understanding how often owners/stakeholders are involved in the decision making process in terms of BIM usage.

Question 3.5: What role does BIM have within your company? – The intent of this question was to form an understanding as to what extent BIM is being used within a company's practices. As BIM provides multiple operations concerning all aspects of the AEC industry, it is important to understand how the different occupational roles utilize BIM. The functional roles of BIM listed in the question were provided through a 2009 study concerning paradigm trajectories of BIM practice in project networks (Taylor et al. 2009). The respondents were given the option to select multiple BIM functions as utilized through company practices.

Question 3.6: Rate the following statements according to your perception of BIM and the skepticism of its use in the industry – A series of statements were provided regarding this question and respondents were required to rank their answers on a 5-point Likert Scale ranging from 'Strongly Disagree' to 'Strongly Agree.' The series was

based on the following five statements concerning frequent skepticism about the use of BIM in the AEC industry:

- BIM is currently too complicated to use;
- BIM is currently not a cost-effective measure for the industry;
- BIM is currently not designed to be used specifically for my profession;
- BIM is currently not a necessity within the industry, therefore, there is no need to implement it, and;
- BIM currently does not operate in an optimal standardized format making it difficult to translate data seamlessly.

The responses were used to develop an understanding of what the potential drawbacks of BIM which are keeping it from being used within the AEC industry.

Question 3.7: Rate the importance of the following features found within BIM software packages – Similar to Question 3.6, a series of potential product features was provided and the respondents were required to rank their answers on a 7-point Likert Scale ranging from 'Very Low' to 'Very High.' This series of questions was based on the following eight features typically associated with BIM software packages:

- Direct integration with energy analysis software applications;
- Direct integration with project management software;
- Direct integration for construction related tasks;
- Support for production of construction documents with the need for another application;
- Standardization of software platforms to facilitate interoperability in the building industry;
- Multidisciplinary capabilities;
- Ability to support collaborative and distributed work processes, and;

- Relative ease of software use adjoined with helpful tutorials, supporting documentation, and other learning resources.

The responses were used as a way to understand the participant's opinion on certain BIM features collectively within the AEC industry as well as categorically through the responses found in Sections 1 and 2.

3.2.4 Sustainable Building Practices

Similar to Section 3 of the survey questionnaire, Section 4 was designed to understand the participant's company use of sustainable design and building practices as part of its current practices in order to provide data to answer the survey objectives. The questions in this section primarily target the company's opinion on certain key aspects of sustainable design and construction as utilized in order to achieve green building certifications.

Question 4.1: Approximately what percentage of projects completed by this company has received either a LEED or green building equivalent certification within the past 5 years? – This question offered insight into how devoted companies are to pursuing green buildings. Although this question does not entirely explain how involved a company is in terms of sustainability it does provide enough of a perspective to perform an analysis

Question 4.2: Approximately what percentage of projects completed by this company has been required by the owners/stakeholders to receive either a LEED or green building equivalent certification within the past 5 years? – Similar to Question 4.1, this question provided an understanding of how often owners/stakeholders are involved with the decision making in terms of implementing sustainable practices within the completion of a built project.

Question 4.3: Rate the following statements according to your perception of your company and sustainability – The intent of this question was to provide a way to assess a company's active involvement in sustainable business practices. A series of statements were given and the respondents had to use a 5-point Likert Scale ranging from 'Strongly Disagree' to 'Strongly Agree.' The series was based on the following five statements concerning the participant's perception of their company and sustainability:

- My company finds the role of sustainability important;
- My company has been proactive in educating employees on recent sustainable practice developments;
- My company utilizes the latest innovations in technology to enhance our sustainability mechanisms;
- My company actively advises owners/stakeholders to pursue sustainable methods and practices during projects, and;
- My company provides incentives to encourage sustainable practices during projects.

The responses were used to determine to what degree sustainability is being pursued by the participants and their corresponding companies as well as what methods are being used most frequently to promote achieving sustainable practices.

Question 4.4: Rate the priority of the following in terms of its potential impact on sustainable construction – Similar to Questions 4.3, the intent of this question was to provide a means of understanding how the participant viewed the importance of commonly used design and construction practices to enhance sustainable measures. The question was asked with a series of common sustainable categories on a 7-point Likert Scale ranging from 'Very Low' to 'Very High.' The series was based on the following eight categories:

- Sustainable site development
- Water efficiency
- Energy efficiency
- Sustainable materials
- Indoor air quality
- Project management
- Building commissioning
- Post construction facility operations

The responses were used to determine the importance of each sustainable category according to the respective participant, particularly in combination with Question 5.6.

3.2.5 Building Information Modeling (BIM) and Sustainable Building Practices

Section 5 of the survey questionnaire was designed to understand the correlation between BIM in support for sustainable design and construction practices. The primary goal of this section was to target any definitive relationship between the two topics discussed in Section 3 and 4. The questions in this section were used in determining what BIM methods and strategies are used in order to facilitate sustainable design and construction practices. Additionally, the respondents were provided an open-ended question in order to ascertain any other information that the survey may have not included or unintentionally omitted.

Question 5.1: At what phase would implementing BIM contribute most to providing sustainable design or construction practices throughout the duration of a project? – The responses to this question were used to determine at what phase during a built project the use of BIM was a valuable asset in terms of sustainability. This question provides

for assessment based on a combination of results from other sections of the survey, allowing analysis through stratified measures.

Question 5.2: Which of the following types of computer aided analysis has been utilized by your company in one form or another? – The intent of this question was to understand what sustainable environmental analysis tools were used in order to assess building performance. This question allowed for a comparison between types of BIM software used (i.e. Question 3.1) and the various types of environmental analysis used to enhance sustainable design and construction practices.

Question 5.3: Which of the following building performance analysis software has been utilized by your company in one form or another? – Similar to Question 5.2, this question was included in order to determine what specific types of environmental software were utilized to perform environmental analysis. As most building performance analysis software packages are designed to work directly with BIM software packages, this question was used to assess the interdependence of both types of virtual analysis and evaluate the advantages and drawbacks of each.

Question 5.4: Which of the following project delivery methods provides the best environment for the utilization of BIM software as a mechanism for sustainable design and building practices? – The responses from this question were intended to provide information regarding participant's viewpoints as to at what stage BIM should be implemented during a project's duration in order to optimize sustainable practices. This question allowed for analysis to determine relevance in comparison with the participant's responses with respect to the replies in Sections 1 and 2.

Question 5.5: Rate the importance of the suggested improvements in terms of its impact within BIM and sustainable design and practices – The intent of this question was to determine what additional measures would best be implemented to current BIM software packages that would further enhance sustainable practices. The question was asked with a series of suggested items on a 7-point Likert Scale based ranging from 'Very Low' to 'Very High.' The series consisted of the following three suggestions:

- Improvements within interoperability between software packages
- Integration of a carbon accounting tracker
- Interactivity of live weather data

The responses were used to determine the relevance of each item based on the respective participant and as a collective group.

Question 5.6: Rate the current BIM software packages in terms of its effectiveness in achieving the following sustainability categories during a project – Similar to Question 4.4, the intent of this question was to analyze the effectiveness of BIM as a means to improve sustainable practices within the participant's company. The question was asked with a series of common sustainable categories on a 7-point Likert Scale ranging from 'Highly Ineffective to 'Highly Effective.' The series was based on the following eight categories:

- Sustainable site development
- Water efficiency
- Energy efficiency
- Sustainable materials
- Indoor air quality
- Project management

- Building commissioning
- Post construction facility operations

The responses to this question were compared with Question 4.4 in order to determine any direct relationships.

Question 5.7: How do you feel current BIM software is being used to facilitate sustainable design and construction practices? What changes, if any, need to be made to enhance its ability to support sustainable practices? – This question allowed the participant to provide any additional information regarding BIM and sustainable business practices that the survey might have not included or unintentionally omitted. The responses were primarily used to gain perspective from the firms regarding the use of BIM and sustainability in current practices

3.2.6 Optional Section

The final section of the survey questionnaire concluded with an optional response regarding the participant's rights to receive the final results of the study as a way of both rewarding the respondent for taking part in the survey and to share information which may be of some value to the company. Again, the respondents were instructed prior to beginning the survey that their responses would be held in complete confidentiality and that none of the responses would be released or reported on individually.

3.3 Sample Population

The second phase of this investigation consisted of selecting a list of potential survey participants in order to distribute the proposed survey questionnaire among the AEC industry. The selected target audience was intended to be from companies from various sectors within the AEC industry (e.g. architects, engineers, general contractors,

and subcontractors) who were primarily interested in vertical construction. Additionally, this investigation by design was to include participants from different project types, localities, and sizes. Although the project delivery method was identified as an important characteristic within the scope of this study, the primary target audience for this research was selected as practitioners of the design-build and integrated project delivery methods as they are specifically designed for extensive collaborative efforts through contractual agreements. Because the ideology behind the Design-Build Institute of America (DBIA) encompassed all the necessary traits desired with this study, members found within the organization were considered to be ideal candidates for this investigation. Therefore, the potential survey participants contacted were generated through a registration attendance list given to the attendees of the DBIA National Conference in Washington DC in November 2009.

A total of 657 companies were acquired from the generated list of potential survey participants all from within the AEC industry. Based on a 95% confidence level, with a confidence interval of 5%, the preferred sample size was calculated at 243 responses. Therefore, a response rate of nearly 37% was desired to claim this study to be significantly relevant within the population sample. The participants were emailed an electronic survey through the web-based survey generator Zoomerang™ (http://www.zoomerang.com). The survey was launched on January 26, 2010 and closed 16 days later on February 11, 2010.

3.4 Method of Analysis

The third phase of the research design involved receiving the respondent's answers, upon which a detailed analysis ensued in order ascertain any correlations

found between BIM and sustainable design and construction practices. In order to fully analyze the results of the survey, the responses to each question were studied through the use of descriptive statistics. Each section of the survey was assessed through an analysis based upon comparisons against one another in order to find whether or not there were differences among the sampled population. All questions in the survey were analyzed collectively to determine the viewpoints as a whole concerning the intended subject matter. Using the method of stratified sampling, so as to eliminate bias among the results, relationships were generated in Sections 3 through 5 based on responses obtained through the responses to Sections 1 and 2. The intent of the analysis was to establish a means to compare the participant's opinions on BIM and sustainability within the AEC industry to determine current trends and possible future developments.

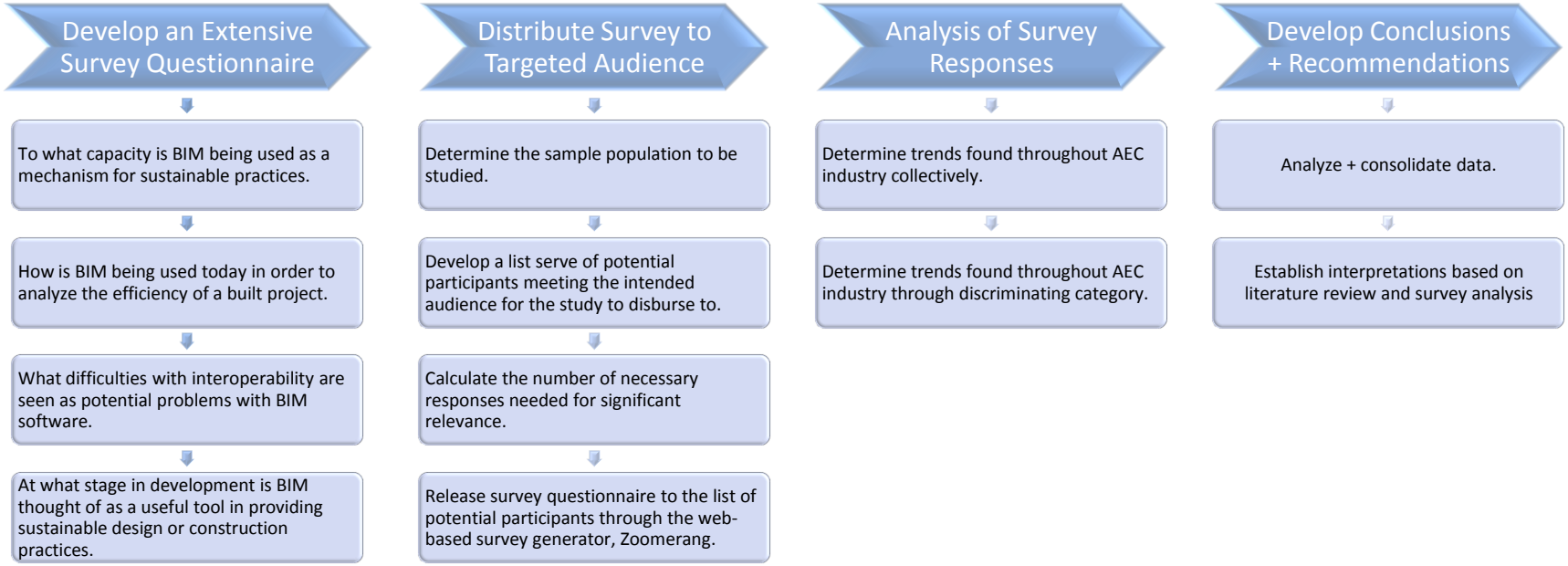


Figure 3-1. Research methodology process

CHAPTER 4
SURVEY RESULTS

Upon the date of closing the survey, 259 respondents had visited the survey website, and 123 completed surveys in addition to 56 partial responses were received. In order to maintain consistency with the results all partial responses were excluded from the reported results. The survey response rate was calculated at 18.7% which is under the minimum response rate of 37% desired in order to provide meaningful support for the entire sample population. Therefore, although the results should not be considered significantly relevant for the entire population sampled, the results still provide insight on current development in BIM, the trends in sustainable practices, and the overall potential for the future of BIM guidelines in sustainability.

The results of the survey questionnaire are provided in the following section with a brief analysis on each section. The results in the chapter are described through the use of descriptive statistics using the population sample as a whole. Chapter 5 will provide with more in depth analysis regarding specific details of the data using the method of sample stratification.

4.1 Section 1 and 2 Results

Section 1 and Section 2 of the survey questionnaire were given as a means to analyze the sample population through various categories in order to determine trends between specific characteristics found within the AEC industry and Sections 3 through 5.

4.1.1 Question 1.1

In order to determine what percentage of the population belonged within certain sectors in the AEC industry, Question 1.1 was developed as a way to evaluate the

composition of the respondents. The results found in Table 4-1 indicated that the highest percentage in the sample were general contractors at 27.6% (34 participants), followed by architects at 20.3% (25 participants), then engineers and subcontractors at 14.6% (18 participants) each. Another category 'Other' was created in the case that additional disciplines were not provided as an option. This category included but was not limited to management positions, commissioning agents, and energy modelers, therefore, although undefined this category broadly influenced the samples as it includes nearly 22.8% (28 participants) of the total sample. The information gathered in this question will be vital in terms of performing analysis through sample stratification.

Table 4-1. Respondents' role in the AEC industry (Q1.1).

AEC Company Role	Number of Participants	% of Total
General Contractor	34	27.6%
Other	28	22.8%
Architect	25	20.3%
Engineer	18	14.6%
Subcontractor	18	14.6%
Column Totals	123	100%

4.1.2 Question 1.2

The responses to Question 1.2 provided information regarding the status of the individual as LEED AP. According to the responses from the survey approximately 48% (59 participants) of the sample population had earned their LEED AP accreditation, while 25.2% (31 participants) had stated they had yet to earn the status but planned to do so in the future. The remaining participants, 26.8% (33 participants) had not earned the recognition and did not plan to in the future. The results are shown in Table 4-2.

Table 4-2. Respondents with LEED AP affiliation (Q1.2)

Number of Years	Number of Participants	% of Total
Yes	59	48%
No	33	26.8%
Not currently, but I plan to be.	31	25.2%
Column Totals	123	100%

4.1.3 Question 1.3

The final question of Section 1 was posed in order to find relevance between number of years a professional had worked in comparison with the results found throughout the survey. The responses from the survey indicated that the majority of the sample population ranged from 11 to 30 years of experience with nearly 54% (66 participants) of respondents being from within that time frame. Conversely, the least populated category in regards to this question was the range 0 to 5 years at a total of only 13% (15 participants). The rest of the results are shown in Table 4-3, which breaks down the population into more specific age groups.

Table 4-3. Number of years respondents have worked in the AEC industry as a professional (Q1.3).

Number of Years	Number of Participants	% of Total
0 - 2 years	8	7%
3 - 5 years	7	6%
6 - 10 years	22	18%
11 - 20 years	26	21%
21 - 30 years	40	33%
More than 30 years	20	16%
Column Totals	123	100%

4.1.4 Question 2.1

Section 2 of the survey questionnaire was aimed at finding out about the company the participant worked at. Therefore, Question 2.1 was posed to examine what project types the respondents' companies performed work on. The results as shown in Table 4-4 indicate that the majority of the population performed work within the commercial

sector, at 87% (107 participants). Additionally, 40% (49 participants) performed work in the Industrial sector and 33% (40 participants) worked within the residential sector. Similar to Question 1.1, an option of 'Other' was provided as another choice for those that pursued other project types. This group included a number of respondents who performed work within the health, government, and Institutional sectors of the AEC industry.

Table 4-4. Type of projects respondents' company perform work on (Q2.1).

Project Type	Number of Participants	% of Total
Commercial	107	87%
Industrial	49	40%
Residential	40	33%
Other	34	28%
Transportation	26	21%
Heavy Civil	8	7%

4.1.5 Question 2.2

Question 2.2 was designed to analyze responses based on the size of a company in terms of its revenue. Generally, the more revenue a company accumulated annually the larger the company. The results within this category varied substantially ranging from the $1M to $5B. However, it was determined that the majority of companies responding to this survey earned annual revenue of $100 Million to $1 Billion at 29% (36 participants) of the population. Annual revenue in the range of $1 Million to $10 Million was considered the next highest selected subcategory with nearly 19% (23 participants) of the population sample. The remaining options were spread evenly with each choice ranging between 11 to 15%. The results are shown in Table 4-5, which breaks down the population into more specific revenue categories.

Table 4-5. Annual revenue of respondents' company (Q2.2).

Annual Revenue	Number of Participants	% of Total
Less than $500,000	9	7%
$500,000 - $999,999	6	5%
$1,000,000 - $9,999,999	23	19%
$10,000,000 - $49,999,999	19	15%
$50,000,000 - $99,999,999	13	11%
$100,000,000 - $1 Billion	36	29%
$1 Billion - $5 Billion	15	12%
$5 Billion - $10 Billion	2	2%
Over $10 Billion	0	0%
Column Totals	123	100%

4.1.6 Question 2.3

Similar to Question 2.2, this question concerns the size of the respondent companies in terms of number of employees. As shown in Table 4-6, the highest percentage of the responses was held within companies with greater than 500 employees at nearly 31% (38 participants); therefore the most of the responses were within large organizations. With the exception of only a couple of choices, the remainder of the survey sample was spread out quite evenly ranging from 12 to 16% for each of the other categories.

Table 4-6. Number of employees in respondents' company (Q2.3).

Number of Employees	Number of Participants	% of Total
Less than 10 people	15	12%
10 - 49 people	20	16%
50 - 99 people	11	9%
100 - 149 people	4	3%
150 - 249 people	18	15%
250 - 500 people	17	14%
More than 500 people	38	31%
Column Totals	123	100%

4.1.7 Question 2.4

Similar to Question1.2, Question 2.4 was designed to determine the number of LEED accredited professionals within a company. This information is necessary to substantiate claims towards company attitudes concerning sustainability. Table 4-7

shows that companies with fewer than 50 employees (87 participants) had a large proportion of LEED AP employees at nearly 70%. The remaining categories had evenly spread proportions of LEED AP employees ranging from 6 to 11% of their employees.

Table 4-7. Number of LEED AP employees in respondents' company (Q2.4)

Number of Employees	Number of Participants	% of Total
Less than 10 people	52	42%
10 - 49 people	35	28%
50 - 99 people	13	11%
100 - 149 people	8	7%
150 - 249 people	7	6%
More than 250 people	8	7%
Column Totals	123	100%

4.1.8 Question 2.5

Because the sample population was taken throughout the United States AEC industry, it was important to determine what region the respondents were taken from. The results found in Table 4-8 indicate that the highest percentage of the sample population came from the Mid Atlantic region with 34% (42 participants). Following the Mid Atlantic, the South region provided roughly 28% (35) of the responses. The reasoning behind such a bias towards the east coast may be due to the fact the survey population was taken from a National Conference located in the Washington DC metropolitan region.

Table 4-8. Regional location of respondents' company (Q2.5).

Regional Location of Company	Number of Participants	% of Total
Northeast (New England)	5	4%
Northeast (Mid Atlantic)	42	34%
Midwest	18	15%
South	35	28%
West (Mountain)	12	10%
West (Pacific)	11	9%
Column Totals	123	100%

4.1.9 Question 2.6

Very important to the basis of this investigation was determining what type of project delivery methods were used by the respondents, which was the intent of Question 2.6. As shown in Table 4-9, the two delivery methods with the highest percentage among the respondents were the traditional Design-Bid-Build method at 37% (46 participants) and the Design-Build method at 28% (35 participants). The remaining delivery methods were spread out evenly ranging from 6 to 11% of the entire sample population. Again, the addition of the option 'Other' was provided to the survey participants in case the given list did not include their company's practices. Approximately 11% (13 participants) selected responded with this option primarily because they had stated that their operations were not based solely on one delivery method but dealt with projects on a case-by-case basis.

Table 4-9. Primary project delivery methods respondents' company uses in its practice (Q2.6).

Project Delivery Method	Number of Participants	% of Total
Design-Bid-Build (DBB)	46	37%
Construction Management	7	6%
Construction Management at Risk	11	9%
Design-Build	35	28%
Integrated Project Delivery	11	9%
Other	13	11%
Column Totals	123	100%

4.2 Section 3 Results

Section 3 of the survey questionnaire was intended as a means to analyze the sample population in their response towards their use of BIM. This includes but is not limited to: types of software used, function of BIM use, and percentage of BIM's application within business practices. The results of this section allowed for further analysis based on the responses to Sections 1 and 2.

4.2.1 Question 3.1

As Section 3 primarily involved the participant's viewpoint on BIM software and its application within their company's practices, Question 3.1 was designed to offer insight on what current BIM software is being utilized. According to the results shown in Table 4-10, 89% (110 participants) had some form of BIM use within their company practices. Autodesk Revit was the predominant BIM software used within the sample population at 78% (96 participants). Graphisoft ArchiCAD and Bentley Architecture provided the second and third highest selected software being used within the participant's companies at 11.4% (14 participants) and 10.6% (13 participants), respectively. It should be noted that Autodesk NavisWorks was not provided as an option in the survey due the definition of BIM by which the investigation took; however, ''Other' was listed as an alternative choice with roughly 7.3% (9 participants) of the survey respondents stating that they utilize Autodesk NavisWorks as part of their company practices.

Table 4-10. BIM Software used by AEC industry members (Q3.1)

Type of BIM Software	Number of Participants	% of Total
Autodesk Revit	96	78%
Beck-Technology dProfiler	7	6%
Bentley Systems Architecture	13	11%
Gehry Technologies Digital Project	3	2%
Graphisoft ArchiCAD	14	11%
Nemetschek Vectorworks	0	0%
Tekla Structures	12	10%
VICO Constructor	8	7%
Other, please specify	20	16%
None	13	11%

4.2.2 Question 3.2

Similar to Question 3.1, this question was designed to provide information regarding the number of years BIM has been in used within the respondents' companies. Based on the data from Table 4-11, the majority of the survey participants have used BIM roughly between 1 to 5 years (65%, or 81 participants). Conversely, about 12% (14 participants) of the survey population had used BIM for more than 6 years; therefore, it is clear that BIM has only been recently been implemented into the AEC industry as an operational tool.

Table 4-11. Number of years respondents' company have utilized BIM (Q3.2)

Number of Years	Number of Participants	% of Total
We have yet to implement it	14	11%
0 - 1 year	14	11%
1 - 2 years	30	24%
3 - 5 years	51	41%
6 - 9 years	6	5%
10 - 15 years	7	6%
More than 15 years	1	1%
Column Totals	123	100%

4.2.3 Question 3.3 – 3.4

Questions 3.3 and 3.4 of the survey questionnaire were intended to briefly understand the use of BIM on two levels, through the company's practices and through owner requirements. The intent of this comparison was to understand how influential the owner was on the company in terms of utilizing BIM on a project. According to the data in Table 4-12, the sample population holds that 30.5% of projects were completed with the use of BIM within the past five years and only 12.5% of projects were required by owners to utilize BIM. The ratio of company BIM practices to owner requirements from the data collected is roughly 0.41; therefore, there is little correlation between the

use of BIM within a company's practice and the influence of the owners or stakeholders. This may be due primarily because of the owner's lack of knowledge about the use of BIM and its benefit.

Table 4-12. BIM's use within company practices and owner's influence on BIM use (Q3.3 and Q3.4)

Question	% of Total
Q3.3 – Company performs BIM practices	30.5%
Q3.4 – Owners require company to perform BIM practices	12.5%

4.2.4 Question 3.5

According to Taylor et al. (2009) four emergent BIM model categories are fully applied in current practices: visualization; coordination; analysis; and, supply/chain integration. Question 3.5 is designed in order to fully understand the sample population's use of BIM as a vital tool in its operations. As shown in Table 4-13, the majority of the survey respondents use BIM as a project visualization tool as well as for project coordination (70% and 72%, respectively). Additionally, 59% of participants used BIM as a tool for analysis. Lastly, 28% (34 participants) utilized BIM as a product for supply/vendor integration.

Table 4-13. Roles of BIM and its use within respondents' company (Q3.5)

BIM Roles	Number of Participants	% of Total
Project coordination	89	72%
Project visualization	86	70%
Project analysis	73	59%
Project supply/vendor integration	34	28%
None	10	8%
Other, please specify	6	5%

4.2.5 Question 3.6

The skepticism surrounding BIM has caused a dissuasive attitude within the AEC industry that has caused many companies and organizations to not invest time and/or money in implementing BIM within the company practices. Question 3.6 is utilized as a means of understanding the respondents' viewpoint on the potential drawbacks seen within current BIM software. Table 4-14 shows the data generated from the survey questionnaire. In addition to understanding the viewpoints, a weighted scale using the following equation:

$$\sum_{1}^{n} \frac{nx}{123}, \; x = \text{number of responses}; \; n = \text{rating score} \qquad (1)$$

was included, where each statement was rated according to the number of the responses within each ranking against the total number of participants. The equation was used as a means to rank the respondents views on the given statements. Figure 4-1 shows a graphical representation of the results.

Table 4-14. Perceptions of BIM and its skepticism in the AEC industry (Q3.6)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
A.) BIM is currently too complicated to use.	38 31%	29 24%	34 28%	19 15%	3 2%
B.) BIM is currently not a cost-effective measure for the industry.	38 31%	33 27%	23 19%	27 22%	2 2%
C.) BIM is currently not designed to be used specifically for my profession.	53 43%	34 28%	9 7%	20 16%	7 6%
D.) BIM is currently not a necessity within the industry; therefore there is no need to implement it.	64 52%	28 23%	16 13%	12 10%	3 2%
E.) BIM currently does not operate in an optimal standardized format making it difficult to translate data seamlessly.	14 11%	17 14%	24 20%	47 38%	21 17%

Upon analysis of the data the following results were obtained:

- Of the survey respondents, 31% stated they strongly disagreed and 28% stated they were neutral that *BIM is too complicated to use*. Having applied a weighted score to each of the selection options, an average rating score of **2.35** was attained.

- Of the survey respondents, 31% stated that they strongly disagreed and 27% stated they somewhat disagreed that *BIM is not cost-effective*. Having applied a weighted score to each of the selection options, an average rating score of **2.37** was attained.

- Of the survey respondents, 43% stated they strongly disagreed and 28%stated they somewhat disagreed that *BIM is currently not designed for their particular profession*. Having applied a weighted score to each of the selection options, an average rating score of **2.14** was attained.

- Of the survey respondents, 52% stated they strongly disagreed and 23% stated they somewhat disagreed that *BIM is currently not a necessity in the industry*. Having applied a weighted score to each of the selection options, an average rating score of **1.88** was attained.

- Of the survey respondents, 38% stated that they somewhat agreed and 20% stated that they were neutral that *BIM currently does not operate in an optimal standardized format*. Having applied a weighted score to each of the selection options, an average rating score of **3.36** was attained.

Therefore, according to the results most of the respondents viewed BIM as an acceptable tool to be applied within their company practices, however, they also believed there were issues with BIM in terms of interoperability. The following are the rankings of the results from highest to lowest average rating score:

1) BIM currently does not operate in an optimal standardized format (3.36).
2) BIM is not cost-effective (2.37).
3) BIM is too complicated to use (2.35).
4) BIM is currently not designed for their particular profession (2.14).
5) BIM is currently not a necessity in the industry (1.88).

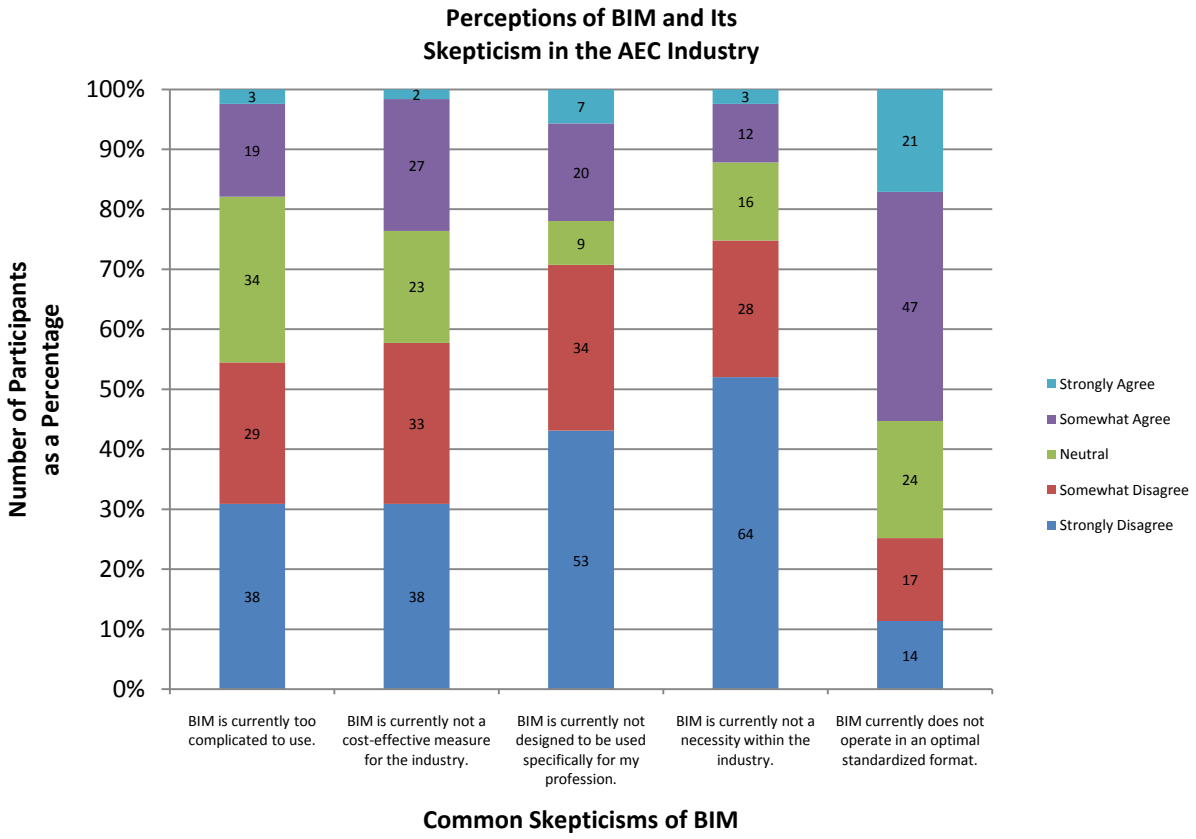


Figure 4-1. Perceptions of BIM and its skepticism in the AEC industry

4.2.6 Question 3.7

Similar to Question 3.6, this question was designed in order to provide feedback concerning features found within the BIM software platforms using a Likert scale questionnaire device. Table 4-15 provides the data generated from the responses of the survey participants. In addition to understanding the viewpoints, a weighted scale using the following equation:

$$\sum_{1}^{n} \frac{nx}{123}, \; x = \text{number of responses}; \; n = \text{rating score} \qquad (2)$$

was included, where each feature was rated according to the number of the responses within each ranking against the total number of participants. The equation was used as

a means to rank the respondents views on the given BIM features. Figure 4-2 provides a graphical representation of the results.

Table 4-15. Importance of common features found in BIM software packages (Q3.7)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1 Very Low	2 Low	3 Med. Low	4 Neutral	5 Med. High	6 High	7 Very High
A.) Direct integration with energy analysis software applications (e.g. Ecotect, IES Virtual Environment).	3 2%	10 8%	3 2%	35 28%	30 24%	18 15%	24 20%
B.) Direct integration with project management software (e.g. Primavera Suretrak, Microsoft Project Planner).	2 2%	9 7%	9 7%	39 32%	26 21%	19 15%	19 15%
C.) Direct integration for construction related tasks (e.g. estimating costs, scheduling, quantity take-offs).	0 0%	5 4%	6 5%	22 18%	27 22%	27 22%	36 29%
D.) Support to produce construction documents without the need for another application.	1 1%	2 2%	4 3%	28 23%	20 16%	27 22%	41 33%
E.) Standardization of software platforms to facilitate inter-operability in the building industry (i.e. IFC compatible).	1 1%	2 2%	1 1%	30 24%	27 22%	24 20%	38 31%
F.) Multidisciplinary capability (e.g. provides service for architects, engineers, MEP, contractors).	0 0%	2 2%	2 2%	20 16%	16 13%	35 28%	48 39%
G.) Ability to support collaborative and distributed work processes (e.g. multiple team members working on the same project).	1 1%	0 0%	3 2%	17 14%	22 18%	29 24%	51 41%
H.) Relative ease of software adjoined with helpful tutorials, supporting documentation, and other learning resources.	2 2%	2 2%	5 4%	29 24%	27 22%	31 25%	27 22%

The following details the analysis of the results:

- Of the survey respondents, 52% believed that *direct integration with energy analysis* is of neutral to medium-high importance. Having applied a weighted score to each of the selection options, an average rating score of **4.86** was attained.

- Of the survey respondents, 53% believed that *direct integration with project management software* is of neutral to medium-high importance. Having applied a weighted score to each of the selection options, an average rating score of **4.72** was attained

- Of the survey respondents, 44% believed that *direct integration for construction related tasks* is of medium-high to high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.41** was attained.

- Of the survey respondents, 55% believed that *support to produce construction documents* is of medium-high to high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.51** was attained.

- Of the survey respondents, 51% believed that *standardization of software platforms* is of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.47** was attained.

- Of the survey respondents, 67% believed that *multidisciplinary capabilities* are of medium-high to high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.82** was attained.

- Of the survey respondents, 65% believed that the *ability to support collaborative and distributed work processes* is of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.85** was attained.

- Of the survey respondents, 47% believed that *relative ease of the software* is of medium-high to high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.26** was attained.

Therefore, according to the results the respondents found each of the features to have importance within the company's practices. The following is a listing of the rankings of the results in descending order from highest to lowest average rating score:

1) Ability to support collaborative and distributed work processes (5.85).
2) Multidisciplinary capabilities (5.82).

3) Support to produce construction documents (5.51).
4) Standardization of software platforms (5.47).
5) Direct integration for construction related tasks (5.41).
6) Relative ease of the software (5.26).
7) Direct integration with energy analysis (4.86).
8) Direct integration with project management software (4.72).

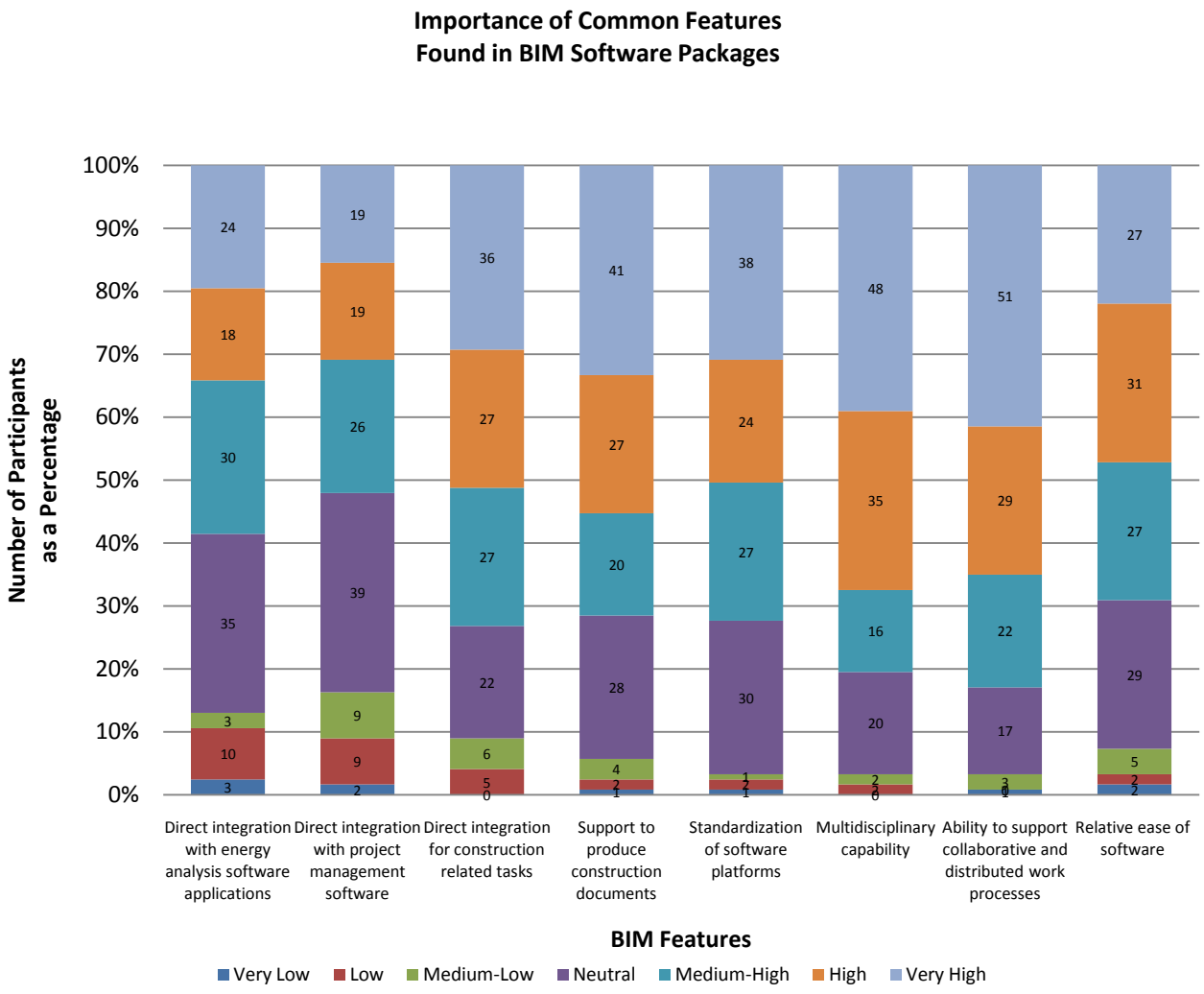


Figure 4-2. Importance of common features found in BIM software packages

4.3 Section 4 Results

Section 4 of the survey questionnaire was intended as a means to analyze the sample population in terms of its viewpoint of sustainable design and construction practices. This includes but is not limited to: company's active role towards

sustainability; importance of common sustainable categories; and, percentage of work performed on sustainable projects. The results of this section allowed for further analysis based on the responses from Sections 1 and 2.

4.3.1 Question 4.1 – 4.2

Similar to Questions 3.3 and 3.4, both of these questions were intended on providing information regarding their company's involvement with green building certification as well as data on owner involvement in company decisions in terms of sustainable practices. Table 4-16 breaks down the percentage of green building certified projects worked on by the respondents' companies as well as the percentage of projects required by owners to achieve green building certification. According to the data 25% of the sample population works towards green building certifications, while 22% of the sample were required by owners to attain green building certification.

Table 4-16. Percentage of LEED projects within company practices and owner's influence on LEED projects (Q3.3 and Q3.4)

Question	% of Total
Q3.3 – Company works towards 'green building' certifications	25%
Q3.4 – Owners require company to attain 'green building' certifications	22%

4.3.2 Question 4.3

With the growing interest in sustainable design and construction practices becoming prevalent within the majority of the AEC industry, it is important to understand what mechanisms company's use in order to promote sustainability. Question 4.3 posed a series of statements regarding the respondents' perception of their company and its measures to enforce sustainability. Table 4-17 contains the results from the

survey respondents. In addition to understanding the viewpoints, a weighted scale using the equation:

$$\sum_{1}^{n} \frac{nx}{123}, \; x = \text{number of responses}; \; n = \text{rating score} \tag{3}$$

was included, where each statement was rated according to the number of the responses within each ranking against the total number of participants. The equation was used as a means to rank the respondents views on the given statements. Figure 4-3 shows a graphical representation of the results.

Table 4-17. Perception of respondents' company and its view on sustainability (Q4.3)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1 Strongly Disagree	2 Somewhat Disagree	3 Neutral	4 Somewhat Agree	5 Strongly Agree
A.) My company finds the role of sustainability to be important.	0 0%	1 1%	4 3%	40 33%	78 63%
B.) My company has been proactive in educating employees on recent sustainable practice developments.	2 2%	5 4%	15 12%	45 37%	56 46%
C.) My company utilizes the latest innovations in technology to enhance our sustainability mechanisms.	1 1%	11 9%	29 24%	52 42%	30 24%
D.) My company actively advises owners/stakeholders to pursue sustainable methods and practices during projects.	0 0%	6 5%	19 15%	55 45%	43 35%
E.) My company provides incentives to encourage sustainable practices during projects.	13 11%	16 13%	48 39%	36 29%	10 8%

The following details the analysis of the results:

- Of the survey respondents, 63% stated they strongly agreed and 33% stated they somewhat agreed that their *company finds the role of sustainability important*. Having applied a weighted score to each of the selection options, an average rating score of **4.59** was attained.

- Of the survey respondents, 46% stated they strongly agreed and 37% stated they somewhat agreed that their *company is proactive in providing sustainability education among employees*. Having applied a weighted score to each of the selection options, an average rating score of **4.20** was attained.

- Of the survey respondents, 42% stated they somewhat agreed, while 48% of the survey population stated that they either strongly agreed (24%) or are neutral (24%) that their *company utilizes the latest innovations in sustainability*. Having applied a weighted score to each of the selection options, an average rating score of **3.80** was attained.

- Of the survey respondents, 35% stated they strongly agreed and 45% stated they somewhat agreed that their *company actively advises owners to pursue sustainable methods and practices during projects*. Having applied a weighted score to each of the selection options, an average rating score of **4.10** was attained.

- Of the survey respondents, 39% stated they are neutral and 29% stated they somewhat agreed that their *company provides incentives to encourage sustainable practices during a project*. Having applied a weighted score to each of the selection options, an average rating score of **3.11** was attained.

Therefore, according to the results the respondents agreed on all statements that their company had an active role in sustainability. However, most respondents answered neutral to providing incentives to encourage sustainable practices therefore there is room for improvement within companies to further enhance their capabilities with promoting sustainability. The following lists the rankings of the results in descending order from highest to lowest average rating score:

1) My company finds the role of sustainability important (4.59).
2) My company is proactive in providing sustainability education among employees (4.20).
3) My company actively advises owners to pursue sustainable methods and practices during projects (4.10).

4) My company utilizes the latest innovations in sustainability (3.80).
5) My company provides incentives to encourage sustainable practices during a project (3.11).

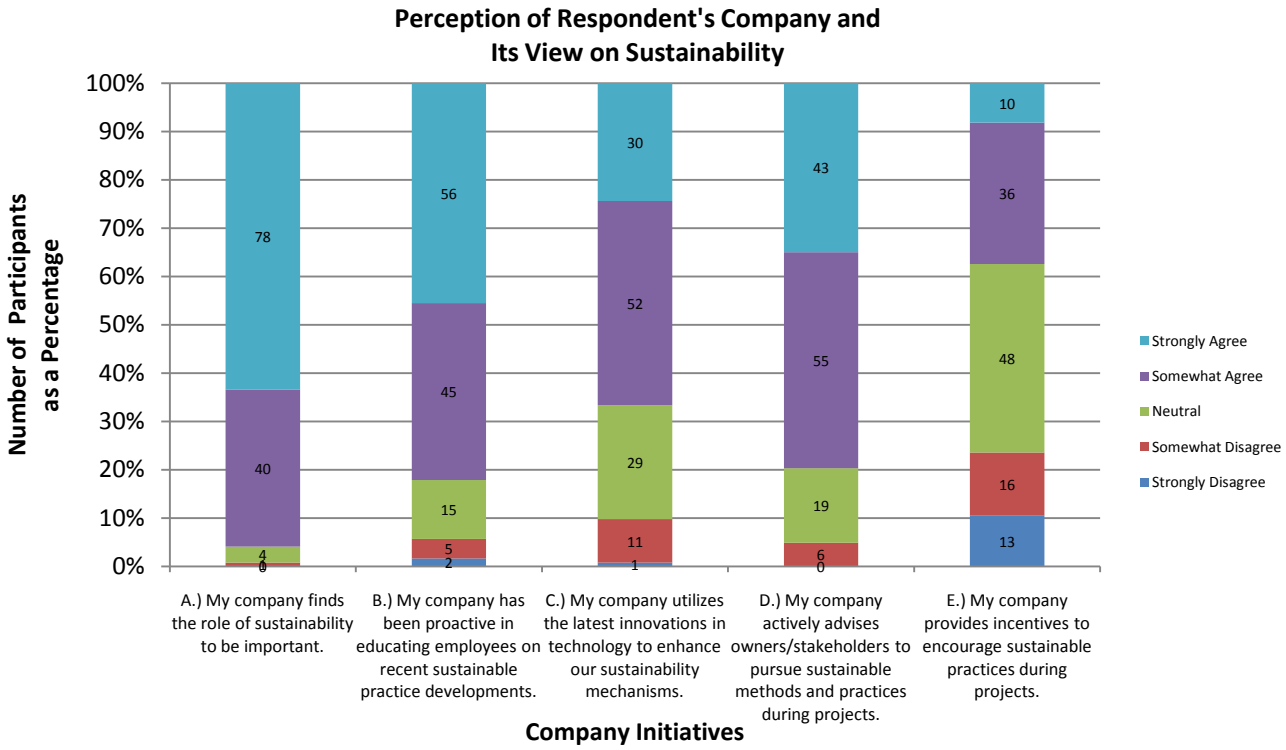


Figure 4-3. Perception of respondent's company and its view on sustainability

4.3.3 Question 4.4

Though many available green building assessment organizations already have developed a list of important sustainable practices (e.g. USGBC LEED, Green Globes) it is important to understand how the respondents viewed certain features within sustainable practices. Question 4.4 therefore utilizes a series of common sustainable categories in order to rank their importance to the respondent. Table 4-18 contains the results generated from the survey questionnaire. In addition to understanding the viewpoints, a weighted scale using the following equation:

$$\sum_{1}^{n} \frac{nx}{123}, \; x = \text{number of responses}; \; n = \text{rating score} \qquad (4)$$

was included, where each category was rated according to the number of the responses within each ranking against the total number of participants. The equation was used as a means to rank the respondents views on the given sustainable features. Figure 4-4 provides a graphical representation of the results.

Table 4-18. Importance of common sustainable features and their impact on construction (Q4.4)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1 Very Low	2 Low	3 Med. Low	4 Neutral	5 Med. High	6 High	7 Very High
A.) Sustainable Site Development (e.g. heat island effect, storm water runoff)	1 1%	0 0%	1 1%	16 13%	38 31%	44 36%	23 19%
B.) Water Efficiency (e.g. reduction of potable water usage, limiting irrigation)	1 1%	1 1%	0 0%	12 10%	31 25%	43 35%	35 28%
C.) Energy Efficiency (e.g. reduction of energy consumption, use of renewable energy resources)	0 0%	0 0%	1 1%	8 7%	17 14%	30 24%	67 54%
D.) Sustainable Materials (e.g. use of recycled materials, reduction of waste)	0 0%	1 1%	2 2%	21 17%	28 23%	42 34%	29 24%
E.) Indoor Air Quality (e.g. use of no VOC's, maximize natural ventilation, thermal comfort)	1 1%	0 0%	2 2%	19 15%	28 23%	39 32%	34 28%
F.) Project Management (e.g. elimination of rework)	3 2%	1 1%	9 7%	25 20%	25 20%	34 28%	26 21%
G.) Building Commissioning (e.g. testing the performance of building systems)	1 1%	0 0%	3 2%	21 17%	23 19%	36 29%	39 32%
H.) Post Construction Facility Operations (e.g. maintain healthy HVAC systems)	1 1%	1 1%	6 5%	17 14%	19 15%	34 28%	45 37%

The following details the analysis of the results:

- Of the survey respondents, 67% believed that *sustainable site development* is of medium-high to high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.55** was attained.

- Of the survey respondents, 63% believed that *water efficiency* is of high to very high importance. Having applied a weighted score to each of the selection options, a total rating score of **5.76** was attained

- Of the survey respondents, 78% believed that *energy efficiency* is of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **6.25** was attained.

- Of the survey respondents, 58% believed that *use of sustainable materials* is of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.59** was attained.

- Of the survey respondents, 60% believed that *indoor air quality* is of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.65** was attained.

- Of the survey respondents, 49% believed that *incorporated project management* is of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.23** was attained.

- Of the survey respondents, 61% believed that *building commissioning* is of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.67** was attained.

- Of the survey respondents, 65% believed that *post-construction facility operations* are of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.72** was attained.

Therefore, according to the results the respondents found each of the categories to be high in importance in terms of sustainable construction. The following lists the rankings of the results in descending order from highest to lowest average rating score:

1) Energy efficiency (6.25).
2) Water efficiency (5.76).
3) Post-construction facility operations (5.72).
4) Building commissioning (5.67).
5) Indoor air quality (5.65).
6) Use of sustainable materials (5.59).
7) Sustainable site development (5.55).
8) Incorporated project management (5.23).

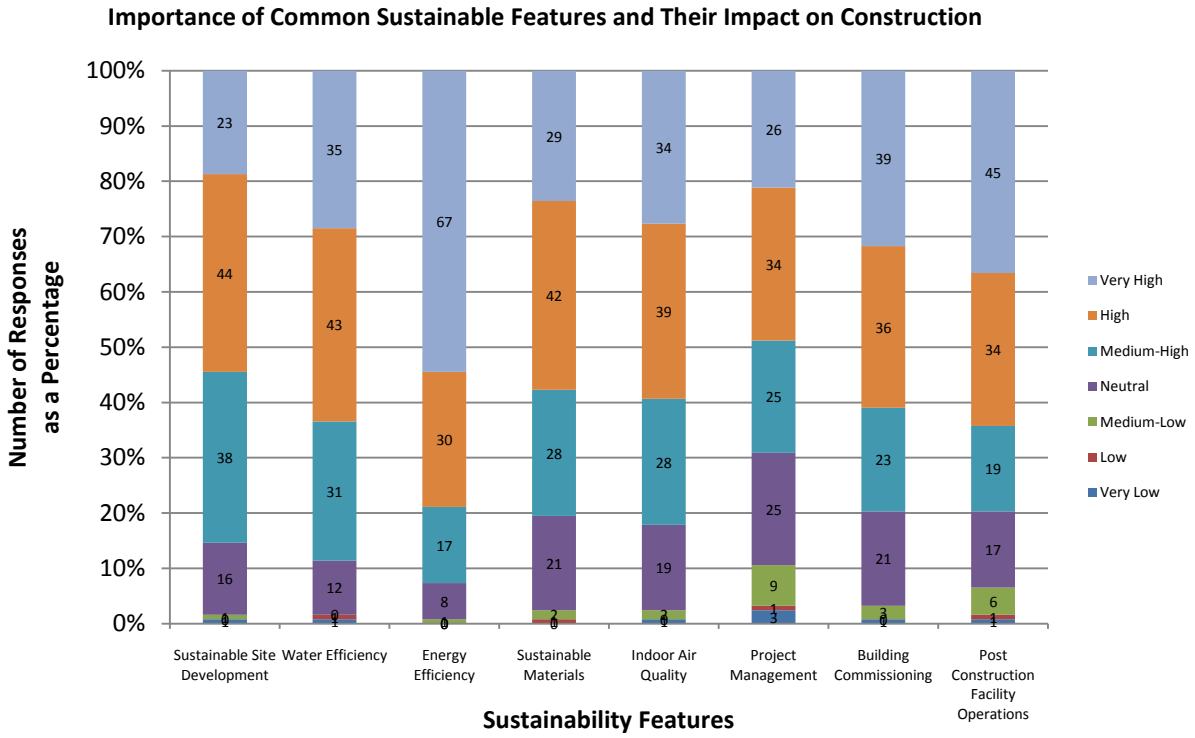


Figure 4-4. Importance of common sustainable features and their impact on construction

4.4 Section 5 Results

4.4.1 Question 5.1

As Section 5 of the survey questionnaire was intended to tie together both BIM and sustainability the questions are posed in order to determine direct correlations between the two topics. Question 5.1 is aimed at assessing BIM implementation during various stages of project development, in regards to enhancing sustainability. As shown in Table 4-19, the highest percentage of the respondents suggested that BIM is optimally implemented in the schematic phase at 40% (49 participants). Additionally, the pre-design and design development phases were selected by 31% (38 participants) and 20% (25 participants), respectively. Therefore, nearly 91% of the responses

indicated that BIM is best utilized to support sustainable design and construction practices early on in a project's design stage.

Table 4-19. Respondent's viewpoint on optimal project phase to implementing BIM during a given project duration (Q5.1)

Project Phase	Number of Participants	% of Total
Schematic Design Phase	49	40%
Pre-design or Program Phase	38	31%
Design Development Phase	25	20%
Construction Documents Phase	4	3%
Preconstruction Phase	3	2%
Other	3	2%
Post-construction Operations Phase	1	1%
Construction Administration Phase	0	0%
Column Totals	123	100%

4.4.2 Question 5.2

There is currently a large number of 2D/3D CAD and BIM analytical software available; therefore, it is necessary to determine what types of analyses are being implemented into normal company practices. Table 4-20 shows information generated based on the responses to Question 5.2 broken down into the various types of computer aided analysis. The highest percentage of the population sample used some form of energy analysis at 59% (72 participants) of the entire sample. Additionally, MEP analysis, structural analysis, and lighting analysis were selected by a large number of participants responses at 50% (62 participants), 44% (54 participants), and 47% (58 participants), respectively. This result is due to the fact that multiple BIM software platforms are trying to integrate different forms of analysis, most typically found are the analysis programs for energy, MEP, and structures.

Table 4-20. Types of computer aided analysis performed by respondents' company (Q5.2)

Type of Analysis	Number of Participants	% of Total
Energy Analysis	72	59%
MEP Analysis	62	50%
Lighting Analysis/Simulation	58	47%
Structural Analysis	54	44%
Thermal/Air Control Analysis	41	33%
Building Function Analysis	25	20%
Acoustic Analysis	24	20%
None	19	15%
Other, please specify	4	3%

4.4.3 Question 5.3

The availability of building performance analysis software directly connected with BIM provides a means to analyze projects in order to create sustainable buildings. Question 5.3 is intended to determine what specific types of building performance analysis software are being utilized in the AEC industry. As shown in Table 4-21, nearly 56% (69 participants) of the respondents at the time do not use any form of building performance analysis software. Of the listed products, Ecotect and eQUEST held the highest responses at 14% (17 participants) and 15% (19 participants), respectively. It should be noted that although various products were not listed 'Other' was included for respondents to add any additional building performance analysis software they had used. The following software were noted by the respondents: EnergyPlus, Trane Trace 700, EcoDesigner, TRNSYS, and Energy Pro.

Table 4-21. Types of building performance analysis software used by respondents' company (Q5.3)

Type of Analysis	Number of Participants	% of Total
None	69	56%
Other, please specify	24	20%
eQUEST	19	15%
Ecotect	17	14%
IES Virtual Environment	15	12%
Green Building Studio	12	10%

4.4.4 Question 5.4

Similar to Question 2.6, this question refers to the respondent's view of project delivery methods as it relates to BIM and sustainable design and construction practices. The intent of the question is to determine which delivery method provides the best environment for BIM to act as a mechanism for sustainability. Table 4-22 shows the responses to the questionnaire in relation with the total survey sample. The data in Table 4-22 shows that both the Design-Build and Integrated Project Delivery methods are regarded by the respondents as the most effective methods at 40% (49 participants) and 37% (46 participants) to bridge together both BIM and sustainable practices within a company in the AEC industry. Design-Bid-Build was selected by 11% (14 participants) of the responses while the other options were selected by few.

Table 4-22. Respondent's viewpoint of what project delivery method provides the best environment for the utilization of BIM software as a mechanism for sustainable design and building practices (Q5.4)

Type of Analysis	Number of Participants	% of Total
Design-Build	49	40%
Integrated Project Delivery	46	37%
Design-Bid-Build (DBB)	14	11%
Other, please specify	9	7%
Construction Management	4	3%
Construction Management at Risk	1	1%
Total	123	100%

4.4.5 Question 5.5

Question 5.5 is intended to determine the respondents' viewpoints on potential improvements and innovations with BIM. The list accompanying this question came from Krygiel et al. (2008) as suggested innovations within BIM to provide for the next steps in enhancing its capabilities with sustainability. Table 4-23 shows the results of

this question. In addition to understanding the viewpoints, a weighted scale using the following equation:

$$\sum_{1}^{n} \frac{nx}{123}\ , x = \text{number of responses; } n = \text{rating score} \qquad (5)$$

was included, where each category was rated according to the number of the responses within each ranking against the total number of participants. The equation was used as a means to rank the respondents views on the given sustainable features. Figure 4-5 provides a graphical representation of the results.

Table 4-23. Importance of potential advancements in BIM in terms of its impact on sustainable practices (Q5.5)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1 Very Low	2 Low	3 Med. Low	4 Neutral	5 Med. High	6 High	7 Very High
A.) Improvements within interoperability between software packages (e.g. importing/exporting data from BIM software into building performance analysis software).	1 1%	0 0%	3 2%	16 13%	20 16%	34 28%	49 40%
B.) Integration of a carbon accounting tracker (e.g. tracking the carbon emissions of a building from construction to post-construction).	6 5%	3 2%	6 5%	50 41%	37 30%	16 13%	5 4%
C.) Interactivity of weather data (i.e. connecting a BIM model directly to weather databases available online).	3 2%	7 6%	9 7%	45 37%	34 28%	14 11%	11 9%

The following details the analysis of the results:

- Of the survey respondents, 68% believed that *improvements within interoperability between software packages* are of high to very high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.86** was attained.
- Of the survey respondents, 71% believed that the *integration of a carbon accounting tracker* is of neutral to medium-high importance. Having applied a weighted score to each of the selection options, an average rating score of **4.44** was attained.
- Of the survey respondents, 65% believed that *interactivity of weather data* is of neutral to medium-high importance. Having applied a weighted score to each of the selection options, an average rating score of **5.65** was attained.

Therefore, according to the results the respondents found the majority of the categories to be high in importance in terms of their impact on sustainable practices, however, the sample population was neutral to the integration of a carbon tracking measuring device. The following lists the rankings of the results in descending order from highest to lowest average rating score:

1) Improvements within interoperability between software packages (5.86).
2) Interactivity of weather data (5.65).
3) Integration of a carbon accounting tracker (4.44).

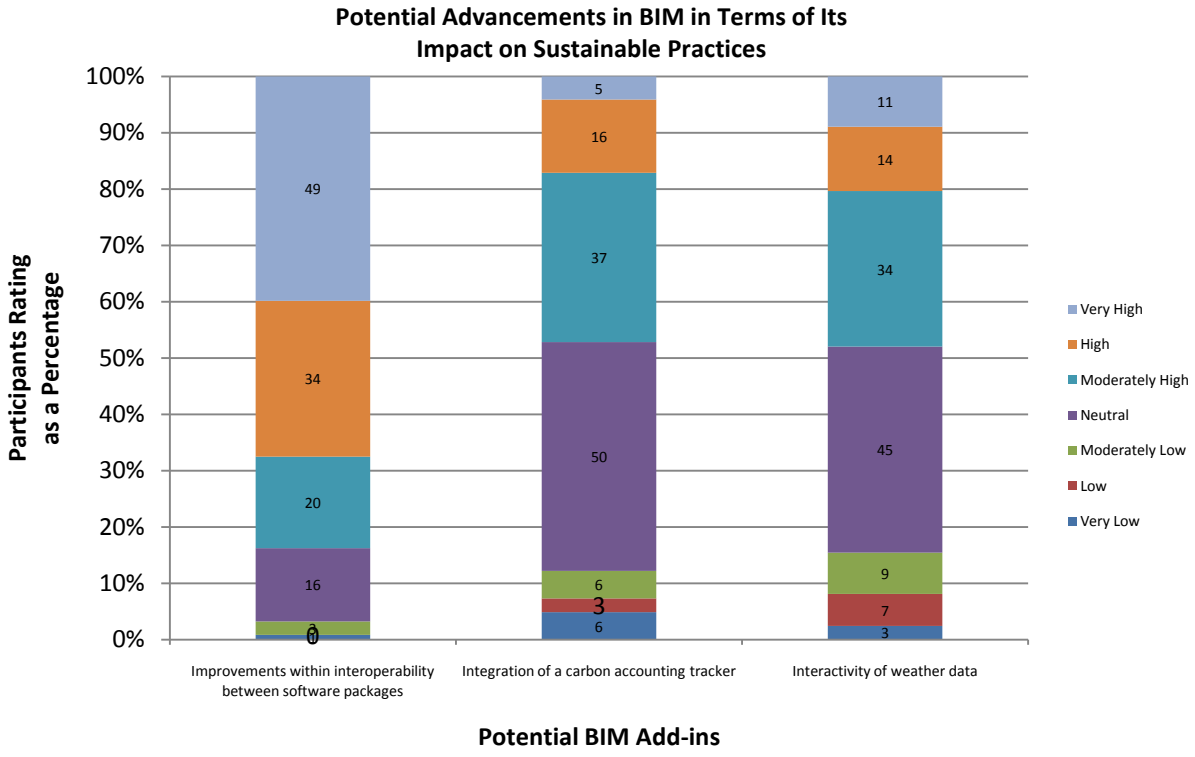


Figure 4-5. Potential advancements in BIM in terms of its impact on sustainable practices

4.4.6 Question 5.6

Similar to Question 4.4, this question targets the effectiveness of BIM in terms of common sustainable practices within the AEC industry. As this study is primarily interested in understanding the capabilities of BIM as a catalyst for sustainable

practices in the AEC industry, this question is imperative in understanding how the respondents view BIM as an effective tool in doing so. Table 4-24 shows the survey responses for Question 5.6. In addition to understanding the viewpoints, a weighted scale using the following equation:

$$\sum_{1}^{n} \frac{nx}{123}, \; x = \text{number of responses}; \; n = \text{rating score} \qquad (6)$$

was included, where each category was rated according to the number of the responses within each ranking against the total number of participants. The equation was used as a means to rank the respondents views on the given sustainable features. Figure 4-6 shows a graphical representation of the results.

Table 4-24. Rating of BIM in terms of effectiveness in achieving sustainability (Q5.6)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1 Highly Ineffective	2 Ineffective	3 Neutral	4 Effective	5 Highly Effective
A.) Sustainable Site Development (e.g. heat island effect, storm water runoff)	8 7%	15 12%	77 63%	21 17%	2 2%
B.) Water Efficiency (e.g. reduction of potable water usage, limiting irrigation)	7 6%	17 14%	80 65%	18 15%	1 1%
C.) Energy Efficiency (e.g. reduction of energy consumption, use of renewable energy resources)	1 1%	8 7%	63 51%	40 33%	11 9%
D.) Sustainable Materials (e.g. use of recycled materials, reduction of waste)	8 7%	15 12%	76 62%	20 16%	4 3%
E.) Indoor Air Quality (e.g. use of no VOC's, maximize natural ventilation, thermal comfort)	8 7%	15 12%	88 72%	10 8%	2 2%
F.) Project Management (e.g. elimination of rework)	4 3%	13 11%	53 43%	29 24%	24 20%
G.) Building Commissioning (e.g. testing the performance of building systems)	4 3%	18 15%	69 56%	29 24%	3 2%
H.) Post Construction Facility Operations (e.g. maintain healthy HVAC systems)	8 7%	17 14%	58 47%	33 27%	7 6%

The following details the analysis of the results (see Figure 4-6):

- Of the survey respondents, 80% believed that BIM's effectiveness with respect to *sustainable site development* is neutral to effective. Having applied a weighted score to each of the selection options, an average rating score of **2.95** was attained.

- Of the survey respondents, 80% believed that BIM's effectiveness with respect to *water efficiency* is neutral to effective. Having applied a weighted score to each of the selection options, an average rating score of **2.91** was attained.

- Of the survey respondents, 84% believed that BIM's effectiveness with respect to *energy efficiency* is neutral to effective. Having applied a weighted score to each of the selection options, an average rating score of **3.42** was attained.

- Of the survey respondents, 78% believed that BIM's effectiveness with respect to *use of sustainable materials* is neutral to effective. Having applied a weighted score to each of the selection options, an average rating score of **2.98** was attained.

- Of the survey respondents, 84% believed that BIM's effectiveness with respect to *indoor air quality* is neutral to ineffective. Having applied a weighted score to each of the selection options, an average rating score of **2.86** was attained.

- Of the survey respondents, 67% believed that BIM's effectiveness with respect to *incorporated project management* is neutral to effective while 20% of the respondents considered the feature to be highly effective. Having applied a weighted score to each of the selection options, an average rating score of **3.46** was attained.

- Of the survey respondents, 80% believed that BIM's effectiveness with respect to *building commissioning* is neutral to effective. Having applied a weighted score to each of the selection options, an average rating score of **3.07** was attained.

- Of the survey respondents, 74% believed that BIM's effectiveness with respect to *post-construction facility operations* is neutral to effective. Having applied a weighted score to each of the selection options, an average rating score of **3.11** was attained.

Therefore, according to the results the respondents were found to be neutral on their viewpoint of BIM and its effectiveness on sustainable practices. This was typical of all categories, however, energy efficiency and incorporating project management were

found to have the highest weighted scores. The following lists the rankings of the results in descending order from highest to lowest average rating scores:

1) Incorporated project management (3.46).
2) Energy efficiency (3.42).
3) Post-construction facility operations (3.11).
4) Building commissioning (3.07).
5) Use of sustainable materials (2.98).
6) Sustainable site development (2.95).
7) Water efficiency (2.91).
8) Indoor air quality (2.86).

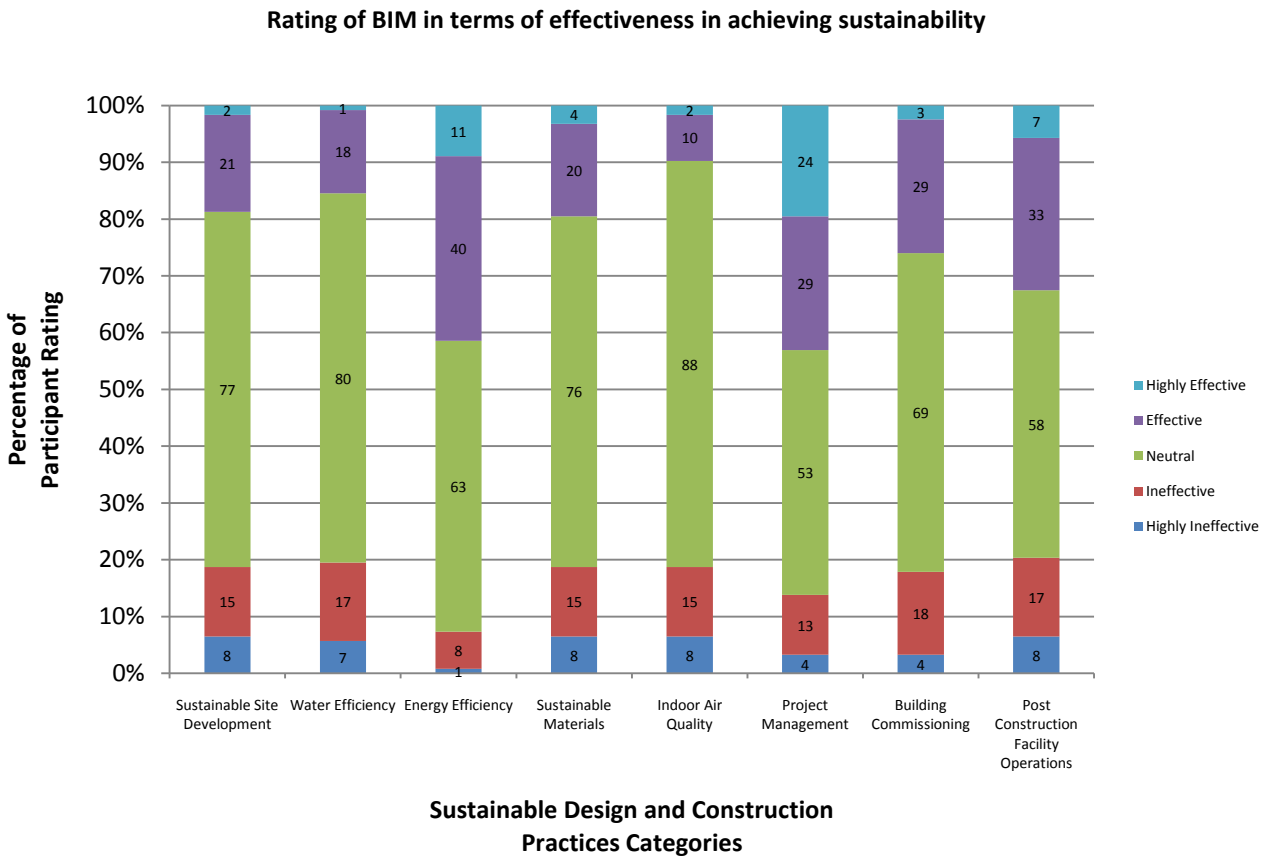


Figure 4-6. Rating of BIM in terms of effectiveness in achieving sustainability

4.4.7 Question 5.7

Question 5.7 was the only open-ended question offered in the survey questionnaire. The intent of the question was to obtain feedback from the respondents

that may not have been given through the survey. The responses are found in their entirety in Appendix D. Selected responses due their insight are listed as the following:

- Currently BIM and sustainable design are independent practices; however the use of BIM directly affects sustainable design practices by providing more opportunities to limit waste, build facilities, and test for efficiency prior to even breaking ground. The only limitations are those which the software inherently posses. Standards need to be set so that the software can build the requirements of the standards into their programs so that no matter which program is utilized, the designers, owners, and future maintenance individuals can utilize the BIM model not just for sustainable practices now, but also into the future.

- BIM within the AEC community is currently in fashion as design tool. Emphasize the word tool, because it is a means, not an end. Sustainability is an end - and can sustainable design can be attained without use of BIM. Once BIM becomes more useful among owners and building managers (years from now), BIM will be useful in analyzing performance maintaining sustainably-designed facilities. BIM can be used to advance sustainable design. Sustainable design can be accomplished without BIM. BIM is a tool, and can be a means towards improving sustainable design. Site design modeling can be hugely helpful toward analyzing stormwater quality and de-conflicting underground utilities. BIM software's limitations as a detailing tool, lack of interoperability, and high cost of staff retraining/migration currently impede its widespread use. Very little actual construction is 'manufactured' - and BIM continues to be of little, if any, use on most construction projects. Few clients can afford customized, engineered, manufactured building components that require BIM modeling - most opt for standardized, unitized building components in wide production that are accepted among and trade installers (and are warrantable). A premise that BIM and sustainable design are interdependent is somewhat thin and difficult to defend. But unquestionably, BIM, as an emerging and continually improving design tool, can facilitate sustainable design.

- Currently, BIM software is more focused on aspects relating to Project Management and trade integration rather than sustainability. However, because BIM models are typically developed in the pre-design phase, the foundation for further integration of sustainable design and building practices should be easily incorporated and likely effective. In my opinion, the areas of building design and construction that are currently able to be effectively integrated with BIM software include: energy efficiency, project management, building commissioning, and post construction facility operations. Conversely, the areas of building and design that are not currently able to be effectively integrated with BIM software include: sustainable site development, water efficiency, sustainable materials, and indoor environmental quality.

CHAPTER 5
STRATIFIED SAMPLING SURVEY RESULTS

As indicated in Chapter 4 of this report, Chapter 5 is intended to analyze the results based on characteristics provided through the responses from Sections 1 and 2 of the survey questionnaire. Upon review of the overall results in Chapter 4 it was determined that the following four aspects should be further investigated as a means to understand the sample population in greater detail: AEC position role (Question 1.1; Table 4-1); project types (Question 2.1; Table 4-4); annual revenue (Question 2.2; Table 4-5); and, project delivery method (Question 2.6; Table 4-9). Although this is an additional form of analysis, the objectives remain the same as Chapter 4 in that the results will be used to determine information regarding current development in BIM, the trends in sustainable practices, and the overall potential for the future applications of BIM within sustainability.

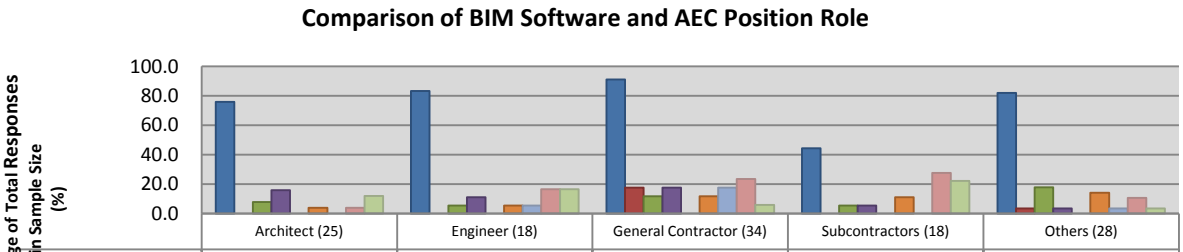
Each category of the study was filtered through the web-based survey generator Zoomerang™ as a means of collecting the data. The results of the filtered survey questionnaire are provided in the following section with a brief analysis on each assessment. The results in the chapter are analyzing through the use of descriptive statistics using the method of stratified sampling.

5.1 Section 3 Stratified Sampling Results

This section presents information regarding the various aspects of BIM and its use within the AEC industry. The intent of this investigation is to analyze the trends within certain categories of the sample population. The results are assessed against other participant responses as well as the total population.

5.1.1 Question 3.1

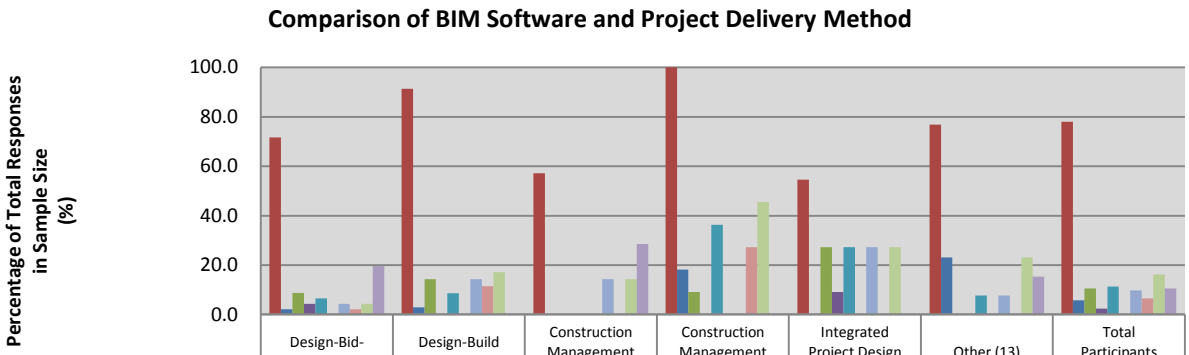
From the results found in Section 4.2.1, it was determined that Autodesk Revit was the industry leader within the AEC community with nearly 78% of the total responses indicating that they use the program at some point during a project's duration. Figures 5-1 to 5-4 show a breakdown of the overall results into the selected categories in order to perform a stratified sampling of the total sample population. As shown in Figure 5-1, the AEC position role with the highest percentage rate utilizing Autodesk Revit was the general contractors (GC) at nearly 91.2% of its total sample size (34 participants). Additionally, the GC category was found to have a higher percentage rate among the other provided software platforms, thus, indicating its prevalence within the BIM market. Engineers (ENG) held the second highest percentage at 88.3% of its respondents (18 participants) and the architecture (ARCH) sector was found to have 76% of its sample size (25 participants) using Autodesk Revit with an additional 16% using Graphisoft ArchiCAD.



	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Others (28)
Autodesk Revit	76.0	83.3	91.2	44.4	82.1
Dprofiler	0.0	0.0	17.6	0.0	3.6
Bentley Architecture	8.0	5.6	11.8	5.6	17.9
Graphisoft ArchiCAD	16.0	11.1	17.6	5.6	3.6
Nemetschek Vectorworks	0.0	0.0	0.0	0.0	0.0
Tekla Structures	4.0	5.6	11.8	11.1	14.3
Vico Constructor	0.0	5.6	17.6	0.0	3.6
Others	4.0	16.7	23.5	27.8	10.7
None	12.0	16.7	5.9	22.2	3.6

Figure 5-1. Comparison of BIM software and AEC position roles.

In terms of project delivery method, as shown in Figure 5-2 the companies that use the Design-Build (DB) and Construction Management at Risk (CM-R) methods had the highest percentage of Autodesk Revit use at 91.4% and 100%, respectively. Of the companies that used Design-Bid-Build (DBD) and Construction Management (CM) methods 19.6% and 28.6% of their respective sample size did not utilize any form of BIM software platform.

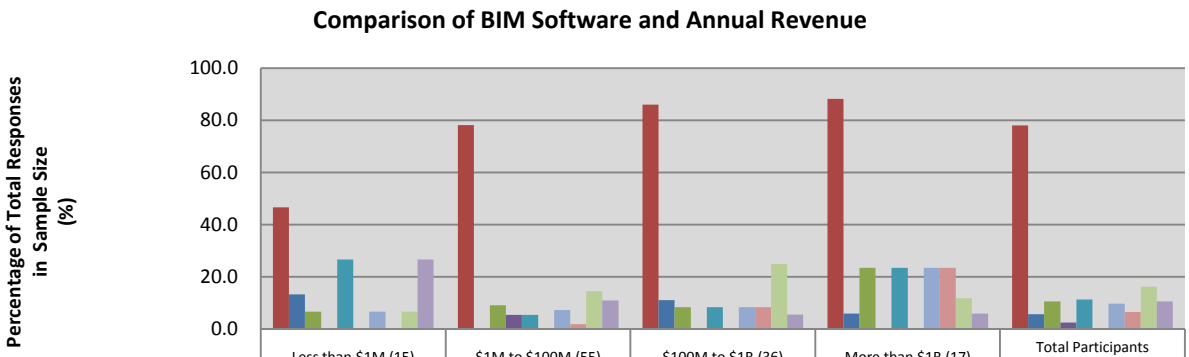


	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Autodesk Revit	71.7	91.4	57.1	100.0	54.5	76.9	78.0
Dprofiler	2.2	2.9	0.0	18.2	0.0	23.1	5.7
Bentley Architecture	8.7	14.3	0.0	9.1	27.3	0.0	10.6
Gehry Technologies Digital Project	4.3	0.0	0.0	0.0	9.1	0.0	2.4
Graphisoft ArchiCAD	6.5	8.6	0.0	36.4	27.3	7.7	11.4
Nemetschek Vectorworks	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tekla Structures	4.3	14.3	14.3	0.0	27.3	7.7	9.8
Vico Constructor	2.2	11.4	0.0	27.3	0.0	0.0	6.5
Others	4.3	17.1	14.3	45.5	27.3	23.1	16.3
None	19.6	0.0	28.6	0.0	0.0	15.4	10.6

Figure 5-2. Comparison of BIM software and project delivery methods.

Analysis based on the annual revenue of a company provided another method to view the application of BIM, that is, whether the size of the company's annual revenue impacted the rate of BIM use within the AEC industry. As shown in Figure 5-3, the highest percentage of BIM use within almost every individual software platforms was seen in the companies with revenue of 'More than $1B.'. Additionally, the data shows that as company revenue increased the use of Autodesk Revit among the respondent's

increased, therefore, establishing a direct connection between the size of the company and its use of Autodesk Revit. The remaining software programs underwent similar trends as the highest percentage of BIM use was found in the largest annual revenue category available, with a few exceptions (i.e. Graphisoft ArchiCAD and DProfiler).



	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Autodesk Revit	46.7	78.2	86.1	88.2	78.0
Dprofiler	13.3	0.0	11.1	5.9	5.7
Bentley Architecture	6.7	9.1	8.3	23.5	10.6
Gehry Technologies Digital Project	0.0	5.5	0.0	0.0	2.4
Graphisoft ArchiCAD	26.7	5.5	8.3	23.5	11.4
Nemetschek Vectorworks	0.0	0.0	0.0	0.0	0.0
Tekla Structures	6.7	7.3	8.3	23.5	9.8
Vico Constructor	0.0	1.8	8.3	23.5	6.5
Others	6.7	14.5	25.0	11.8	16.3
None	26.7	10.9	5.6	5.9	10.6

Figure 5-3. Comparison of BIM software and annual revenue.

Because Question 2.1 concerning the company's project types was posed as a multi-answer response, each project type had the opportunity to incorporate others within its filter. Therefore, Table 5-1 is provided to breakdown the percentages of each project type contained within the filter taken from the total population. Figure 5-4 provides information regarding the project type category in connection with BIM software. According to the data, the Industrial project type at 83.7% (49 participants) and the Heavy/Civil project type at 100% (34 participants) of their sample size worked primarily with Autodesk Revit. Additionally, they were the largest supporters of the

Bentley Architecture at 16.3% and 28.6%, respectively. The Commercial project type, as the largest of the category (107 participants), had diversity within the use of various BIM platforms. The BIM platforms with the highest percentage use in the Commercial sector were: Autodesk Revit (77.6%), Graphisoft ArchiCAD (12.1%), and Bentley Architecture (10.3%).

Table 5-1. Breakdown of the 'Project Type' categories with the percentage of the additional included project types.

Percentage of Additional Project Types	Respondent Project Type				
	Commercial (107)	Residential (40)	Industrial (49)	Heavy Civil (7)	Other (34)
Commercial		40%	46%	7%	22%
Residential	37%		25%	3%	8%
Industrial	43%	62%		6%	11%
Heavy Civil	29%	33%	23%		10%
Other	21%	20%	11%	2%	

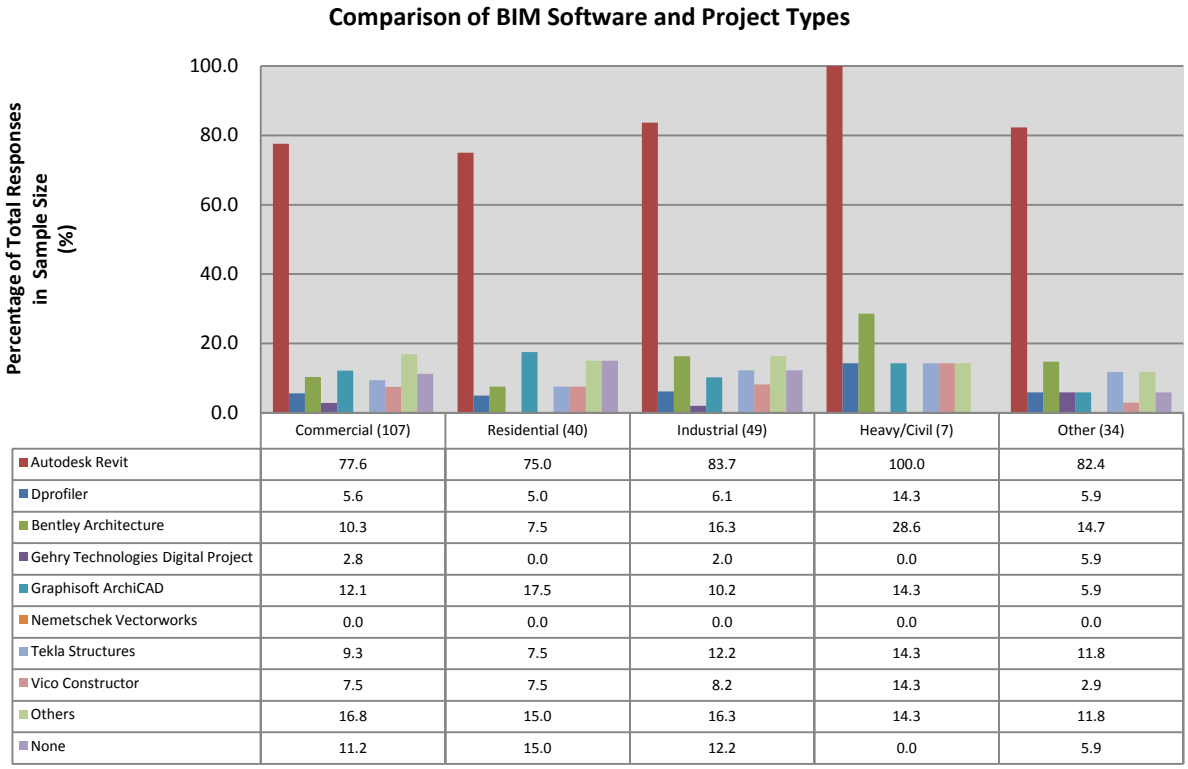
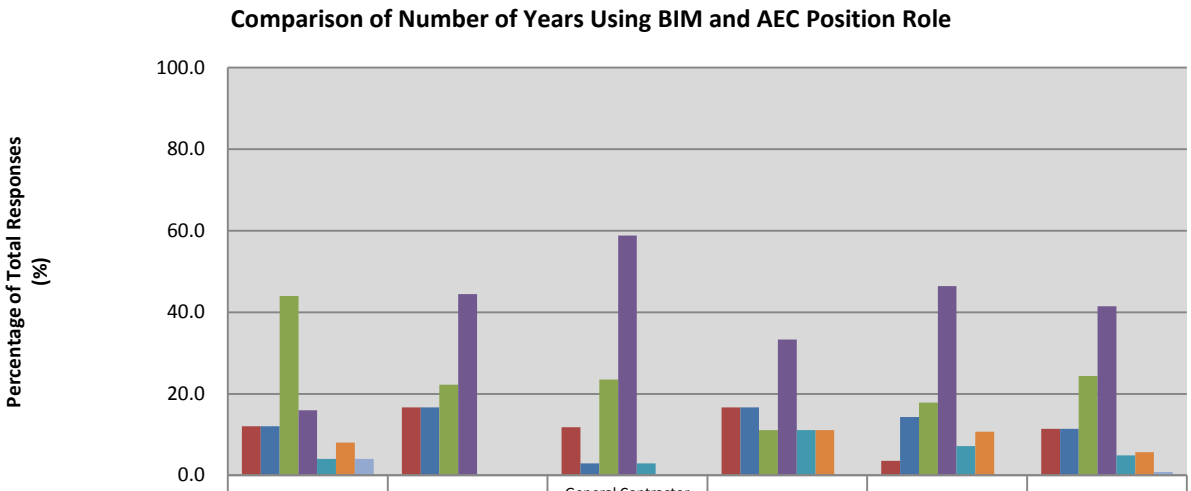


Figure 5-4. Comparison of BIM software and project types.

5.1.2 Question 3.2

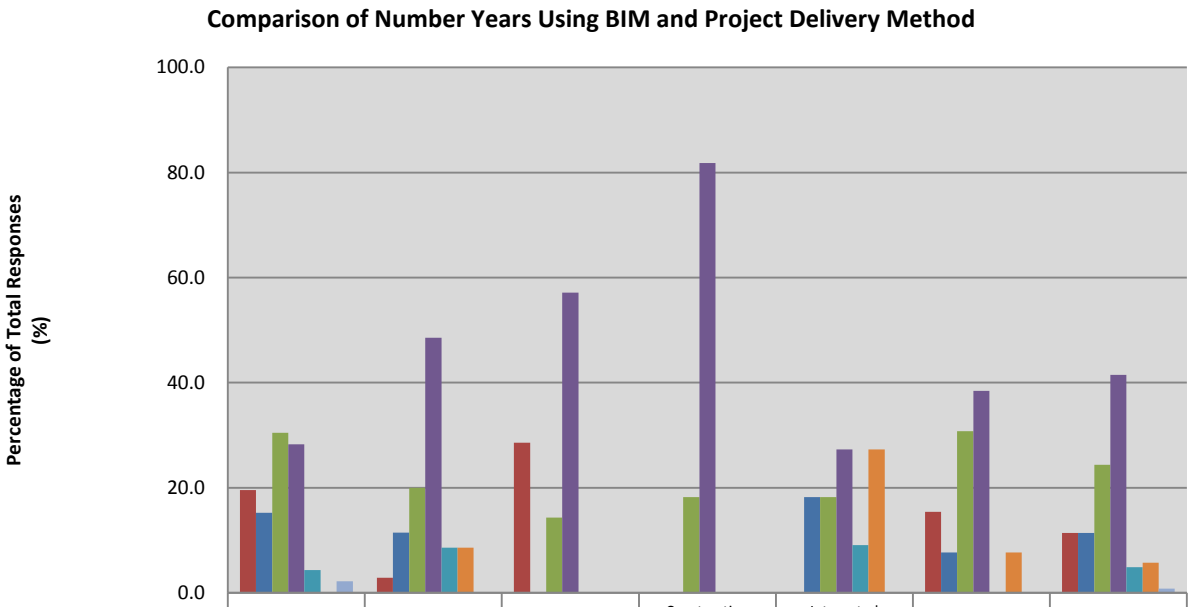
From the results in Section 4.2.2, it was determined that the 65% of the survey participants have used BIM roughly between 1 to 5 years with only 12% of the population having used BIM for more than 6 years. Figures 5-5 to 5-8 provide a breakdown of the data into the discriminating categories. According to Figure 5-5, as indicative of the overall average, the highest percentage of the AEC position roles are found within the time frame of 1-5 years. The subcontractor (SUB) and ENG sectors were found to be in the sectors newest to implementing BIM into their practices with nearly 16.7% of each having implemented BIM into their practices from 0 to 1 year. Additionally, the SUB and ENG sectors held the highest percentage of the AEC position roles at 16.7% to have yet to implement BIM within their company practices.



	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Others (28)	Total Participants
We have yet to implement it.	12.0	16.7	11.8	16.7	3.6	11.4
0-1 Years	12.0	16.7	2.9	16.7	14.3	11.4
1-2 Years	44.0	22.2	23.5	11.1	17.9	24.4
3-5 Years	16.0	44.4	58.8	33.3	46.4	41.5
6-9 Years	4.0	0.0	2.9	11.1	7.1	4.9
10-15 Years	8.0	0.0	0.0	11.1	10.7	5.7
More than 15 Years	4.0	0.0	0.0	0.0	0.0	0.8

Figure 5-5. Comparison of number of years using BIM and AEC position roles.

Figure 5-6 shows a comparison between project delivery method and the number of years of having used BIM. In reference to the average percentage rate of the total sample population, there was little variation found with the results, however, it is worth mentioning that the DB and Integrated Project Delivery (IPD) methods held the highest percentage rate among the others with BIM use of greater than 5 years at 17.2% and 36.4%, respectively.

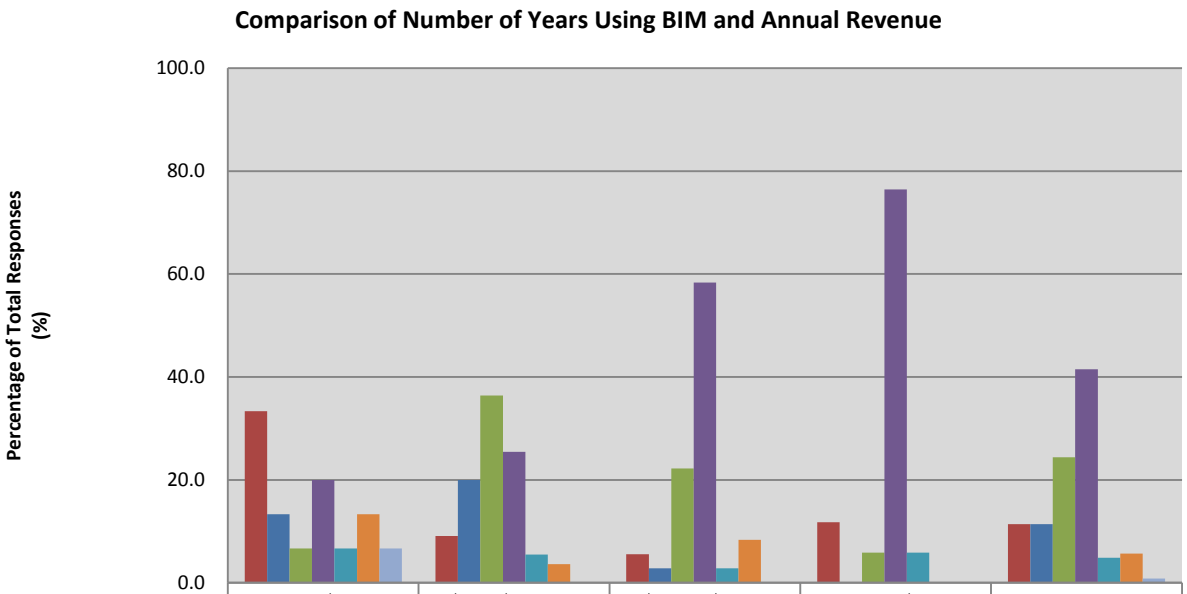


	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
We have yet to implement it.	19.6	2.9	28.6	0.0	0.0	15.4	11.4
0-1 Years	15.2	11.4	0.0	0.0	18.2	7.7	11.4
1-2 Years	30.4	20.0	14.3	18.2	18.2	30.8	24.4
3-5 Years	28.3	48.6	57.1	81.8	27.3	38.5	41.5
6-9 Years	4.3	8.6	0.0	0.0	9.1	0.0	4.9
10-15 Years	0.0	8.6	0.0	0.0	27.3	7.7	5.7
More than 15 Years	2.2	0.0	0.0	0.0	0.0	0.0	0.8

Figure 5-6. Comparison of number of years using BIM and project delivery methods.

Similar to the responses from the question in Section 5.1.1, the number of years of having used BIM increased as the amount of revenue increased, as seen in Figure 5-7. Additionally, companies with revenue 'Less than $1M' were found to have the largest

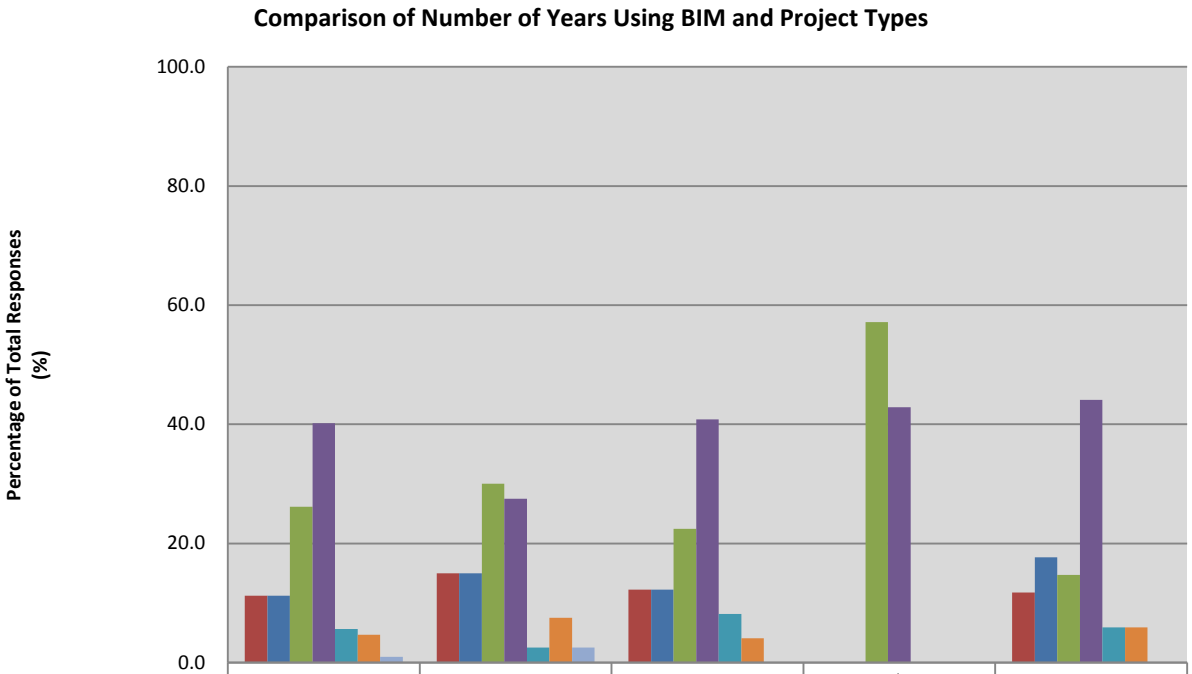
percentage of respondents having yet to implement BIM within their practices at 33% of its sample size (15 participants). Therefore, it can be said that the amount of revenue a company produces annually has a direct impact on the number of years BIM has been used by that company.



	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
We have yet to implement it.	33.3	9.1	5.6	11.8	11.4
0-1 Years	13.3	20.0	2.8	0.0	11.4
1-2 Years	6.7	36.4	22.2	5.9	24.4
3-5 Years	20.0	25.5	58.3	76.5	41.5
6-9 Years	6.7	5.5	2.8	5.9	4.9
10-15 Years	13.3	3.6	8.3	0.0	5.7
More than 15 Years	6.7	0.0	0.0	0.0	0.8

Figure 5-7. Comparison of number of years using BIM and annual revenue.

Figure 5-8 shows the results from the comparison between project type and the number of years BIM has been used. According to the results, it was found that the highest percentage of all project types had used BIM between '1 to 5 years.' Additionally, nearly 12% of the sample populations in the Commercial, Residential, Industrial, and 'Other' project types had used BIM for longer than 5 years. Therefore, there was little variation between the project type and number of years of using BIM.



	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
We have yet to implement it.	11.2	15.0	12.2	0.0	11.8
0-1 Years	11.2	15.0	12.2	0.0	17.6
1-2 Years	26.2	30.0	22.4	57.1	14.7
3-5 Years	40.2	27.5	40.8	42.9	44.1
6-9 Years	5.6	2.5	8.2	0.0	5.9
10-15 Years	4.7	7.5	4.1	0.0	5.9
More than 15 Years	0.9	2.5	0.0	0.0	0.0

Figure 5-8. Comparison of number of years using BIM and project types.

5.1.3 Question 3.3 – 3.4

Table 5-2 shows a breakdown of the percentage of companies that use BIM as well as the percentage of owner's that require companies to use BIM practices on a project, both through analysis of the sample population as a whole and individually by AEC position roles. Individually, the ARCH sector attained the highest rate of BIM application in their projects at 41.6% of their sample size; however, it also held the lowest rate (6%) of owner requirements. The SUB sector had the next highest rate of BIM use at 35.6% of its respondents with 10% of its respondents being required by owners to use BIM. The remaining sectors were similar in both categories.

Table 5-2. Cross-tabular comparison of company BIM use and owner requirements.

Position Roles (# of Participants in the Study)	A Percentage of Companies that Performs BIM Practices (%)	B Percentage of Owners That Require Companies to Perform BIM Practices (%)	Ratio of Results (A/B)
Others (28)	27.3	18.9	0.692
Engineer (18)	22.8	14.4	0.632
General Contractor (34)	26.3	12.2	0.464
Architect (25)	41.6	6.0	0.144
Subcontractors (18)	35.6	10	0.281
Total Participants (123)	30.5	12.5	0.410

In order to provide a fair comparison among the individual sectors, this investigation used a simple ratio of the results in order to determine a direct correlation between the impacts an owner has on the utilization of BIM in their company practices. Figure 5-9 graphically displays the relationship between the individual sectors against the average. As shown, both the ARCH and SUB sectors were found to be below the average while ENG, GC, and the 'Other' sectors were located above the average. This indicates that the ENG, GC, and 'Other' sectors of the AEC industry were more affected by owner's requirements than the ARCH and SUB sectors.

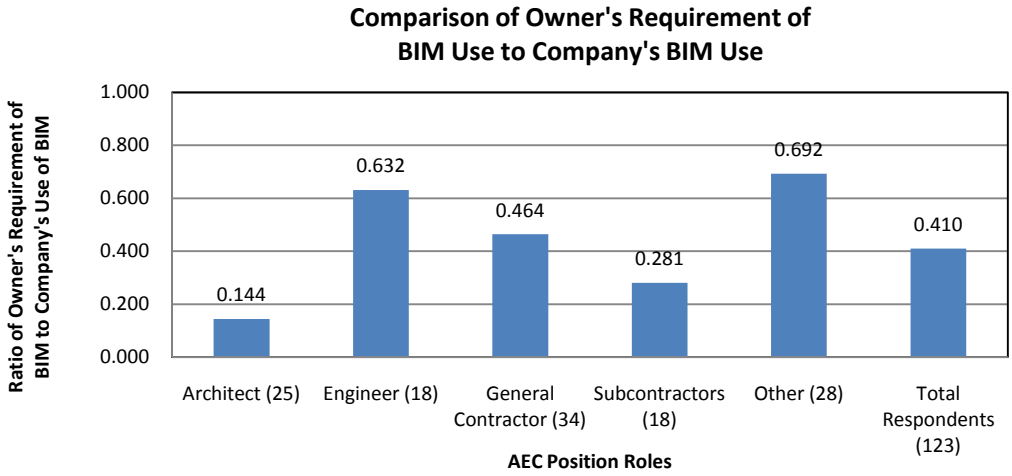
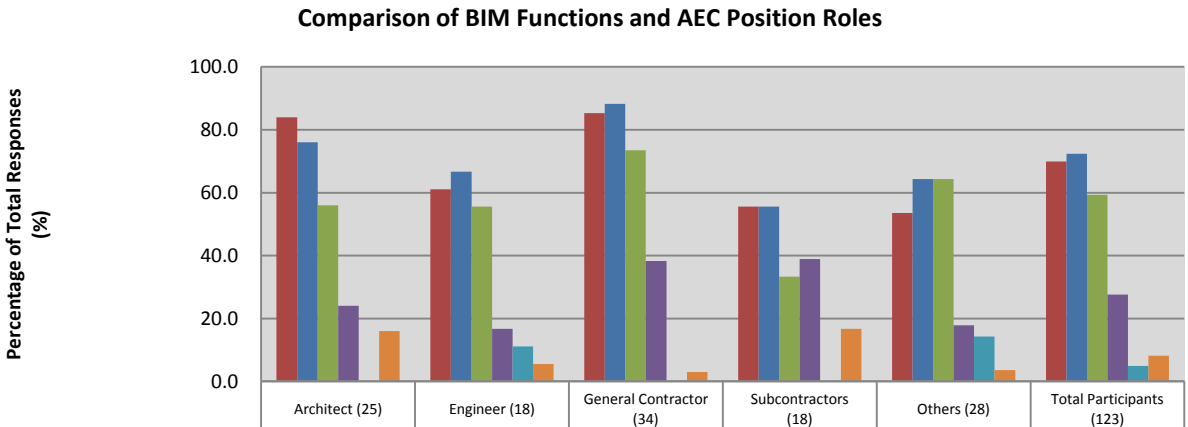


Figure 5-9. Comparison of owner's requirement to perform BIM use versus company's direct use of BIM.

5.1.4 Question 3.5

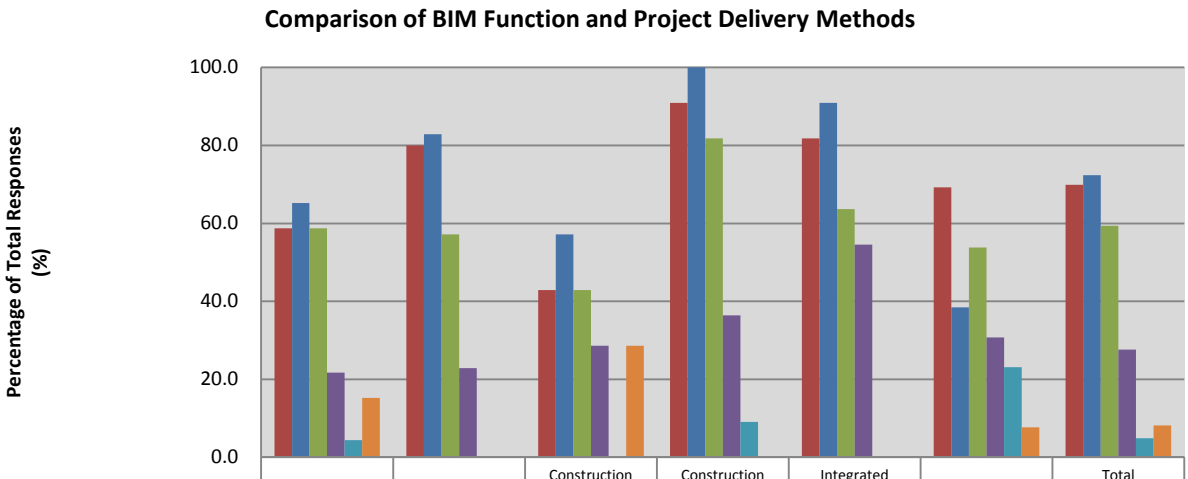
The results found in Section 4.2.4 indicated that the survey respondents utilized BIM primarily for project visualization, project coordination, and building performance analysis. Figures 5-10 to 5-13 provide further analysis of the results breaking the data down into the respective categories established for the scope of this study. As shown in Figure 5-10, of the AEC position roles the highest percentage of the participants in terms of BIM project visualization were the ARCH and the GC sectors at 84% and 85.3%, respectively. This is primarily due to the fact that the two sectors must be able to communicate with owners concerning project details and any other relevant information. Additionally, the GC sector had the highest percentage response within BIM project coordination at 88.2% of its sample size. In regards to project supply/vendor integration both the GC and SUB sectors had the highest percentages at 38.2% and 38.9%, respectively, for BIM project coordination.



	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Others (28)	Total Participants (123)
Project Visualization	84.0	61.1	85.3	55.6	53.6	69.9
Project Coordination	76.0	66.7	88.2	55.6	64.3	72.4
Project Analysis	56.0	55.6	73.5	33.3	64.3	59.3
Project Supply/Vendor Integration	24.0	16.7	38.2	38.9	17.9	27.6
Other	0.0	11.1	0.0	0.0	14.3	4.9
None	16.0	5.6	2.9	16.7	3.6	8.1

Figure 5-10. Comparison of BIM functions and AEC position roles.

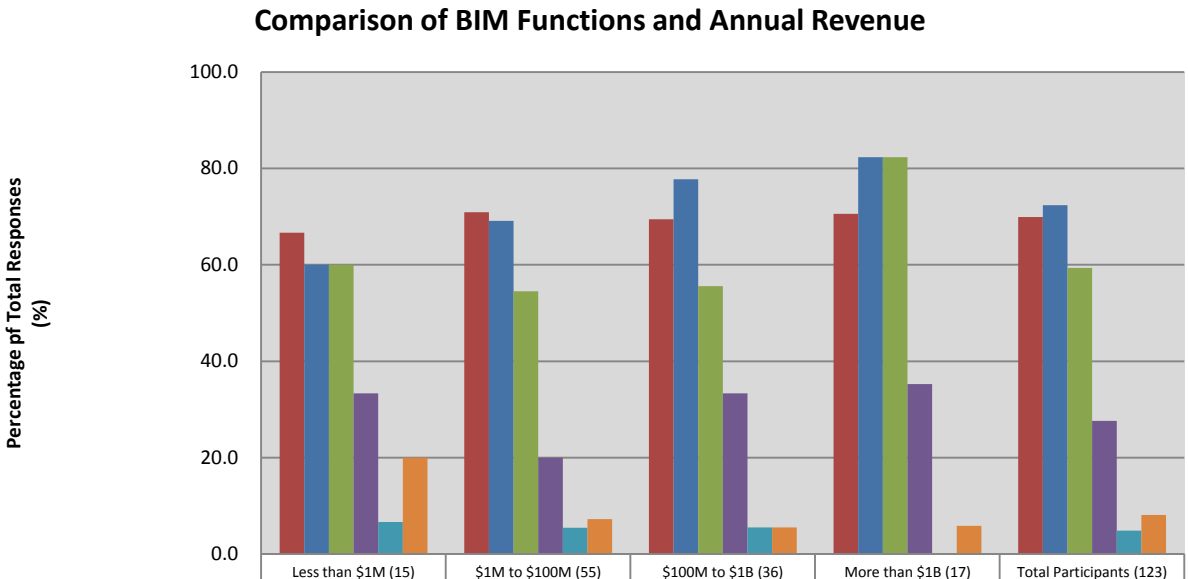
When comparing project delivery methods and BIM functionality, Figure 5-11 indicates that the DB, CM-R, and IPD methods had the highest percentage of its respondents in terms of project visualization and project coordination, each with over 80% of its sample size utilizing BIM for that specific functionality. This can be attributed to the nature of their contract agreements and efforts with multidisciplinary collaboration. Also, with the exception of CM, more than 50% of all the project delivery method survey groups used BIM to perform project analysis. Additionally, IPD at 54.5% of its sample size was seen as having the highest percentage of all categories in terms of project supply/vendor integration. Therefore, in terms of BIM functionality, the project delivery method that requires internal collaboration utilizes the various functions of BIM more frequently than others.



	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Project Visualization	58.7	80.0	42.9	90.9	81.8	69.2	69.9
Project Coordination	65.2	82.9	57.1	100.0	90.9	38.5	72.4
Project Analysis	58.7	57.1	42.9	81.8	63.6	53.8	59.3
Project Supply/Vendor Integration	21.7	22.9	28.6	36.4	54.5	30.8	27.6
Other	4.3	0.0	0.0	9.1	0.0	23.1	4.9
None	15.2	0.0	28.6	0.0	0.0	7.7	8.1

Figure 5-11. Comparison of BIM functions and project delivery method.

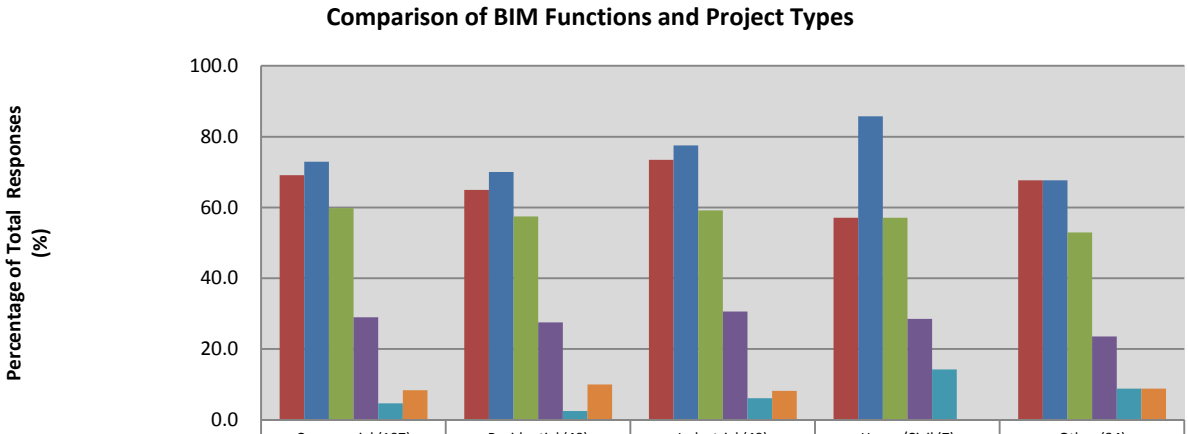
Figure 5-12 shows the results based on the annual revenue of the survey respondents in relation to the utilization of BIM functionality. According to the data, although there was little change seen with the percentage of each category in terms of project visualization, as companies increased their revenue the percentage of respondents within the project coordination and project analysis responses increased. In regards to project analysis, the companies with revenue 'More than $1B' at 82.4% of its sample size was seen as greater than the average percentage of the total sample population (59.3%). It should be noted that nearly 20% of the respondents with revenue of 'Less than $1M' did not utilize any of the listed BIM functions, therefore, as the revenue of a company increases, the more likely a company is to utilize BIM to its fullest capacity.



	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Project Visualization	66.7	70.9	69.4	70.6	69.9
Project Coordination	60.0	69.1	77.8	82.4	72.4
Project Analysis	60.0	54.5	55.6	82.4	59.3
Project Supply/Vendor Integration	33.3	20.0	33.3	35.3	27.6
Other	6.7	5.5	5.6	0.0	4.9
None	20.0	7.3	5.6	5.9	8.1

Figure 5-12. Comparison of BIM functions and annual revenue.

In terms of BIM functionality and project type, Figure 5-13 shows the results generated using the filtered data. Upon analyzing the assessments, there was little variation found in regards to the individual categories as each was seen to be relatively close to one another in terms of their percentages. Therefore, project type was seen as a non-factor in using BIM functions within a company's practices.



	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
Project Visualization	69.2	65.0	73.5	57.1	67.6
Project Coordination	72.9	70.0	77.6	85.7	67.6
Project Analysis	59.8	57.5	59.2	57.1	52.9
Project Supply/Vendor Integration	29.0	27.5	30.6	28.6	23.5
Other	4.7	2.5	6.1	14.3	8.8
None	8.4	10.0	8.2	0.0	8.8

Figure 5-13. Comparison of BIM functions and project types.

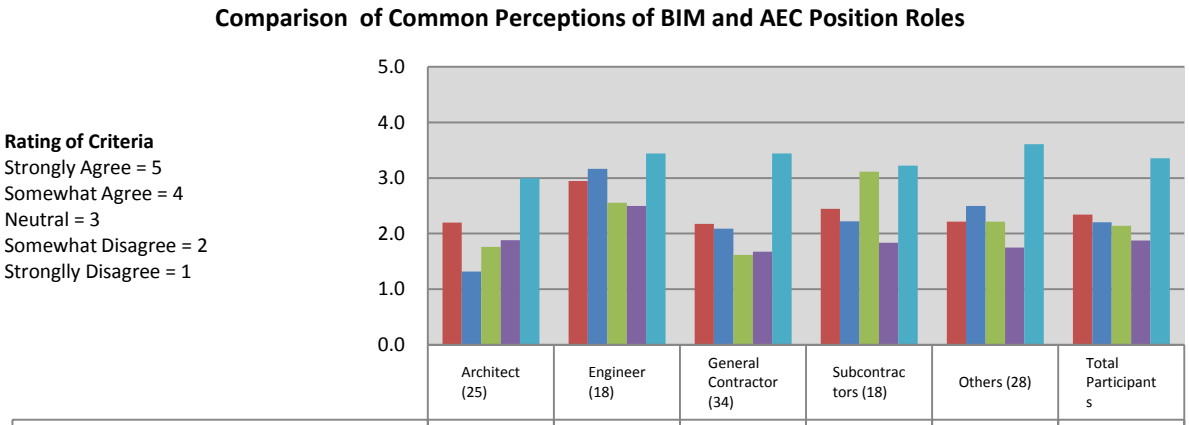
5.1.5 Question 3.6

From the results found in Section 4.2.5, the calculated data provided a means of understanding common difficulties seen with BIM as a tool to be used in the AEC industry. The following ranking of statements was generated from the total sample population in descending order from strongly agree (rating of 5) to strongly disagree (rating of 1):

1) BIM currently does not operate in an optimal standardized format (3.36).
2) BIM is not cost-effective (2.37).

3) BIM is too complicated to use (2.35).
4) BIM is currently not designed for their particular profession (2.14).
5) BIM is currently not a necessity in the industry (1.88).

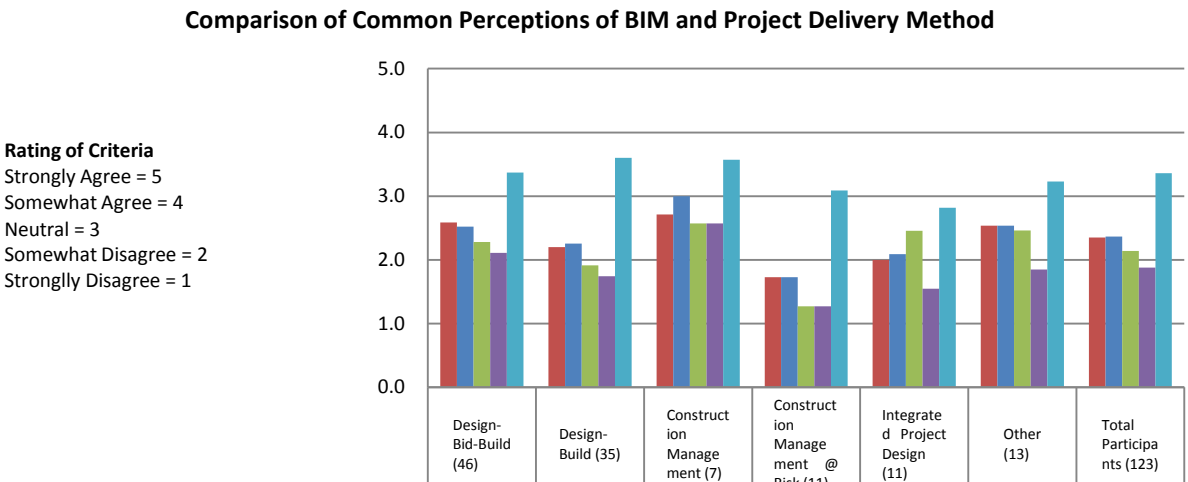
Figures 5-14 through 5-17 were created as a means to measure the four discriminating characteristics to the average rating scores of the total results. Figure 5-14 shows the comparison between the individual AEC sectors and common perceptions of BIM. According to the data, in unanimous agreement all the AEC sectors believed that BIM does not operate in an optimal standardized format. Similarly, most of the sectors disagreed with the statement that BIM is not a necessity within the industry. In regards to the other statements, the ARCH and GC sectors assigned lower ratings (i.e. a higher level of disagreement) that BIM was too complicated, not cost-effective, and not designed for their particular profession than the other categories. Overall, the ENG and SUB sectors assigned higher ratings (i.e. a higher level of agreement) of the statements than the others sectors in the AEC industry in regards to their perceptions of BIM.



	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Others (28)	Total Participants
BIM is currently too complicated to use.	2.2	2.9	2.2	2.4	2.2	2.3
BIM is currently not a cost-effective measure for the industry.	1.3	3.2	2.1	2.2	2.5	2.2
BIM is currently not designed to be used specifically for my profession.	1.8	2.6	1.6	3.1	2.2	2.1
BIM is currently not a necessity within the industry.	1.9	2.5	1.7	1.8	1.8	1.9
BIM currently does not operate in an optimal standardized format.	3.0	3.4	3.4	3.2	3.6	3.4

Figure 5-14. Comparison of common perceptions of BIM and AEC position roles.

In relation to project delivery methods, with the exception of IPD, all respondents agreed that BIM does not operate in an optimal standardized format (see Figure 5-15). Additionally, all respondents disagreed that BIM is not a necessity within the AEC industry. In comparison to the average ratings of the entire sample population, DBD and CM assigned higher ratings in reference to the remaining statements, while DB, CM-R, and IPD were lower. It should be noted that CM-R assigned the lowest ratings, thus higher level of disagreement, in each statement, with the exception to the statement regarding interoperability (IPD).

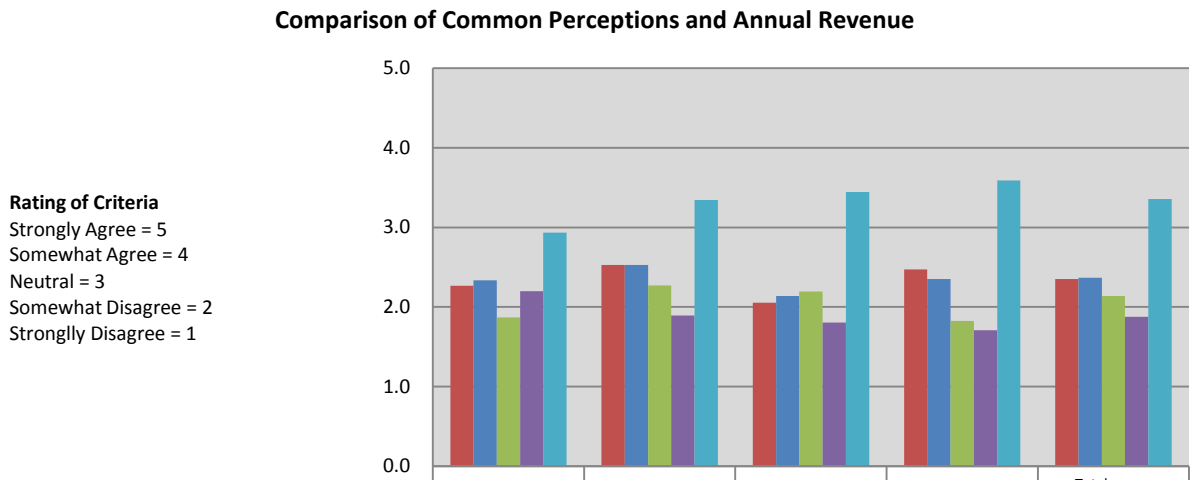


	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
BIM is currently too complicated to use.	2.6	2.2	2.7	1.7	2.0	2.5	2.3
BIM is currently not a cost-effective measure for the industry.	2.5	2.3	3.0	1.7	2.1	2.5	2.4
BIM is currently not designed to be used specifically for my profession.	2.3	1.9	2.6	1.3	2.5	2.5	2.1
BIM is currently not a necessity within the industry.	2.1	1.7	2.6	1.3	1.5	1.8	1.9
BIM currently does not operate in an optimal standardized format.	3.4	3.6	3.6	3.1	2.8	3.2	3.4

Figure 5-15. Comparison of common perceptions of BIM and project delivery method.

Figure 5-16 shows the averaged ratings taken from the viewpoint of the survey participant's annual revenue. According to the data, all respondents agreed that BIM did not support an optimal standardized format, with the exception of the respondents with revenue of 'Less than $1M' category. In similar fashion, all respondents somewhat

disagreed that BIM was not a necessity within the industry. The remaining statements identified that companies with revenue of '$1M to $100M' attained a higher rating against the average score, while the other categories received equivalent or lower ratings than the average score.

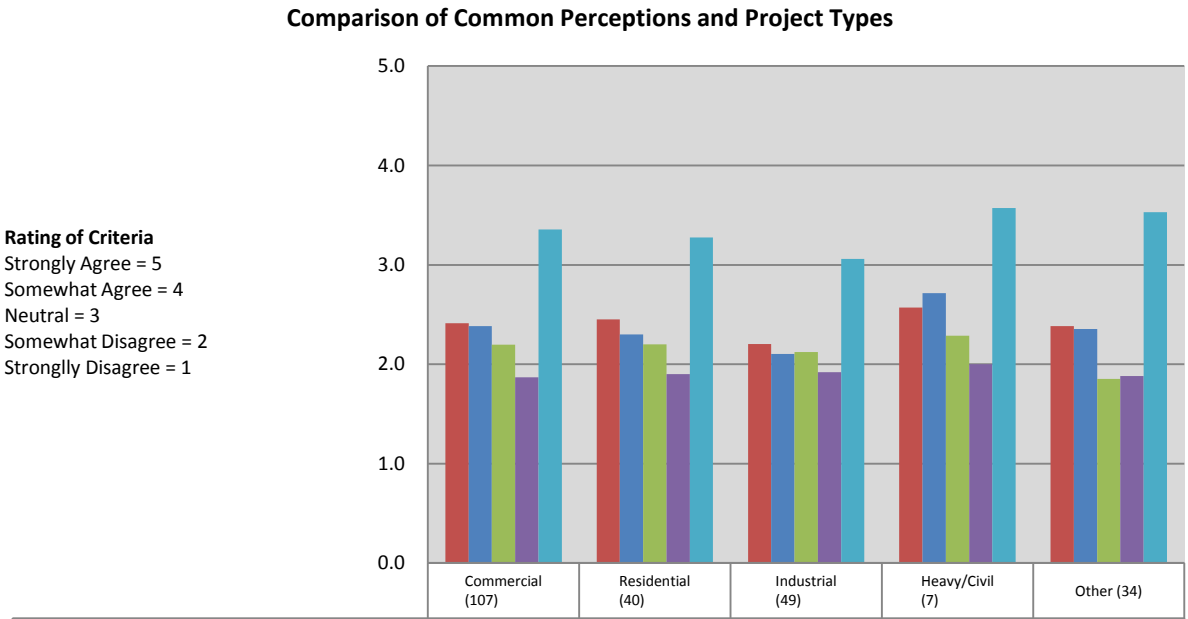


	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
BIM is currently too complicated to use.	2.3	2.5	2.1	2.5	2.3
BIM is currently not a cost-effective measure for the industry.	2.3	2.5	2.1	2.4	2.4
BIM is currently not designed to be used specifically for my profession.	1.9	2.3	2.2	1.8	2.1
BIM is currently not a necessity within the industry.	2.2	1.9	1.8	1.7	1.9
BIM currently does not operate in an optimal standardized format.	2.9	3.3	3.4	3.6	3.4

Figure 5-16. Comparison of common perceptions and annual revenue.

Similar to the previous comparisons, all respondents agreed that BIM did not support an optimal standardized file format in relation to project type (see Figure 5-17). Additionally, all respondents disagreed that BIM was not a necessity within the industry. In regard to the remaining statements, the Industrial category assigned a lower level of agreement when compared to the average rating score of the total sample population, with the exception of one (BIM is currently not designed for my particular profession). Conversely, Heavy/Civil attained higher levels of agreement compared to the average in

every statement. The other categories were nearly equal to the average in each of the statements.



	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
BIM is currently too complicated to use.	2.4	2.5	2.2	2.6	2.4
BIM is currently not a cost-effective measure for the industry.	2.4	2.3	2.1	2.7	2.4
BIM is currently not designed to be used specifically for my profession.	2.2	2.2	2.1	2.3	1.9
BIM is currently not a necessity within the industry.	1.9	1.9	1.9	2.0	1.9
BIM currently does not operate in an optimal standardized format.	3.4	3.3	3.1	3.6	3.5

Figure 5-17. Comparison of common perceptions and project types.

5.1.6 Question 3.7

The results presented in Section 4.2.6, provided a measure for understanding AEC industry viewpoints on BIM features. From the information provided a ranking system was generated from the total sample population in descending order from very high importance (rating of 7) to very low importance (rating of 1). The rankings are as follows:

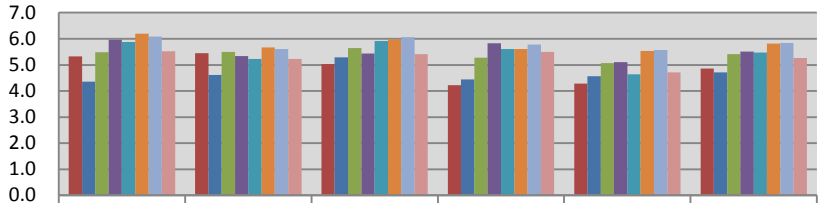
1) Ability to support collaborative and distributed work processes (5.85).
2) Multidisciplinary capabilities (5.82).
3) Support to produce construction documents (5.51).
4) Standardization of software platforms (5.47).

5) Direct integration for construction related tasks (5.41).
6) Relative ease of the software (5.26).
7) Direct integration with energy analysis (4.86).
8) Direct integration with project management software (4.72).

Figure 5-18 displays the results from a stratified sampling of the total population through position role filters. In relation to the average rating score of the total population, it was found that the ARCH and GC categories attained higher ratings than average (i.e. a higher level of importance) for nearly every BIM feature listed. Conversely, the ENG and 'Other' categories had lower ratings (i.e. lower level of importance) than the average on nearly every BIM feature listed. Of noted importance was the BIM feature "integration with energy analysis" to which the ARCH, ENG, and GC sectors all assigned high importance, while the SUB and Other categories thought of it as less important. Similarly, the "integration with project management software" was deemed of high importance to the GC category; however, the remaining categories placed lower importance to this BIM feature.

Comparison of Importance of BIM Features and AEC Position Roles

Rating of Criteria
Very High = 7
High = 6
Medium-High= 5
Neutral = 4
Medium-Low = 3
Low= 2
Very Low = 1



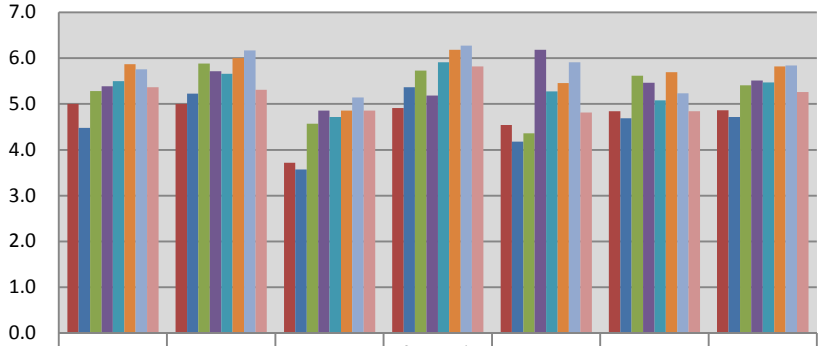
	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Direct integration with energy analysis software applications	5.3	5.4	5.0	4.2	4.3	4.9
Direct integration with project management software	4.4	4.6	5.3	4.4	4.6	4.7
Direct integration for construction related tasks	5.5	5.5	5.6	5.3	5.1	5.4
Support to produce construction documents	6.0	5.3	5.4	5.8	5.1	5.5
Standardization of software platforms	5.9	5.2	5.9	5.6	4.6	5.5
Multidisciplinary capability	6.2	5.7	6.0	5.6	5.5	5.8
Ability to support collaborative and distributed work processes	6.1	5.6	6.1	5.8	5.6	5.8
Relative ease of software	5.5	5.2	5.4	5.5	4.7	5.3

Figure 5-18. Comparison of importance of BIM features and AEC position roles.

In comparison with the respondent's project delivery methods and the importance of the listed BIM features, Figure 5-19 shows the ratings for the individual BIM features in terms of the responses from Question 2.6. According to the results, it was found that the companies that use both the DB and CM-R project delivery methods assigned higher ratings than the average ratings in regards to all listed BIM features, therefore, these methods found the listed BIM features more important than average. Conversely, the CM, IPD, and 'Other' delivery methods were found to have lower ratings than the average and, thus, of lower importance. Additionally, the DBD delivery method held higher ratings than average in regards to integration of energy analysis, multidisciplinary capabilities, and relative ease of software.

Comparison of Importance of BIM Features and Project Delivery Method

Rating of Criteria
Very High = 7
High = 6
Medium-High= 5
Neutral = 4
Medium-Low = 3
Low= 2
Very Low = 1



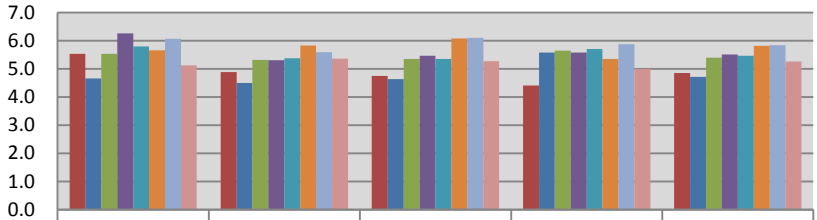
	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Direct integration with energy analysis software applications	5.0	5.0	3.7	4.9	4.5	4.8	4.9
Direct integration with project management software	4.5	5.2	3.6	5.4	4.2	4.7	4.7
Direct integration for construction related tasks	5.3	5.9	4.6	5.7	4.4	5.6	5.4
Support to produce construction documents	5.4	5.7	4.9	5.2	6.2	5.5	5.5
Standardization of software platforms	5.5	5.7	4.7	5.9	5.3	5.1	5.5
Multidisciplinary capability	5.9	6.0	4.9	6.2	5.5	5.7	5.8
Ability to support collaborative and distributed work processes	5.8	6.2	5.1	6.3	5.9	5.2	5.8
Relative ease of software	5.4	5.3	4.9	5.8	4.8	4.8	5.3

Figure 5-19. Comparison of importance of BIM features and project delivery method.

According to Figure 5-20, the comparison between annual revenue and the importance of BIM features showed that companies with revenue of 'Less than$1M' and 'More than $1B' gave higher ratings, thus higher level of importance, than average on each of the BIM features, with the exception of multidisciplinary capabilities and relative ease. Additionally, companies with revenue of 'More than $1B' assigned a lower rating than the average on the BIM feature "direct integration of energy analysis software," thus they considered it of lower importance. Similarly, with the exception of relative ease, companies with revenue of '$1M to $100M' assigned lower ratings than average; therefore, they believed the features to be of lower importance. Companies with revenue of '$100 to $1B' were found to have most of their ratings to be lower than average, however, they attained higher ratings than average within the BIM features "multidisciplinary capabilities" and "ability to support collaborative and distributed work processes."

Comparison of Importance of BIM Features and Annual Revenue

Rating of Criteria
Very High = 7
High = 6
Medium-High= 5
Neutral = 4
Medium-Low = 3
Low= 2
Very Low = 1



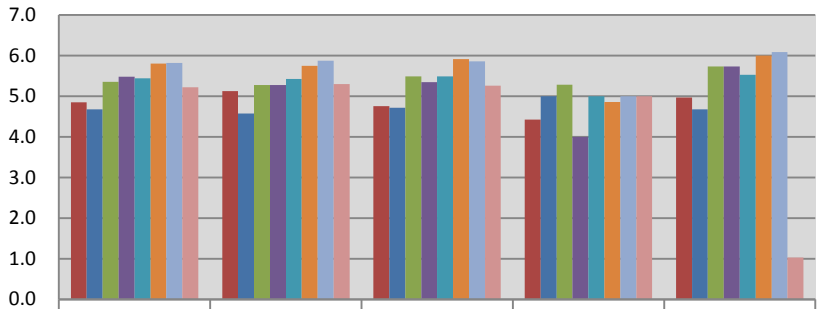
	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Direct integration with energy analysis software applications	5.5	4.9	4.8	4.4	4.9
Direct integration with project management software	4.7	4.5	4.6	5.6	4.7
Direct integration for construction related tasks	5.5	5.3	5.4	5.6	5.4
Support to produce construction documents	6.3	5.3	5.5	5.6	5.5
Standardization of software platforms	5.8	5.4	5.4	5.7	5.5
Multidisciplinary capability	5.7	5.8	6.1	5.4	5.8
Ability to support collaborative and distributed work processes	6.1	5.6	6.1	5.9	5.8
Relative ease of software	5.1	5.4	5.3	5.0	5.3

Figure 5-20. Comparison of importance of BIM features and annual revenue.

Figure 5-21 shows the results comparing project type and the given BIM features. According to the data, the companies that perform Heavy/Civil project types attained lower ratings than average; therefore, they considered the given BIM features of low importance. The largest constituent, the Commercial project type, was found to be equivalent to the average ratings for all statements; therefore the respondents maintained similar results for the total population. The Residential project type was found to have ratings lower than the average on most of the BIM features listed, however, it received high ratings on “direct integration of energy analysis software” and “ability to support collaborative and distributed work processes.” The Industrial project type was found to be equivalent to the average in its rating of all BIM features; however, it assigned lower ratings in regards to “direct integration of energy analysis software” and “support to produce construction documents.”

Comparison of Importance of BIM Features and Project Types

Rating of Criteria
Very High = 7
High = 6
Medium-High= 5
Neutral = 4
Medium-Low = 3
Low= 2
Very Low = 1



	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
Direct integration with energy analysis software applications	4.9	5.1	4.8	4.4	5.0
Direct integration with project management software	4.7	4.6	4.7	5.0	4.7
Direct integration for construction related tasks	5.4	5.3	5.5	5.3	5.7
Support to produce construction documents	5.5	5.3	5.3	4.0	5.7
Standardization of software platforms	5.4	5.4	5.5	5.0	5.5
Multidisciplinary capability	5.8	5.8	5.9	4.9	6.0
Ability to support collaborative and distributed work processes	5.8	5.9	5.9	5.0	6.1
Relative ease of software	5.2	5.3	5.3	5.0	1.0

Figure 5-21. Comparison of importance of BIM features and project types.

5.2 Section 4 Stratified Sampling Results

This section collected information regarding the various aspects of sustainability and its application within the AEC industry. The intent of this investigation was to analyze the trends within certain categories of the sample population. The results were assessed against other participant responses as well as the total population.

5.2.1 Question 4.1 – 4.2

Each targeted questions was analyzed through assessments based on the entire sample population as well as the individual AEC position roles. As shown in Table 5-3, the GC sector held the highest percentage of green building certification projects as well as green building certification owner requirements at 33.4% and 31.3%, respectively. Conversely, the lowest sector was determined to be the SUB sector with only 11.9% of the companies having performed green building certified projects and only 10.8% of its responses having owner requirements towards performing green building certification. The remaining sectors are well within the boundaries set by the two extremes.

Table 5-3. Cross-tabular comparison of company LEED projects and owner requirements.

Position Roles (# of Participants in the Study)	A Company Performs LEED Certified Bldgs. (%)	B Owners Require Company to Build Certified Bldgs. (%)	Ratio of Results (A/B)
Architect (25)	17.40	14.20	0.816
Engineer (18)	20.28	19.17	0.945
General Contractor (34)	33.38	31.32	0.938
Subcontractors (18)	11.94	10.83	0.907
Others (28)	32.50	28.57	0.879
Total Respondents (123)	24.88	22.44	0.902

In order to provide a fair comparison among the individual sectors, this investigation used a simple ratio of the results in order to determine relationships between the impacts an owner has on the amount of work performed to achieve green

building certification. Figure 5-22 shows the relationships between the individual sectors and the average. Although the ARCH and 'Other' sectors were located below the average, because the ratios were all above 0.80 there is evidence to support the conclusion that an owner's involvement in requiring green certified buildings can impact a company's practice of building green certified buildings.

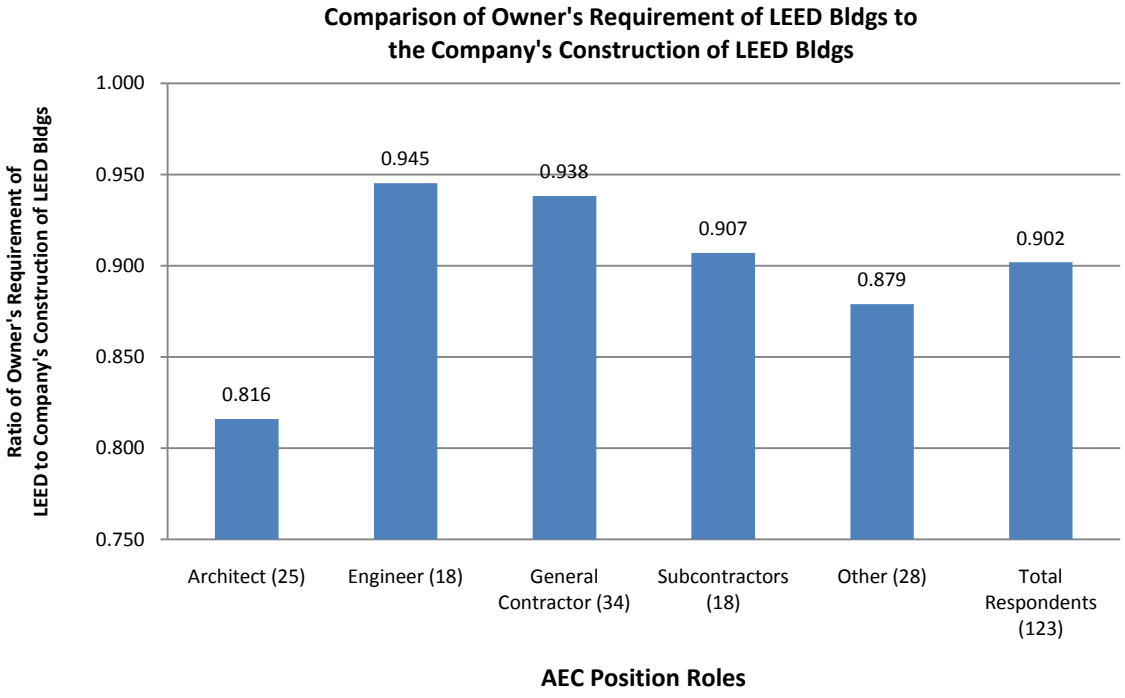


Figure 5-22. Comparison of owner's requirements of LEED buildings to the company's construction of LEED buildings.

5.2.2 Question 4.3

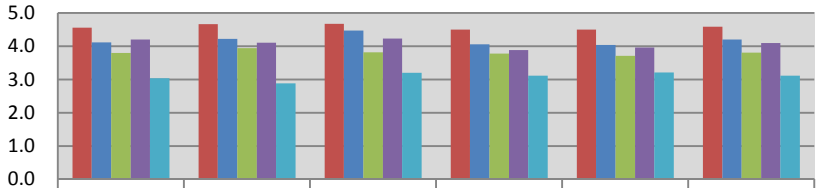
From results found in Section 4.3.2, the data generated through analysis of the responses established an understanding of participant's perceptions towards their company and its perceptions of sustainability. From the data collected a ranking system was generated from the total sample population in descending order from strongly agree (rating of 5) to strongly disagree (rating of 1). The rankings are as follows:

1) My company finds the role of sustainability important (4.59).
2) My company is proactive in providing sustainability education among employees (4.20).
3) My company actively advises owners to pursue sustainable methods and practices during projects 4.10).
4) My company utilizes the latest innovations in sustainability 3.80).
5) My company provides incentives to encourage sustainable practices during a project (3.11).

According to the data in Figure 5-23, in relation to the average rating scores, the GC and ENG assigned higher ratings (i.e. a higher level of agreement) than the average; therefore, they had a greater support for sustainability in company practices. Conversely, the SUB and 'Other' sectors were found to have lower ratings (i.e. a higher level of disagreement) than average. The ARCH category remained equivalent to the average ratings of the total population. It is worth noting that although there were differences seen with each sector's rating score, all position roles considered sustainability to be relevant criteria within their company practices.

Comparison of Company Perception and AEC Position Role

Rating of Criteria
Strongly Agree = 5
Somewhat Agree = 4
Neutral = 3
Somewhat Disagree = 2.
Stronglly Disagree = 1

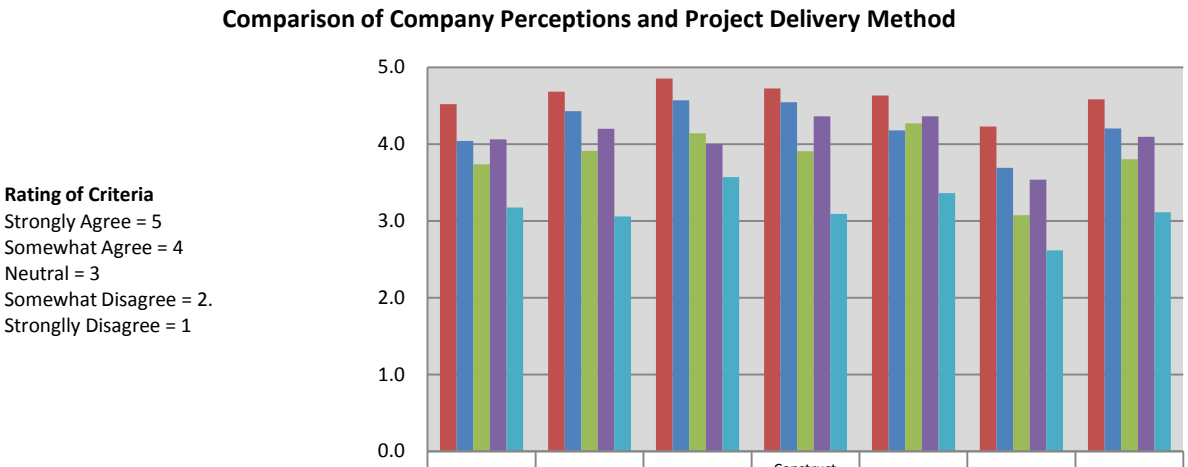


	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
My company finds the role of sustainability to be important.	4.6	4.7	4.7	4.5	4.5	4.6
My company has been proactive in educating employees on recent sustainable practice developments.	4.1	4.2	4.5	4.1	4.0	4.2
My company utilizes the latest innovations in technology to enhance our sustainability mechanisms.	3.8	3.9	3.8	3.8	3.7	3.8
My company actively advises owners/stakeholders to pursue sustainable methods and practices during projects.	4.2	4.1	4.2	3.9	4.0	4.1
My company provides incentives to encourage sustainable practices during projects.	3.0	2.9	3.2	3.1	3.2	3.1

Figure 5-23. Comparison of company perception and AEC position roles.

In terms of project delivery method, Figure 5-24 shows that the DB, CM, CM-R, and IPD methods were assigned higher ratings within their own sectors than the

average of the entire population on all statements in the question, thus, showing a greater agreement on the importance of sustainability within company's practices. On the other hand, the DBD and 'Other' methods suffered lower ratings than the average. Similar to position roles, although there were differences found within each delivery method, all sectors were found to agree that sustainability was important to their company's practices.

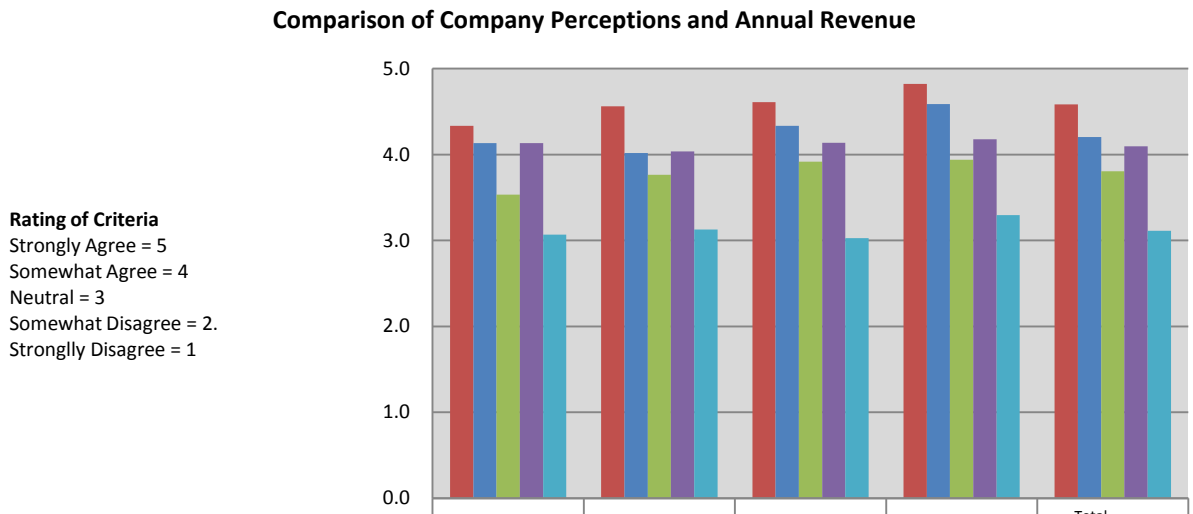


	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
My company finds the role of sustainability to be important.	4.5	4.7	4.9	4.7	4.6	4.2	4.6
My company has been proactive in educating employees on recent sustainable practice developments.	4.0	4.4	4.6	4.5	4.2	3.7	4.2
My company utilizes the latest innovations in technology to enhance our sustainability mechanisms.	3.7	3.9	4.1	3.9	4.3	3.1	3.8
My company actively advises owners/stakeholders to pursue sustainable methods and practices during projects.	4.1	4.2	4.0	4.4	4.4	3.5	4.1
My company provides incentives to encourage sustainable practices during projects.	3.2	3.1	3.6	3.1	3.4	2.6	3.1

Figure 5-24. Comparison of company perceptions and project delivery method.

In regards to annual revenue, Figure 5-25 shows that the companies with revenue of 'More than $1B' assigned a higher rating in all statements than the average of the total population, thus, indicating greater agreement on the importance of sustainability within company practices. The companies with revenue of 'Less than $1M' and '$1M to $100M' both assigned lower ratings than the average rating, in respect to all

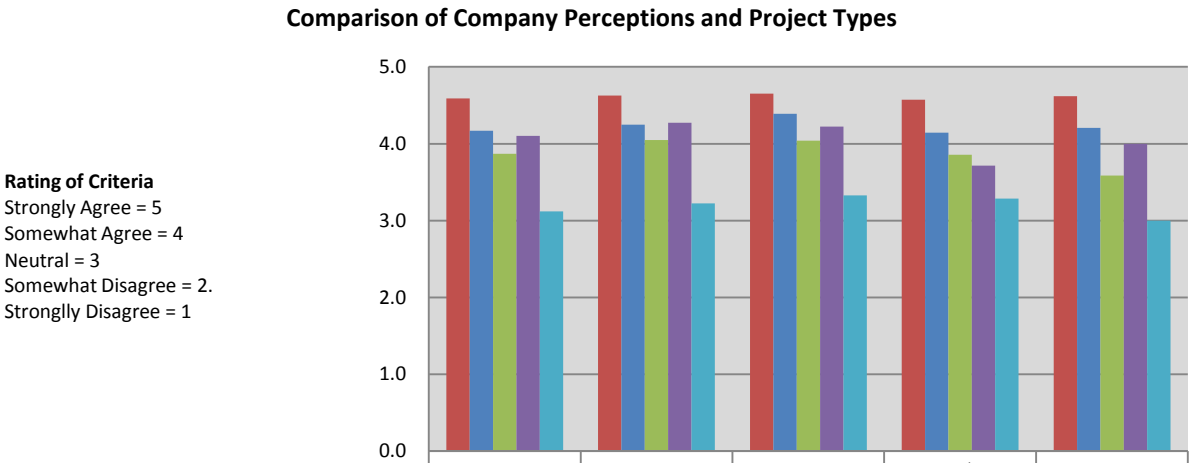
statements. However, even though there were differences found between each category, all revenues were found to agree on the importance of sustainability within company practices.



	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
My company finds the role of sustainability to be important.	4.3	4.6	4.6	4.8	4.6
My company has been proactive in educating employees on recent sustainable practice developments.	4.1	4.0	4.3	4.6	4.2
My company utilizes the latest innovations in technology to enhance our sustainability mechanisms.	3.5	3.8	3.9	3.9	3.8
My company actively advises owners/stakeholders to pursue sustainable methods and practices during projects.	4.1	4.0	4.1	4.2	4.1
My company provides incentives to encourage sustainable practices during projects.	3.1	3.1	3.0	3.3	3.1

Figure 5-25. Comparison of company perceptions and annual revenue.

In terms of the project type, Figure 5-26 shows that both the Residential and Industrial categories were found to have higher ratings than the average rating, in respect to all statements, therefore, there was a greater agreement on the importance of sustainability within company practices. Counter to that, the 'Other' category was found to have lower ratings than the average of the total population within all statements. Overall, all projects types agreed that sustainability was important within company practices.



	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
My company finds the role of sustainability to be important.	4.6	4.6	4.7	4.6	4.6
My company has been proactive in educating employees on recent sustainable practice developments.	4.2	4.3	4.4	4.1	4.2
My company utilizes the latest innovations in technology to enhance our sustainability mechanisms.	3.9	4.1	4.0	3.9	3.6
My company actively advises owners/stakeholders to pursue sustainable methods and practices during projects.	4.1	4.3	4.2	3.7	4.0
My company provides incentives to encourage sustainable practices during projects.	3.1	3.2	3.3	3.3	3.0

Figure 5-26. Comparison of company perceptions and project types.

5.2.3 Question 4.4

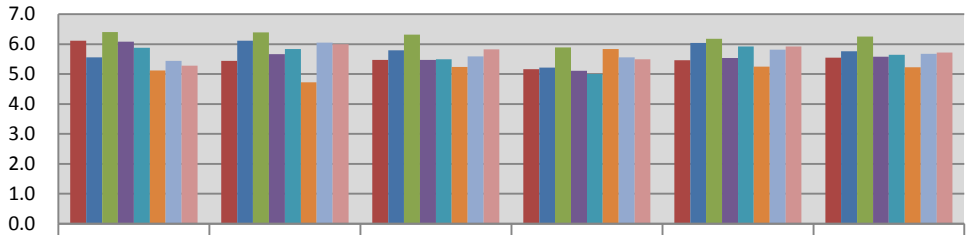
From the results found in Section 4.3.3, the calculated responses provided a measure for understanding AEC industry viewpoints on common sustainable practices and their impact on construction. From collected data a ranking system was generated from the total sample population in descending order from very high (rating of 7) to very low (rating of 1). The rankings of the sustainable features listed in the survey are as follows:

1) Energy efficiency (6.25).
2) Water efficiency (5.76).
3) Post-construction facility operations (5.72).
4) Building commissioning (5.67).
5) Indoor air quality (5.65).
6) Use of sustainable materials (5.59).
7) Sustainable site development (5.55).
8) Incorporated project management (5.23).

Figure 5-27 provides a tabulated view of the data gathered through filtering the results though position roles. In relation to average ratings of the total population, it was found that ARCH category assigned higher ratings (i.e. a higher level of importance) in regards to sustainable site development, energy efficiency, sustainable materials, and indoor air quality. The ENG and 'Other' sector assigned higher ratings within every sustainable practice listed with the exception of "sustainable site development" and "project management." The SUB sector was found to be lower with its ratings (i.e. a lower level of importance) in regards to its viewpoint on the importance of sustainable practices, with the exceptions of "project management" and "post-construction facilities operations." Additionally, the GC category was found to be equivalent with respect to most of the sustainable practices listed in the survey question.

Comparison of Common Sustainable Features and AEC Position Roles

Rating of Criteria
Very High = 7
High = 6
Medium-High= 5
Neutral = 4
Medium-Low = 3
Low= 2
Very Low = 1

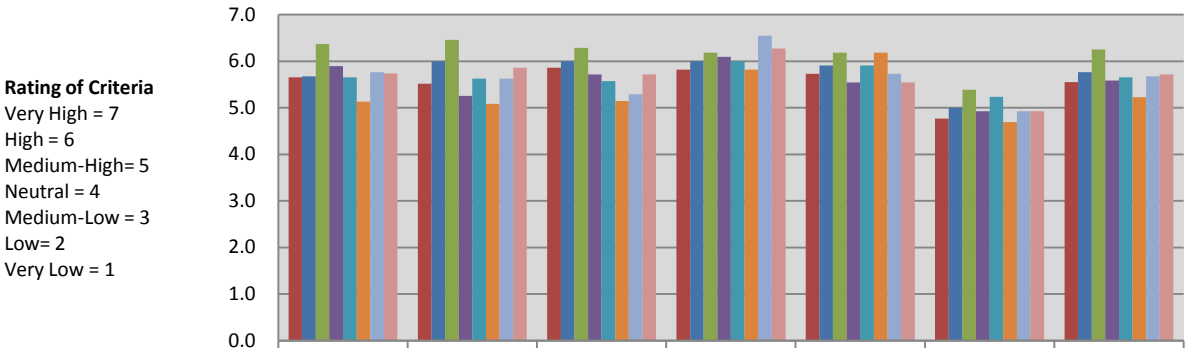


	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Sustainable Site Development	6.1	5.4	5.5	5.2	5.5	5.6
Water Efficiency	5.6	6.1	5.8	5.2	6.0	5.8
Energy Efficiency	6.4	6.4	6.3	5.9	6.2	6.3
Sustainable Materials	6.1	5.7	5.5	5.1	5.5	5.6
Indoor Air Quality	5.9	5.8	5.5	5.0	5.9	5.7
Project Management	5.1	4.7	5.2	5.8	5.3	5.2
Building Commissioning	5.4	6.1	5.6	5.6	5.8	5.7
Post Construction Facility Operations	5.3	6.0	5.8	5.5	5.9	5.7

Figure 5-27. Comparison of common sustainable features and AEC position roles.

Through a comparison between the selected project delivery method and the sustainable features listed, it was found that respondents from the companies that use

the CM-R delivery method assigned higher ratings than the average of the total population, and therefore found the sustainable features to be of greater importance than average. Additionally, IPD assigned higher ratings in almost all the sustainable features listed with the exceptions of “energy efficiency” and “sustainable materials.” DB, DBD, and CM each attained high ratings in some of the features and lower ratings in the remaining, as displayed in Figure 5-28. The ‘Other’ category was found to have received significantly lower ratings than the average ratings.



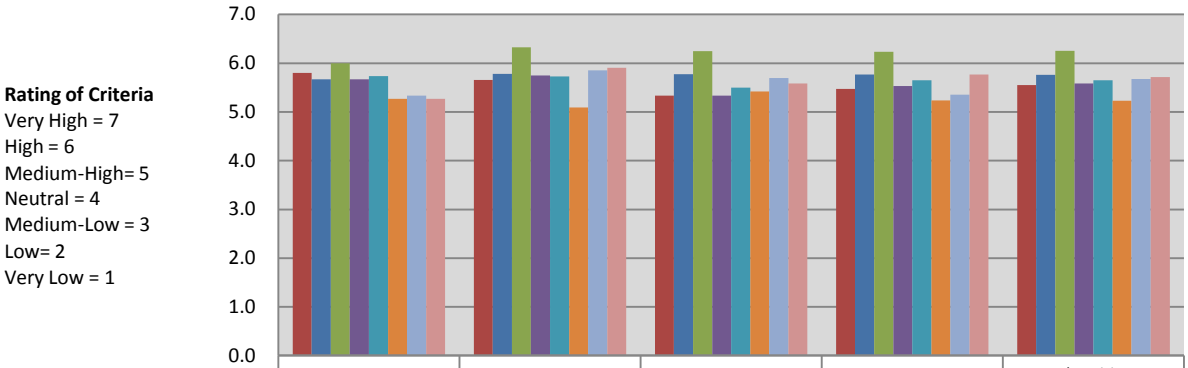
	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Sustainable Site Development	5.7	5.5	5.9	5.8	5.7	4.8	5.6
Water Efficiency	5.7	6.0	6.0	6.0	5.9	5.0	5.8
Energy Efficiency	6.4	6.5	6.3	6.2	6.2	5.4	6.3
Sustainable Materials	5.9	5.3	5.7	6.1	5.5	4.9	5.6
Indoor Air Quality	5.7	5.6	5.6	6.0	5.9	5.2	5.7
Project Management	5.1	5.1	5.1	5.8	6.2	4.7	5.2
Building Commissioning	5.8	5.6	5.3	6.5	5.7	4.9	5.7
Post Construction Facility Operations	5.7	5.9	5.7	6.3	5.5	4.9	5.7

Figure 5-28. Comparison of common sustainable features and project delivery method.

Figure 5-29 provides an opportunity to evaluate the relationships between annual revenue and sustainable features. According to the data generated, the companies with revenue of ‘More than$1B’ were found to attain lower ratings of importance than the average of the total respondents in regards to the listed sustainable features, with the

exception of the feature “post-construction facilities operations.” Additionally, it was found that the companies with revenue ‘Less than $1M’ assigned higher ratings to the following features: sustainable site development; sustainable materials; and, project management. Companies with revenue ‘Less than $1M’ also assigned lower levels of importance than average for the following features: water efficiency; energy efficiency; building commissioning; and, post-construction facility operations.

Comparison of Common Sustainable Features and Annual Revenue

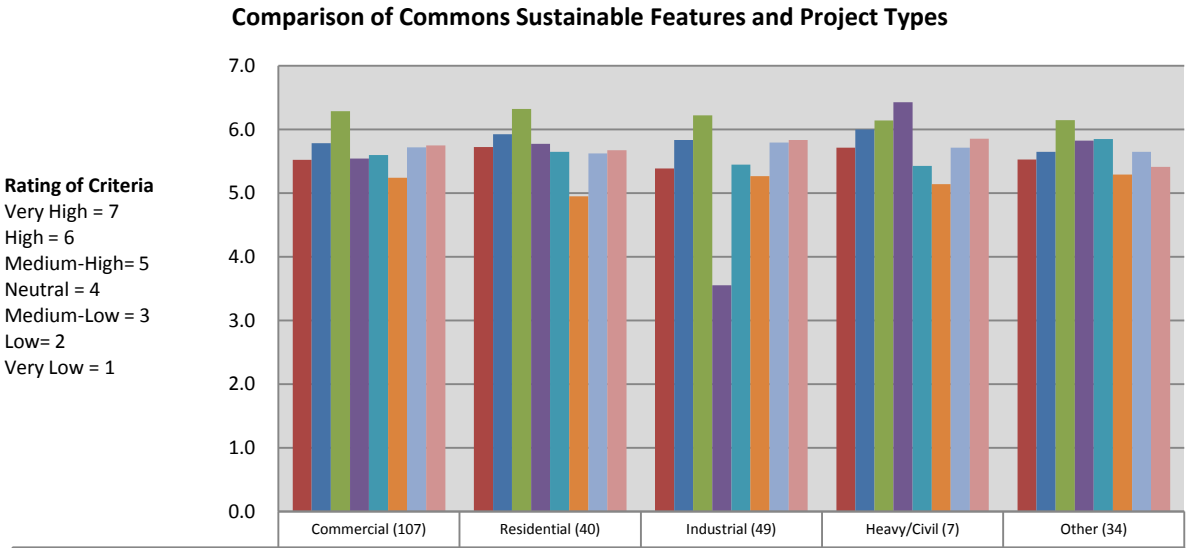


	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Sustainable Site Development	5.8	5.7	5.3	5.5	5.6
Water Efficiency	5.7	5.8	5.8	5.8	5.8
Energy Efficiency	6.0	6.3	6.3	6.2	6.3
Sustainable Materials	5.7	5.7	5.3	5.5	5.6
Indoor Air Quality	5.7	5.7	5.5	5.6	5.7
Project Management	5.3	5.1	5.4	5.2	5.2
Building Commissioning	5.3	5.9	5.7	5.4	5.7
Post Construction Facility Operations	5.3	5.9	5.6	5.8	5.7

Figure 5-29. Comparison of common sustainable features and annual revenue.

When comparing the categories of project type to the sustainable features listed (see Figure 5-30), it was found that the companies that build Industrial projects assigned lower ratings than the average of the total population, therefore they placed a lower level of importance on the sustainable features, with the exception of “project management,” “building commissioning,” and “post-construction facility operations.”

The Commercial category again remained equivalent to the average ratings, with the exception of the “sustainable materials” and “indoor air quality” features which was considered less important. The Residential and Heavy/Civil project types were found to have received both higher and lower ratings in comparison to the average ratings, yet each remained in near equivalence with the average of the total population.



	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
Sustainable Site Development	5.5	5.7	5.4	5.7	5.5
Water Efficiency	5.8	5.9	5.8	6.0	5.6
Energy Efficiency	6.3	6.3	6.2	6.1	6.1
Sustainable Materials	5.5	5.8	3.6	6.4	5.8
Indoor Air Quality	5.6	5.7	5.4	5.4	5.9
Project Management	5.2	5.0	5.3	5.1	5.3
Building Commissioning	5.7	5.6	5.8	5.7	5.6
Post Construction Facility Operations	5.7	5.7	5.8	5.9	5.4

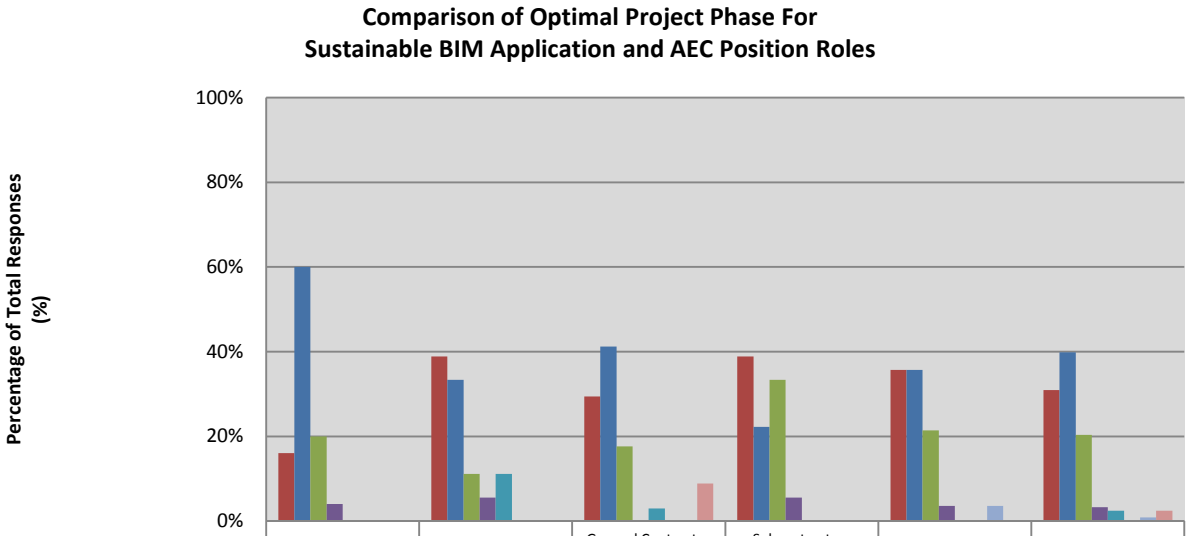
Figure 5-30. Comparison of common sustainable features and project types.

5.3 Section 5 Stratified Sampling Results

This section presents information regarding the various aspects of BIM and its application in sustainability within the AEC industry. The intent of this section is to analyze the trends within certain categories of the sample population. The results are assessed against other participant responses as well as the total population.

5.3.1 Question 5.1

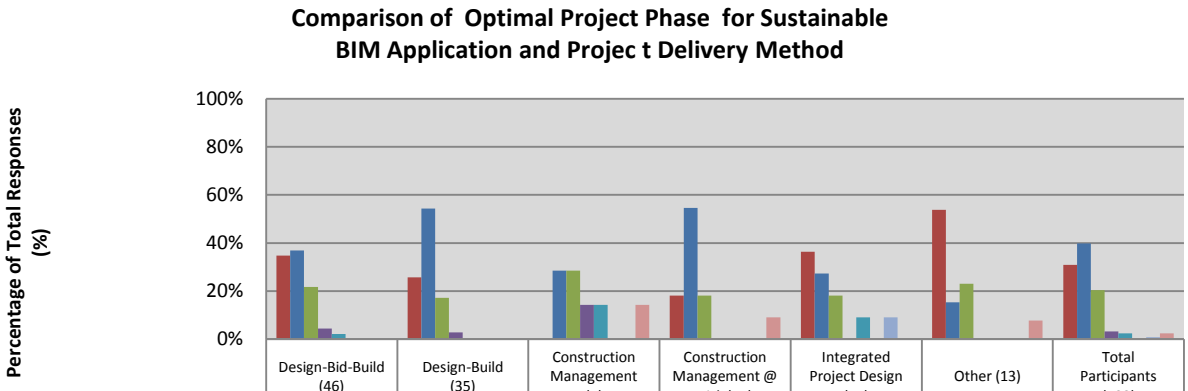
From the results found in Section 4.4.1, 71% of the respondents suggested that the optimal phase for BIM applications to be utilized within sustainable practices was within the pre-design or program phase (31%) and the schematic design phase (40%). Figures 5-31 to 5-34 show further analysis of the results from the survey through a stratification of the survey samples. Figure 5-31 shows that the ARCH and GC sectors stated that the schematic design phase was the optimal phase to implement BIM within their practice to ensure sustainable guidelines as selected by 60% and 41% of their sector respondents. The remaining sectors stated that the pre-design or program phase was the most optimal phase to use BIM towards sustainable practices.



	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Predesign or Program Phase	16%	39%	29%	39%	36%	31%
Schematic Design Phase	60%	33%	41%	22%	36%	40%
Design Development Phase	20%	11%	18%	33%	21%	20%
Construction Documents Phase	4%	6%	0%	6%	4%	3%
Preconstruction Phase	0%	11%	3%	0%	0%	2%
Construction Administration Phase	0%	0%	0%	0%	0%	0%
Postconstruction Operations Phase	0%	0%	0%	0%	4%	1%
Other	0%	0%	9%	0%	0%	2%

Figure 5-31. Comparison of optimal project phase for sustainable BIM use and AEC position roles.

Figure 5-32 was developed from an analysis using the Project Delivery Methods as the filter and varies slightly from the results found when using with the position roles as a filter. Fifty-four percent (54%) of the companies that use the DB method and 55% of the companies that use the CM-R method indicated that the schematic design phase was the optimal time to implement BIM. The companies that use the DBD, IPD, and the 'Other' methods were found to be equally divided among the first three phases of a project's duration. The companies that use the CM method had a greater number of responses stating the optimal period to use BIM towards sustainability was from the schematic phase to the preconstruction phase at 28% of their sectors response.

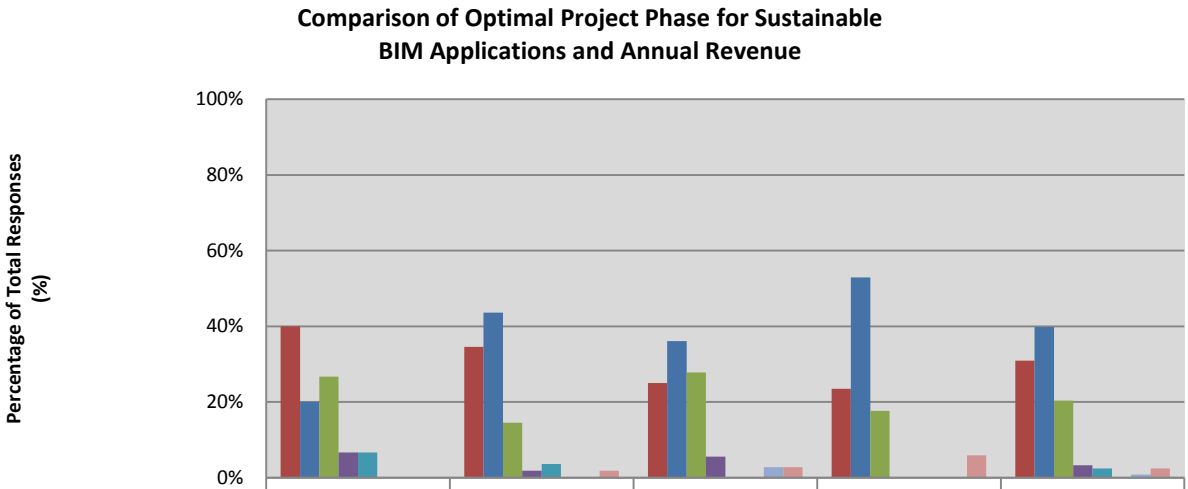


	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Predesign or Program Phase	35%	26%	0%	18%	36%	54%	31%
Schematic Design Phase	37%	54%	29%	55%	27%	15%	40%
Design Development Phase	22%	17%	29%	18%	18%	23%	20%
Construction Documents Phase	4%	3%	14%	0%	0%	0%	3%
Preconstruction Phase	2%	0%	14%	0%	9%	0%	2%
Construction Administration Phase	0%	0%	0%	0%	0%	0%	0%
Postconstruction Operations Phase	0%	0%	0%	0%	9%	0%	1%
Other	0%	0%	14%	9%	0%	8%	2%

Figure 5-32. Comparison of optimal project phase for sustainable BIM applications and project delivery method.

In terms of annual revenue, Figure 5-33 shows that the majority of respondents in each of the categories believe that the schematic design phase was the optimal time to implement BIM into their practices to enhance sustainable measures, with the exception

of the companies with revenue of 'Less than $1M.' The highest percentage of the companies with revenue of 'Less than $1M,' at 40% of the sample size, believed that the pre-design phase was the most optimal time to implement BIM.



	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Predesign or Program Phase	40%	35%	25%	24%	31%
Schematic Design Phase	20%	44%	36%	53%	40%
Design Development Phase	27%	15%	28%	18%	20%
Construction Documents Phase	7%	2%	6%	0%	3%
Preconstruction Phase	7%	4%	0%	0%	2%
Construction Administration Phase	0%	0%	0%	0%	0%
Postconstruction Operations Phase	0%	0%	3%	0%	1%
Other	0%	2%	3%	6%	2%

Figure 5-33. Comparison of optimal project phase for sustainable BIM applications and annual revenue.

According to Figure 5-34, similar to the other filters, the schematic design phase was viewed as the most optimal project phase to implement BIM. The Commercial, Residential, and Industrial categories had 20% of their respective sample sizes state that the design development phase was viewed as the optimal setting for BIM to be implemented. Additionally, the Heavy/Civil strongly believed that the schematic phase was the most optimal phase as nearly 86% of its sector respondents viewed it as the best phase to use BIM to enhance sustainable practices.

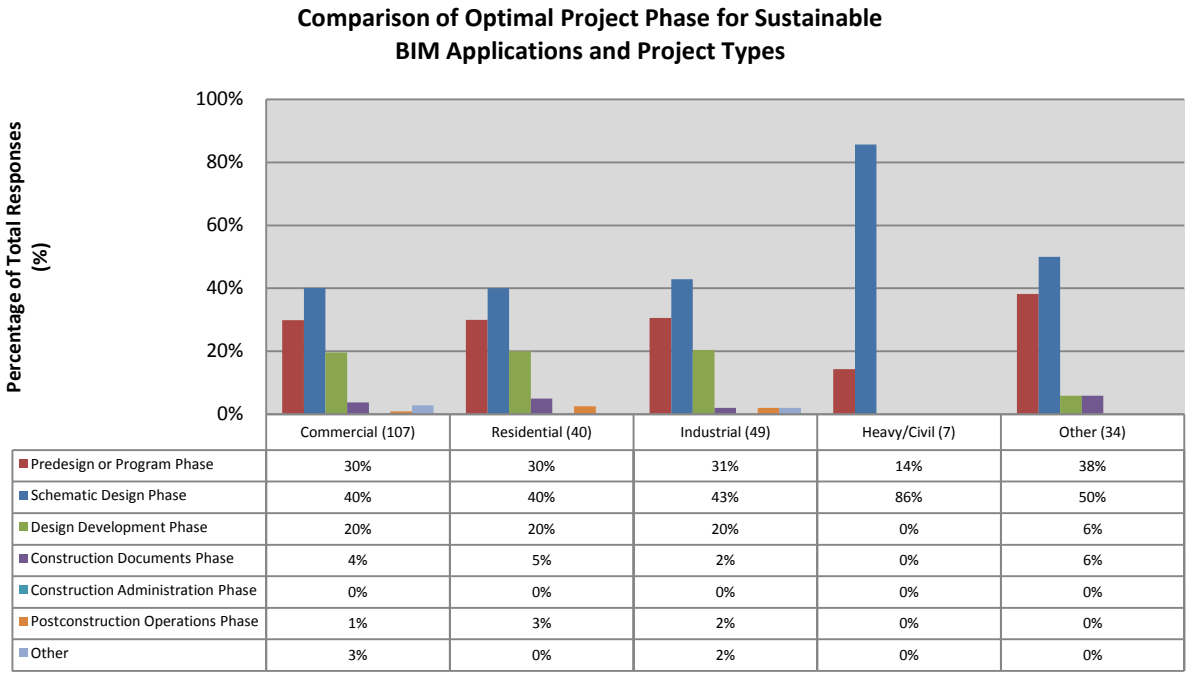
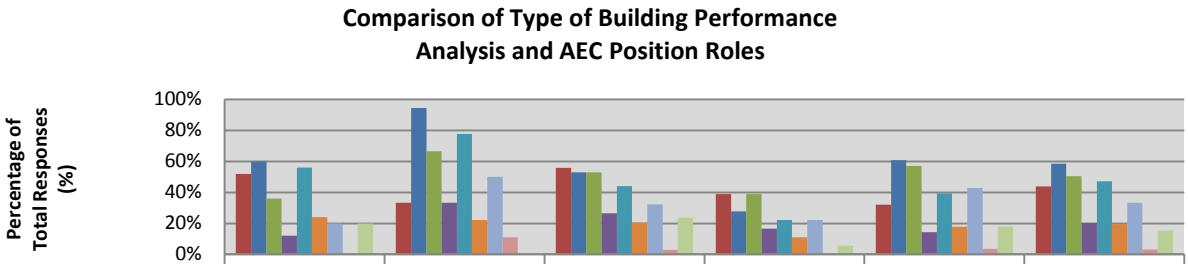


Figure 5-34. Comparison of optimal project phase for sustainable BIM applications and project types.

5.3.2 Question 5.2

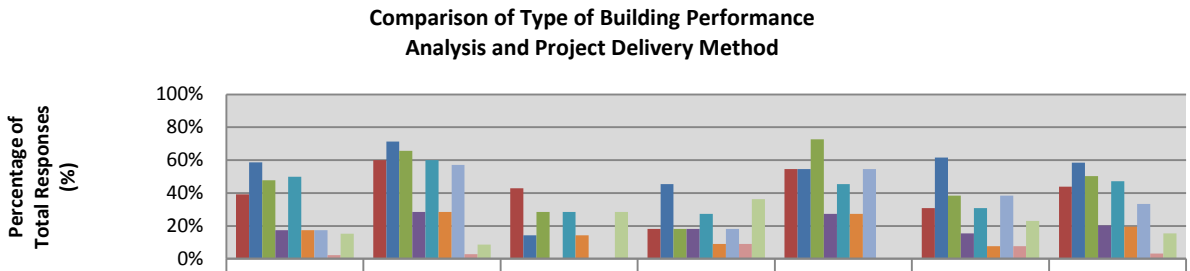
From the results found in Section 4.4.2, it was determined that of all the listed computer aided analysis energy analysis (59%); MEP analysis (50%); and, Lighting Analysis (47%) were the highest percentage utilized analyses. Figures 5-35 through 5-38 provide the information regarding the filtered results of the total population sampled. As shown in Figure 5-35, it was found that of the respondents that used Energy Analysis the majority came from the ARCH (60% of its sector respondents), ENG (94% of its sector respondents), GC (53% of its sector respondents), and 'Other' (61% of its sector respondents). Additionally, Lighting Analysis was performed by 56% of the ARCH's sampled and 78% of the ENG's sampled. Overall, the ENG sector provided more options in terms of its application of computer aided analysis than the remaining categories.



	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Structural Analysis	52%	33%	56%	39%	32%	44%
Energy Analysis	60%	94%	53%	28%	61%	59%
MEP Analysis	36%	67%	53%	39%	57%	50%
Building Function Analysis	12%	33%	26%	17%	14%	20%
Lighting Analysis/Simulation	56%	78%	44%	22%	39%	47%
Acoustic Analysis	24%	22%	21%	11%	18%	20%
Thermal/Air Control Analysis	20%	50%	32%	22%	43%	33%
Other, please specify	0%	11%	3%	0%	4%	3%
None	20%	0%	24%	6%	18%	15%

Figure 5-35. Comparison of building performance analysis and AEC position roles.

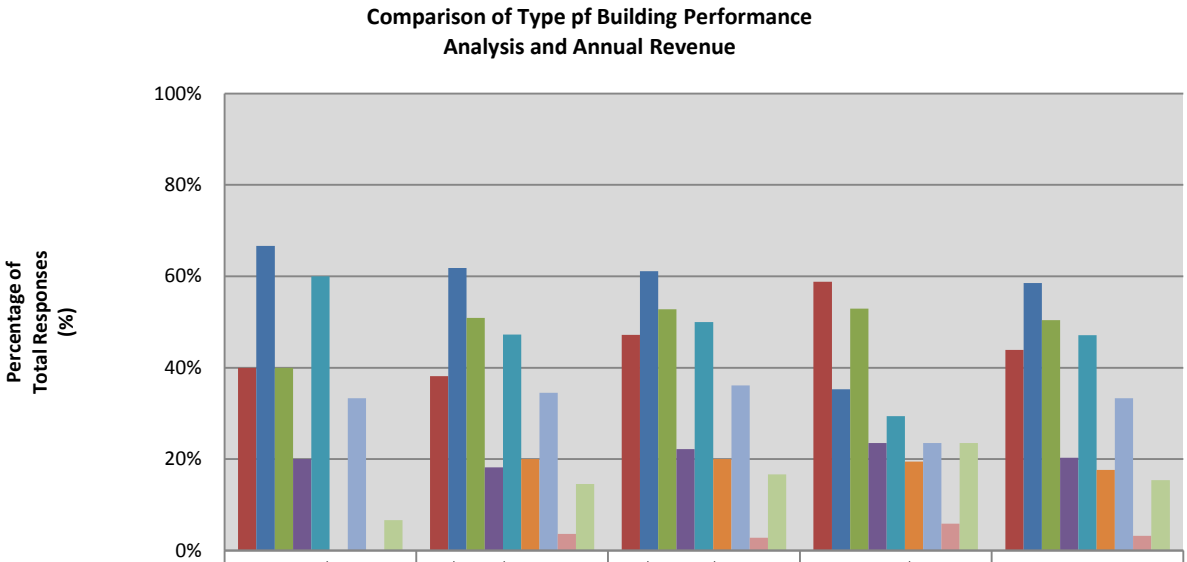
Through a comparison between project delivery method and forms of analysis, it was determined that DB and IPD were both the most effective delivery methods of including the majority of analyses in their practices (see Figure 5-36).



	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Structural Analysis	39%	60%	43%	18%	55%	31%	44%
Energy Analysis	59%	71%	14%	45%	55%	62%	59%
MEP Analysis	48%	66%	29%	18%	73%	38%	50%
Building Function Analysis	17%	29%	0%	18%	27%	15%	20%
Lighting Analysis/Simulation	50%	60%	29%	27%	45%	31%	47%
Acoustic Analysis	17%	29%	14%	9%	27%	8%	20%
Thermal/Air Control Analysis	17%	57%	0%	18%	55%	38%	33%
Other, please specify	2%	3%	0%	9%	0%	8%	3%
None	15%	9%	29%	36%	0%	23%	15%

Figure 5-36. Comparison of type of building performance analysis and project delivery method.

In terms of annual revenue, Figure 5-37 shows the relationship between the amount of annual revenue and the types of computer analysis listed in the survey. According to the results, the highest percentage of analysis performed was found within the '$1M to $100M' and '$100M $1B' categories. Interestingly, 24% of the sample size from the category 'More than $1B' did not perform any analysis within their practices. Again, the most commonly found analyses were Energy, MEP, and Light Simulations.

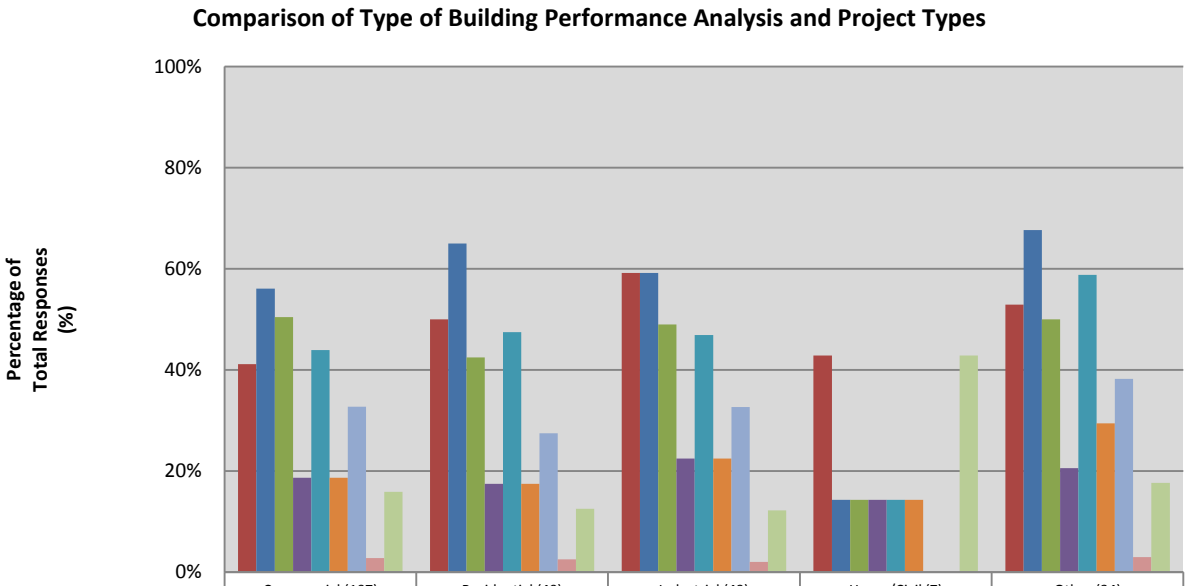


	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Structural Analysis	40%	38%	47%	59%	44%
Energy Analysis	67%	62%	61%	35%	59%
MEP Analysis	40%	51%	53%	53%	50%
Building Function Analysis	20%	18%	22%	24%	20%
Lighting Analysis/Simulation	60%	47%	50%	29%	47%
Acoustic Analysis	0.0	20%	20%	19%	18%
Thermal/Air Control Analysis	33%	35%	36%	24%	33%
Other, please specify	0%	4%	3%	6%	3%
None	7%	15%	17%	24%	15%

Figure 5-37. Comparison of type of building performance analysis and annual revenue.

Figure 5-38 shows the relationship between project type and the types of computer aided analysis. Similar to the previous results, Energy, MEP, and Lighting Simulation analysis were found as the most used within each project type. In addition,

Structural analysis was seen as another major form of analysis within each category, with the exception of Heavy/Civil. Heavy/Civil performed the least amount of analysis among all sectors, mainly due to its involvement in horizontal construction.



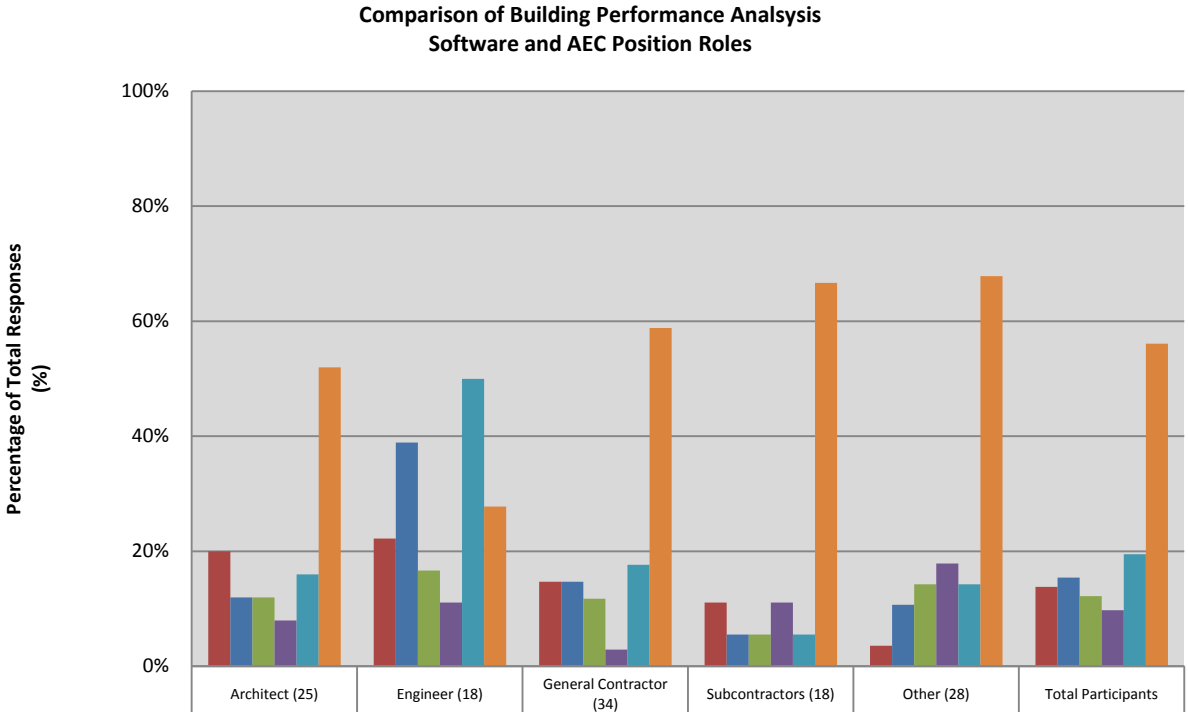
	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
Structural Analysis	41%	50%	59%	43%	53%
Energy Analysis	56%	65%	59%	14%	68%
MEP Analysis	50%	43%	49%	14%	50%
Building Function Analysis	19%	18%	22%	14%	21%
Lighting Analysis/Simulation	44%	48%	47%	14%	59%
Acoustic Analysis	19%	18%	22%	14%	29%
Thermal/Air Control Analysis	33%	28%	33%	0%	38%
Other, please specify	3%	3%	2%	0%	3%
None	16%	13%	12%	43%	18%

Figure 5-38. Comparison of type of building performance analysis and project types.

5.3.3 Question 5.3

From the results in Section 4.4.3, 56% of the respondents claimed that they did not utilize any form of software. Figures 5-39 through 5-42 detail the filtered results of the total population with the intent of understanding any trends found in the use of building performance analysis software. Figure 5-39 shows a comparison of position roles with the use of building performance analysis software, which according to the

results indicates that 52% of the ARCH respondents, 59% of the GC respondents, 67% of the SUB respondents, and 68% of the 'Other' respondents did not use any form of building performance analysis software. The ENG sector with 72% of its respondents having stated that they use building performance analysis software is seen as the sector that utilizes analysis software the most in their business practices. Additionally, the data indicated that of the building performance analysis software used by the ENG sector eQUEST is the most used at 39% of its respondents.

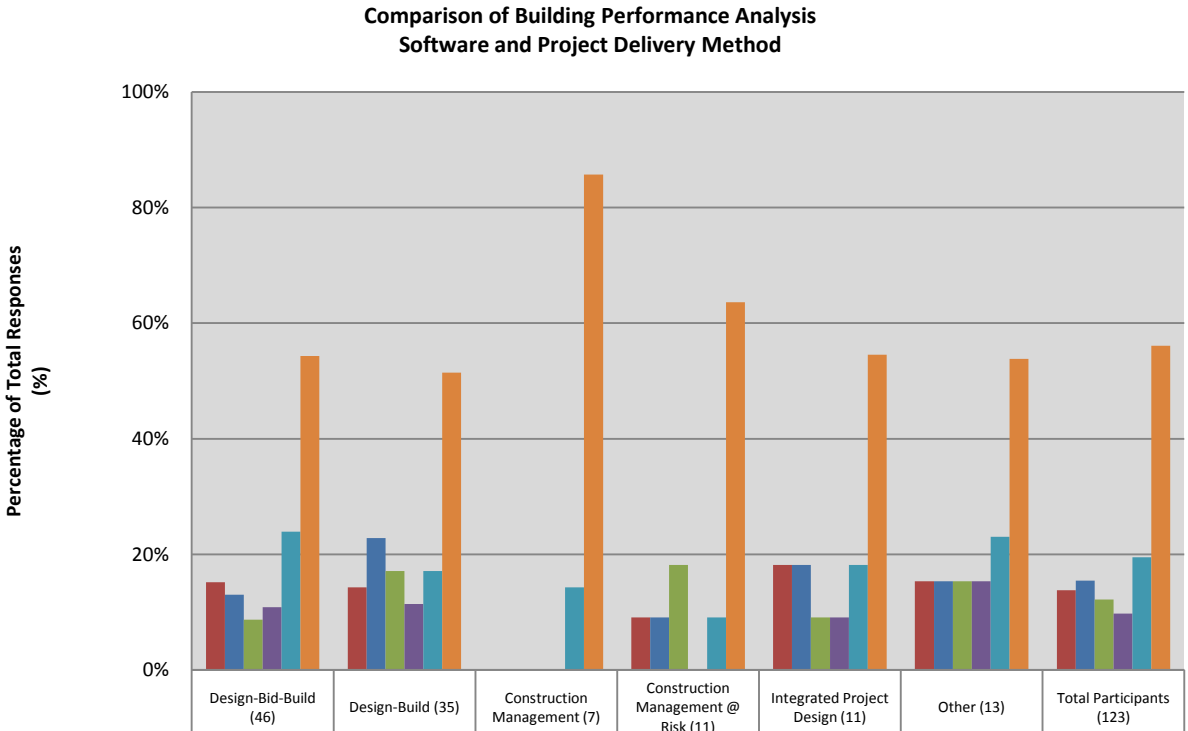


	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Ecotect	20%	22%	15%	11%	4%	14%
eQUEST	12%	39%	15%	6%	11%	15%
IES Virtual Environment	12%	17%	12%	6%	14%	12%
Green Building Studio	8%	11%	3%	11%	18%	10%
Other, please specify	16%	50%	18%	6%	14%	20%
None	52%	28%	59%	67%	68%	56%

Figure 5-39. Comparison of building performance analysis software and AEC position roles.

In terms of project delivery method, as shown in Figure 5-40 over 50% of all project delivery methods do not support any form of building performance analysis

software. It was determined that 18% of companies that use the IPD method utilized the following building performance analysis software: Ecotect, eQUEST, and 'Other.' The companies that use the DB method indicated that 23% used eQUEST and 14% used Ecotect. The companies that use CM and the CM-R methods had the highest percentage in terms of not using analysis software at 86% and 64%, respectively.

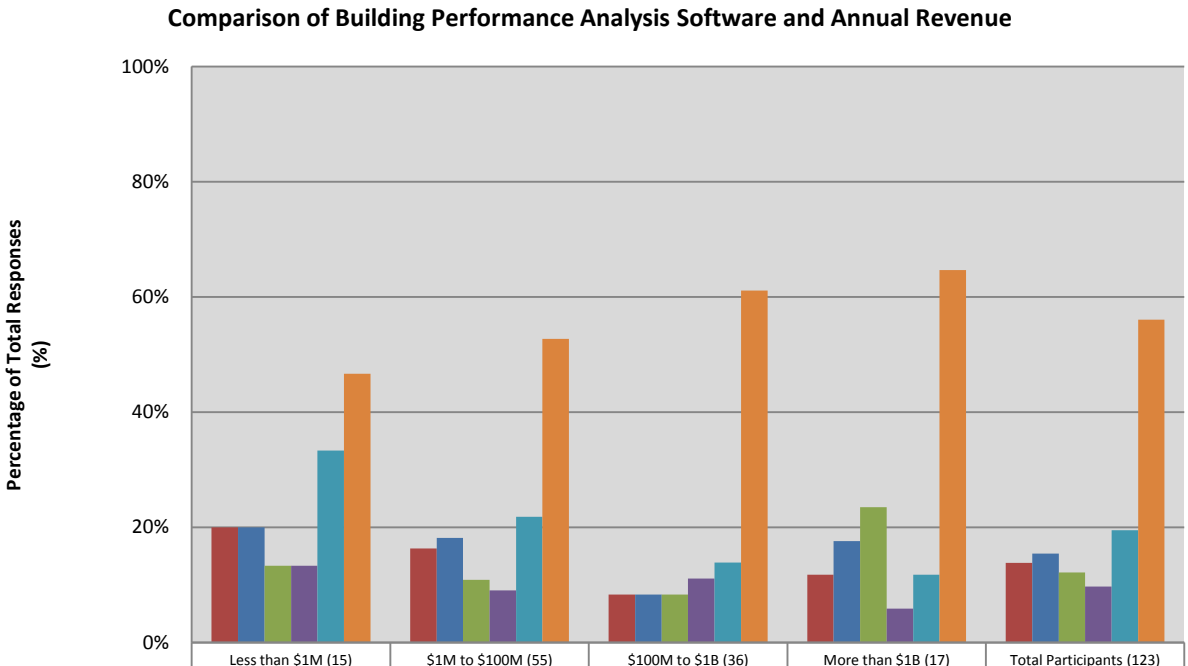


	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Ecotect	15%	14%	0%	9%	18%	15%	14%
eQUEST	13%	23%	0%	9%	18%	15%	15%
IES Virtual Environment	9%	17%	0%	18%	9%	15%	12%
Green Building Studio	11%	11%	0%	0%	9%	15%	10%
Other, please specify	24%	17%	14%	9%	18%	23%	20%
None	54%	51%	86%	64%	55%	54%	56%

Figure 5-40. Comparison of building performance analysis software and project delivery methods.

Figure 5-41 shows the results from the comparison of annual revenue and types of building performance analysis software. From the data it was determined that all but one category had over 50% of its respondents indicate that they did not utilize building

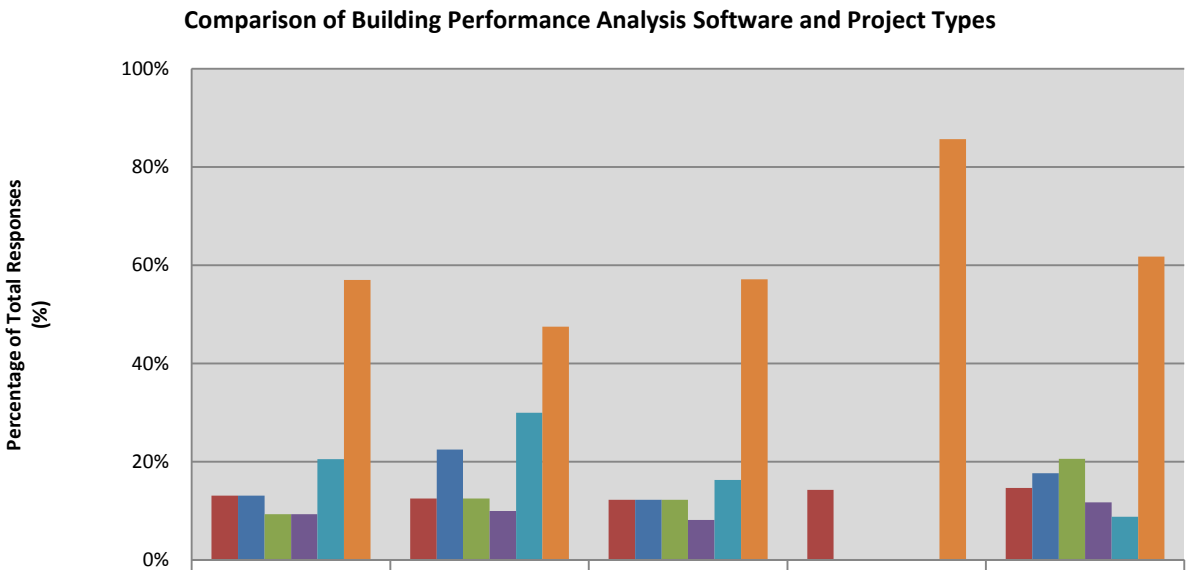
performance analysis software within their practices ('Less than $1M'). The companies with revenue 'Less than $1M' stated that 20% of its sample size used Ecotect and an additional 20% applied eQUEST within their practices.



	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Ecotect	20%	16%	8%	12%	14%
eQUEST	20%	18%	8%	18%	15%
IES Virtual Environment	13%	11%	8%	24%	12%
Green Building Studio	13%	9%	11%	6%	10%
Other	33%	22%	14%	12%	20%
None	47%	53%	61%	65%	56%

Figure 5-41. Comparison of building performance analysis software and annual revenue.

Figure 5-42 shows the result of the comparison between project type and building performance analysis software and indicates all but one project type had over 50% of its sample size state that they did not use any form of analytical software as part of their practices (Residential). The companies that perform Residential project types indicated that 23% of its sector respondents used eQUEST and 30% used 'Other' types of analysis software.



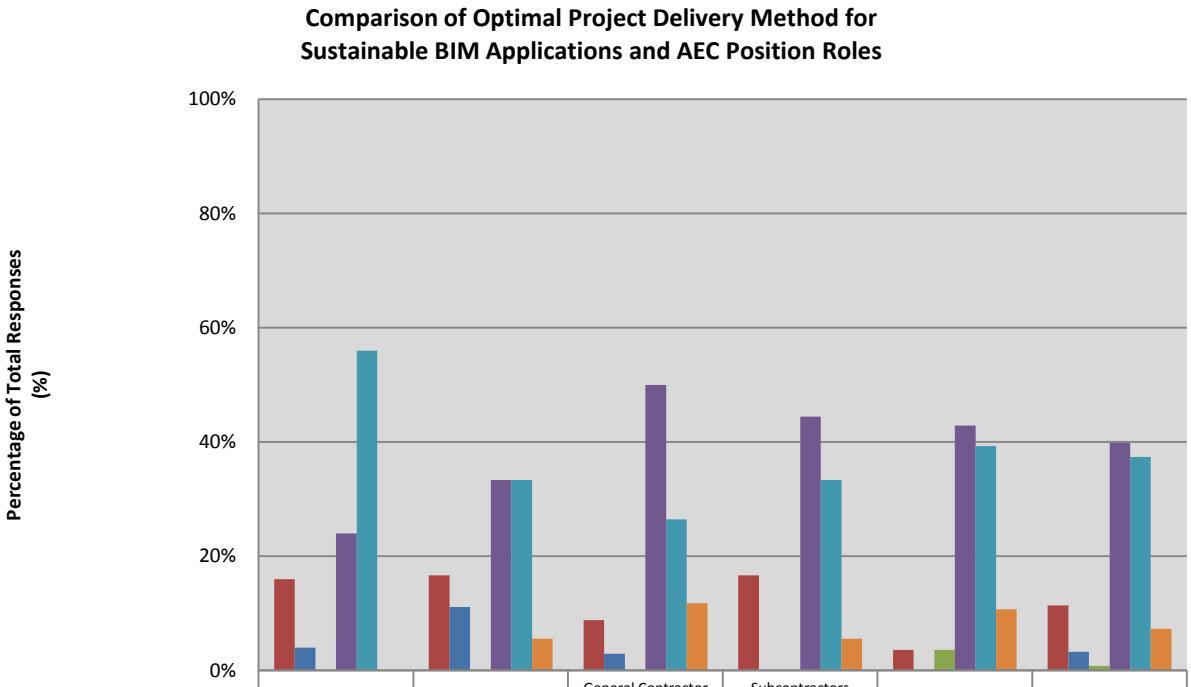
	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
Ecotect	13%	13%	12%	14%	15%
eQUEST	13%	23%	12%	0%	18%
IES Virtual Environment	9%	13%	12%	0%	21%
Green Building Studio	9%	10%	8%	0%	12%
Other	21%	30%	16%	0%	9%
None	57%	48%	57%	86%	62%

Figure 5-42. Comparison of building performance analysis software and project types.

5.3.4 Question 5.4

The results found in Section 4.4.5 indicated that the project delivery methods which provide the most optimal environment for the utilization of BIM software as a mechanism for sustainable design and construction practices was the DB (40%) or the IPD methods (37%). Figures 5-43 through 5-46 show the results of the filtered population sample in order to provide further analysis on BIM applications toward sustainable design and/or construction practices. Figure 5-43 provides a comparison between the optimal project delivery methods for sustainable BIM applications versus AEC industry roles. According to the results, all of the AEC sectors indicated that the companies that use the DB and IPD methods were the most likely to provide for sustainable BIM applications. Additionally, the data showed that 56% of the ARCH

sample population claimed that IDP was the optimal project delivery method, with DB second at 24%. The remaining sectors within this category indicated that either the DB or IPD were the best suited for BIM and sustainability.

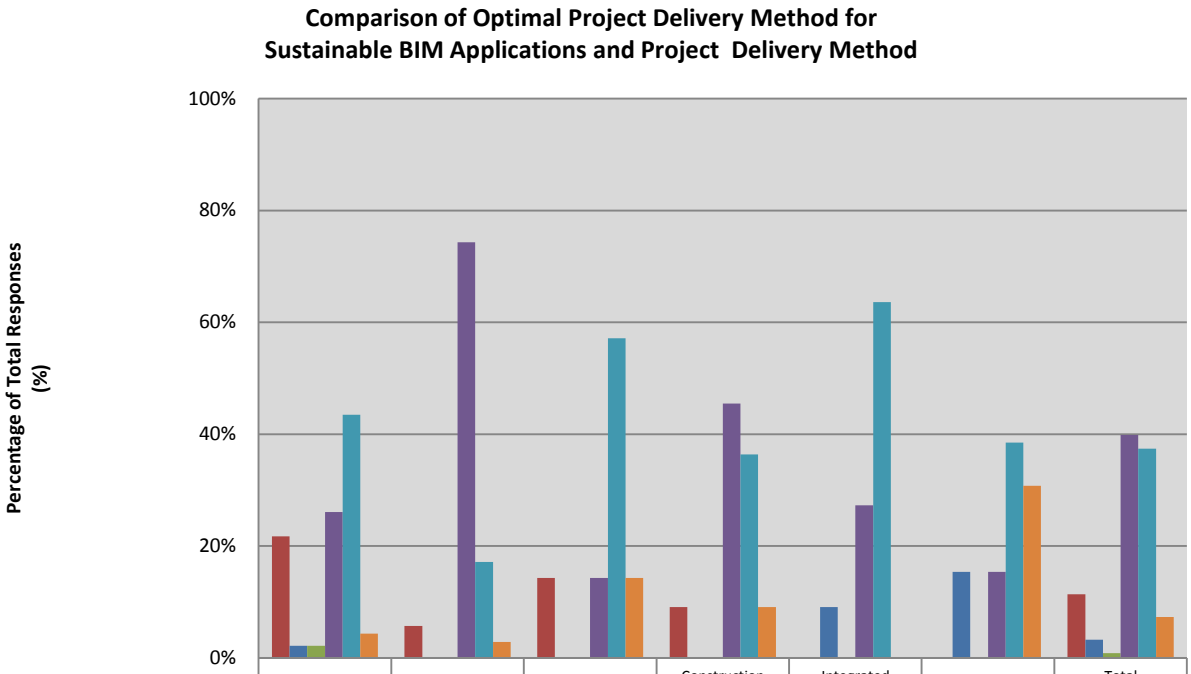


	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Design-Bid-Build (DBB)	16%	17%	9%	17%	4%	11%
Construction Management (CM)	4%	11%	3%	0%	0%	3%
Construction Management at Risk	0%	0%	0%	0%	4%	1%
Design-Build (DB)	24%	33%	50%	44%	43%	40%
Integrated Project Delivery (IPD)	56%	33%	26%	33%	39%	37%
Other	0%	6%	12%	6%	11%	7%

Figure 5-43. Comparison of optimal project delivery method for sustainable BIM applications and AEC position roles.

Figure 5-44 shows the comparison between respondent's current project delivery method and the most optimal project delivery method for sustainable BIM applications. The results show that of all the companies those that use the DB and IPD project delivery methods were the most likely to use sustainable BIM applications. The project delivery methods DBD (43%), CM (57%), IPD (64%), and 'Other' (38%) indicated that

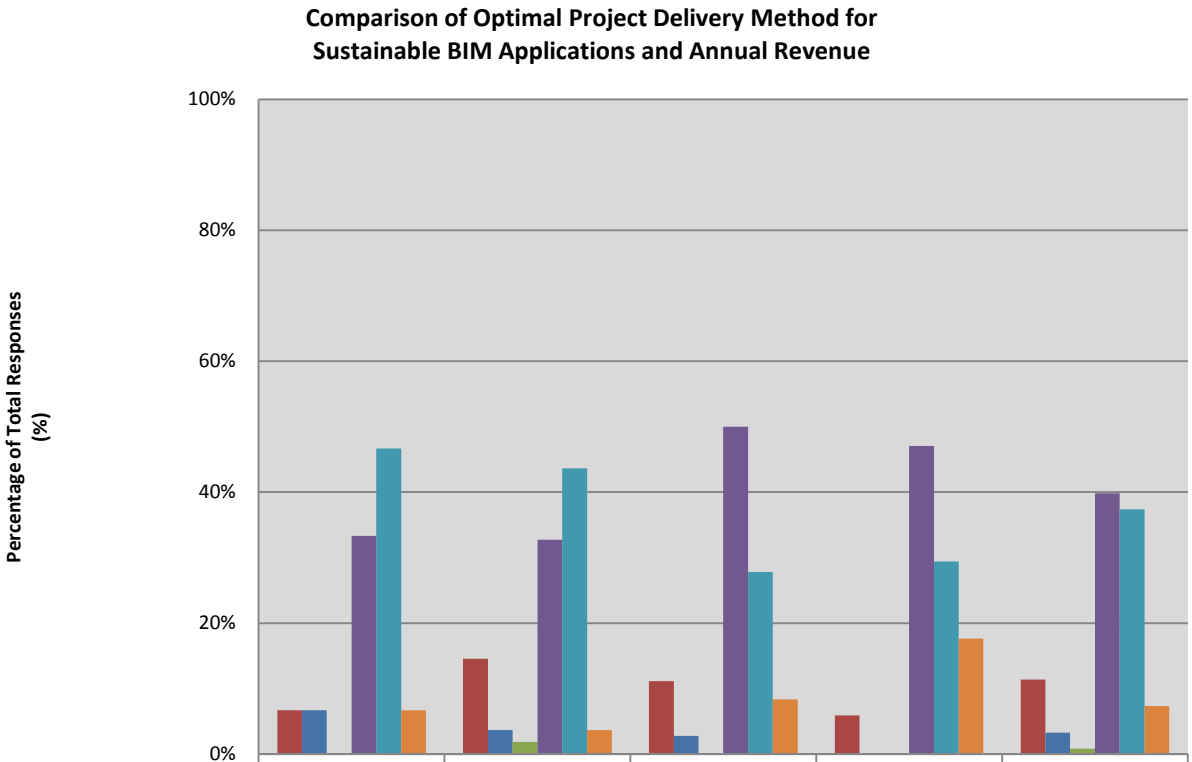
the IPD method was the optimal method to incorporate BIM with sustainability, while DB (74%) and CM-R (45%) indicated that DB was the best method.



	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Design-Bid-Build (DBB)	22%	6%	14%	9%	0%	0%	11%
Construction Management (CM)	2%	0%	0%	0%	9%	15%	3%
Construction Management at Risk	2%	0%	0%	0%	0%	0%	1%
Design-Build (DB)	26%	74%	14%	45%	27%	15%	40%
Integrated Project Delivery (IPD)	43%	17%	57%	36%	64%	38%	37%
Other	4%	3%	14%	9%	0%	31%	7%

Figure 5-44. Comparison of optimal project phase for sustainable BIM applications and project delivery methods.

Figure 5-45 shows the comparison between annual revenue and project delivery methods. According to the results, DB and IPD were found to be the optimal choices for BIM use among all categories. About 47% of the companies with revenue 'Less than $1M' stated that IPD was the optimal method to implement BIM to enhance sustainable practices, while nearly 47% of the companies with revenue 'More than $1B' held that DB was the optimal project delivery method.



	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Design-Bid-Build (DBB)	7%	15%	11%	6%	11%
Construction Management (CM)	7%	4%	3%	0%	3%
Construction Management at Risk	0%	2%	0%	0%	1%
Design-Build (DB)	33%	33%	50%	47%	40%
Integrated Project Delivery (IPD)	47%	44%	28%	29%	37%
Other	7%	4%	8%	18%	7%

Figure 5-45. Comparison of optimal project delivery method for sustainable BIM applications and annual revenue.

Figure 5-46 is based on an analysis of project types and the optimal project delivery methods utilized and shows that within every category DB and IPD was selected as the most optimal method used in order to provide for sustainable BIM applications. Nearly 40% of the companies that perform Residential projects stated that IPD was most optimal while 39% of the companies that perform Commercial projects and 47% of the companies that perform Industrial projects indicated that DB was the best suited for BIM and sustainability.

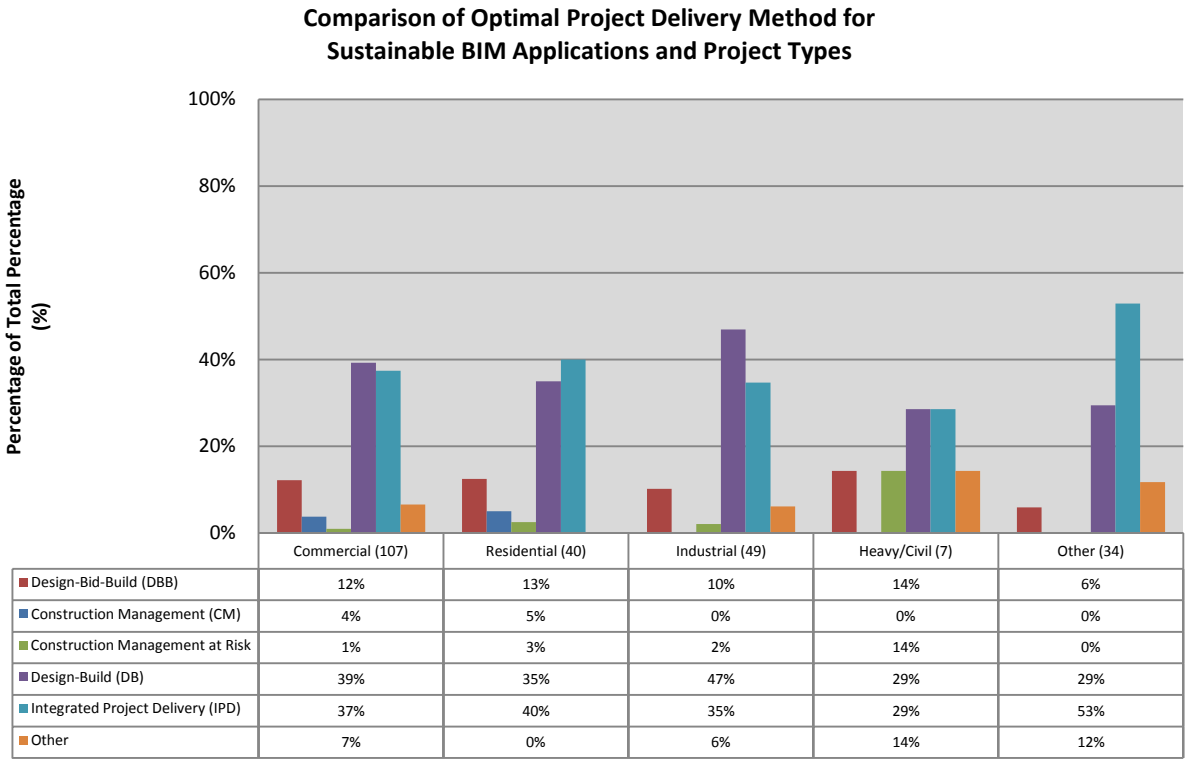


Figure 5-46. Comparison of optimal project delivery method for sustainable BIM applications and project types.

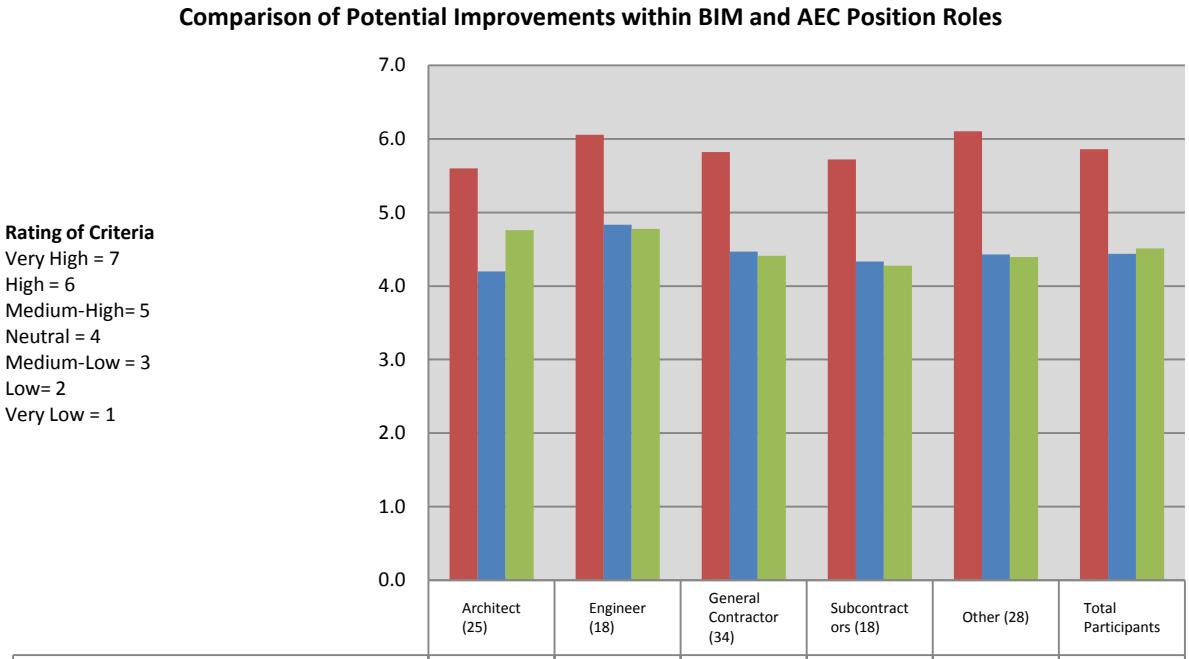
5.3.5 Question 5.5

From the results found in Section 4.4.5, the calculated responses provided a measure for understanding the AEC industry viewpoints on potential improvements and innovations with BIM features. From the information provided a ranking system was generated from the total respondents in descending order from very high importance (rating of 7) to very low importance (rating of 1). The rankings are as follows:

1) Improvements within interoperability between software packages (5.86).
2) Interactivity of weather data (5.65),
3) Integration of a carbon accounting tracker (4.44).

Figures 5-47 through 5-50 were created as a means to analyze the filtered data to AEC viewpoints on potential improvements within BIM features. Figure 5-47 shows the

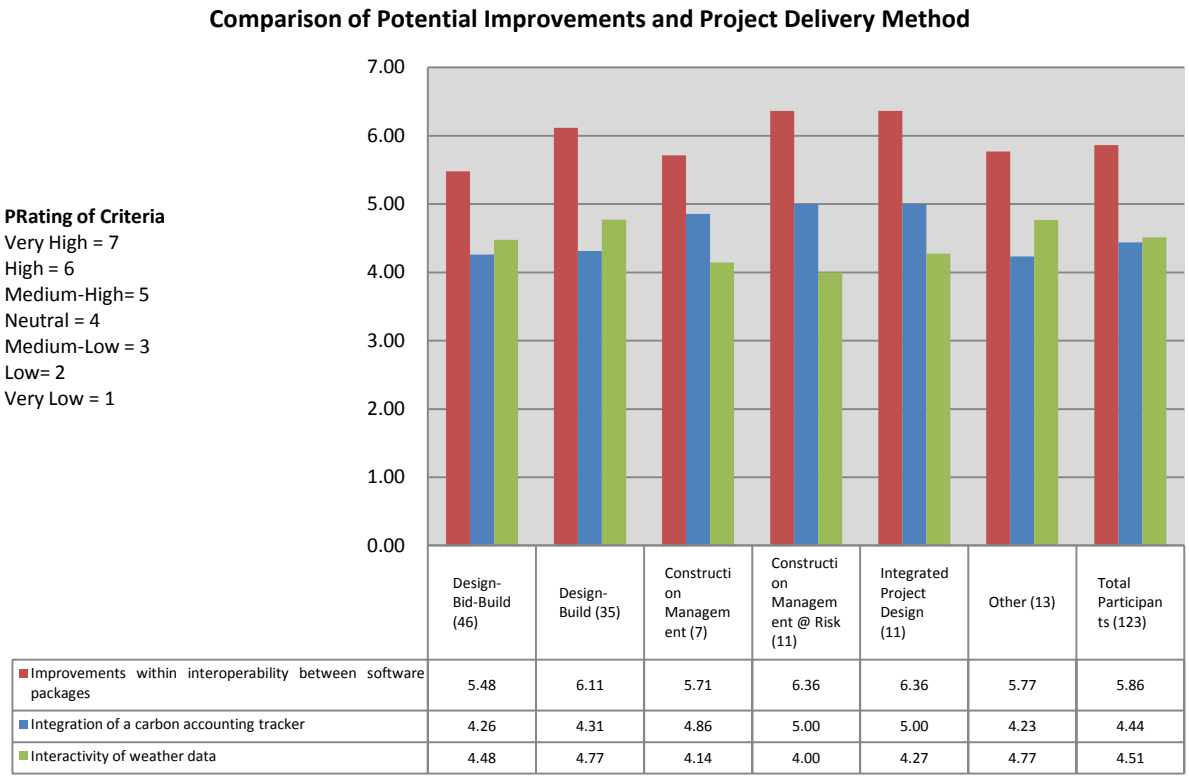
comparison between the individual AEC sectors and proposed improvements or innovations with BIM features. Based on the data, the ARCH, GC, and SUB sectors assigned lower ratings (i.e. a lower level of importance) than the median rating series of the entire population for the majority of the listed items, therefore the improvements within BIM were viewed as less important than average. The ENG sector assigned higher ratings in comparison with the average rating, and were thus of greater importance, whereas the 'Other' sector remained equivalent to the total sample population. However, it is worth mentioning that although the ratings within each sector varied slightly, every sector agreed with each of the statements on the importance of improving BIM within the given criteria, particularly with "improvements within interoperability between software packages."



	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Improvements within interoperability between software packages	5.6	6.1	5.8	5.7	6.1	5.9
Integration of a carbon accounting tracker	4.2	4.8	4.5	4.3	4.4	4.4
Interactivity of weather data	4.8	4.8	4.4	4.3	4.4	4.5

Figure 5-47. Comparison of potential improvements within BIM and AEC position roles.

Figure 5-48 shows the relationship between the proposed improvements within BIM and the various delivery methods. According to the results, the DB and IPD methods assigned higher ratings than the average rating series across the board, therefore the improvements within BIM were viewed as more important for these sectors than the average. Conversely, the DBD method assigned lower ratings than the average rating, and thus the proposed improvements were seen as of lower importance.



	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Improvements within interoperability between software packages	5.48	6.11	5.71	6.36	6.36	5.77	5.86
Integration of a carbon accounting tracker	4.26	4.31	4.86	5.00	5.00	4.23	4.44
Interactivity of weather data	4.48	4.77	4.14	4.00	4.27	4.77	4.51

Figure 5-48. Comparison of potential improvements within BIM and project delivery methods.

Figure 5-49 shows the relationships between the targeted subjects based on annual revenue. According to the responses, companies with revenue 'Less than $1M' assigned higher ratings than the average of the total sample population, and thus viewed the improvements with BIM more important than average. The companies with revenue '$1M to $100M' and 'More than $1B' assigned higher ratings than the average,

with the exception of “improvements within interoperability.” Conversely, the category ‘$100M to $1B’ assigned lower ratings than the average, therefore viewed the features as less important, with the exception of “improvements within interoperability.”

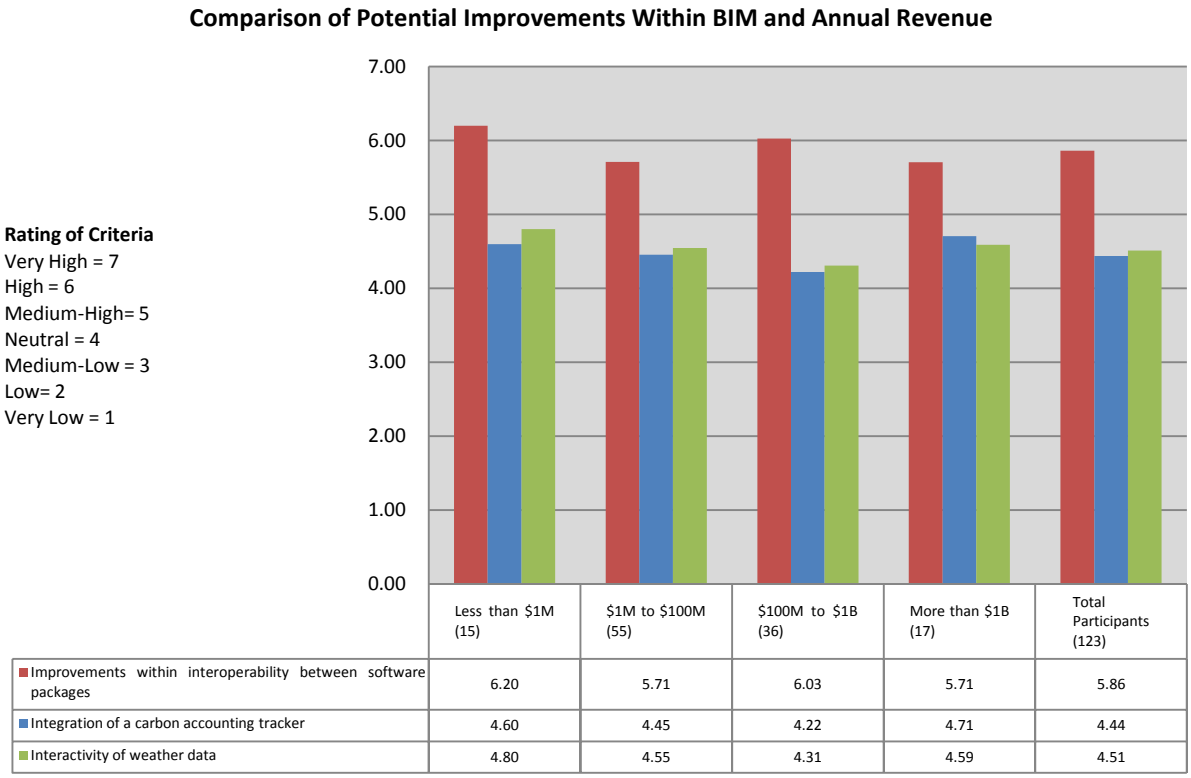


Figure 5-49. Comparison of potential improvements within BIM and annual revenue.

Figure 5-50, displays the data resulting from a filter of the total respondents in comparison with project types. According to the results, both the Commercial and Residential categories assigned higher ratings than the average of the total population, with the exception of “interactivity of weather data.” The Industrial category assigned lower ratings than the median, with respect to all statements. Heavy/Civil underwent a similar trend, however, it attained a higher rating in regards to the statement, “integration of carbon accounting tracker.

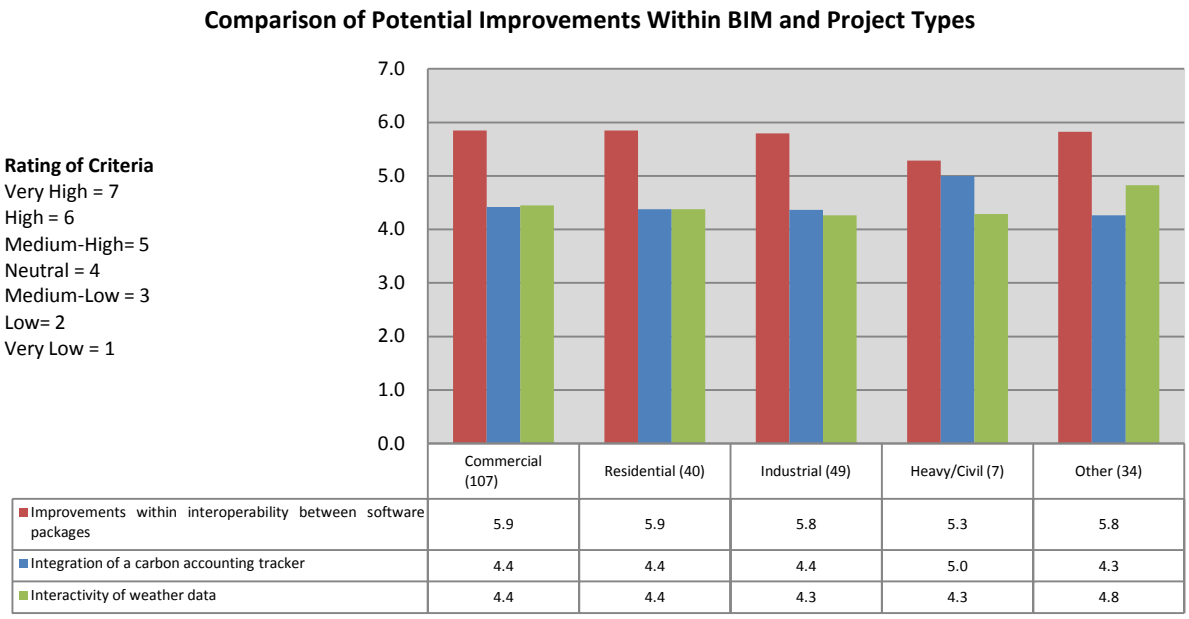


Figure 5-50. Comparison of potential improvements within BIM and project types

5.3.6 Question 5.6

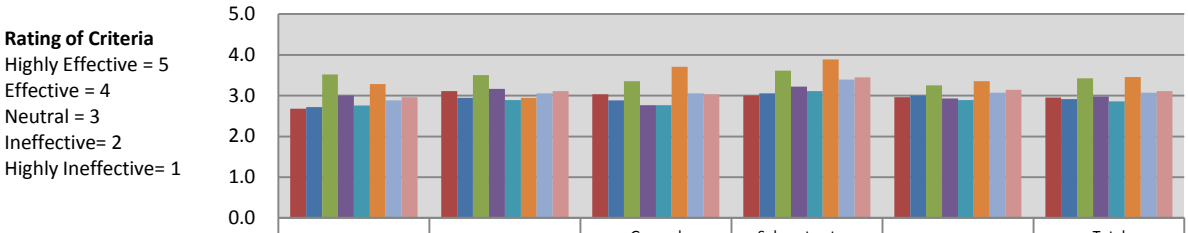
The results in Section 4.4.5 provided a measure for understanding AEC industry viewpoints on the effectiveness of BIM in its application to provide sustainable guidelines. From the given information a ranking system was generated from the total sample population in descending order from highly effective (rating of 5) to highly ineffective (rating of 1). The rankings are as follows:

1) Incorporated project management (3.46).
2) Energy efficiency (3.42).
3) Post-construction facility operations (3.11).
4) Building commissioning (3.07).
5) Use of sustainable materials (2.98).
6) Sustainable site development (2.95).
7) Water efficiency (2.91).
8) Indoor air quality (2.86).

Figures 5-51 through 5-54 were generated as a means to understand the correlations between BIM and its impact on sustainability through analysis of the four characteristics

defined by the scope of this investigation. Figure 5-51 compares the use of BIM as a mechanism for sustainable practices and AEC position roles. According to the data, the ARCH sector assigned lower ratings with respect to all features listed (i.e. lower level of effectiveness) than the average of the total population, with the exception of "energy efficiency," therefore they viewed BIM as less effective in achieving the sustainable guidelines. The SUB sector attained higher ratings when compared to the average within all features listed, and viewed BIM as more effective than average in enhancing the sustainable guidelines. The GC and 'Other' sectors were found to have lower ratings overall than the average. Additionally, the ENG sector was found to have either equivalent or higher ratings in comparison with the average, with the exception of "project management."

Comparison of BIM as a Mechanism for Sustainable Practices and AEC Position Roles

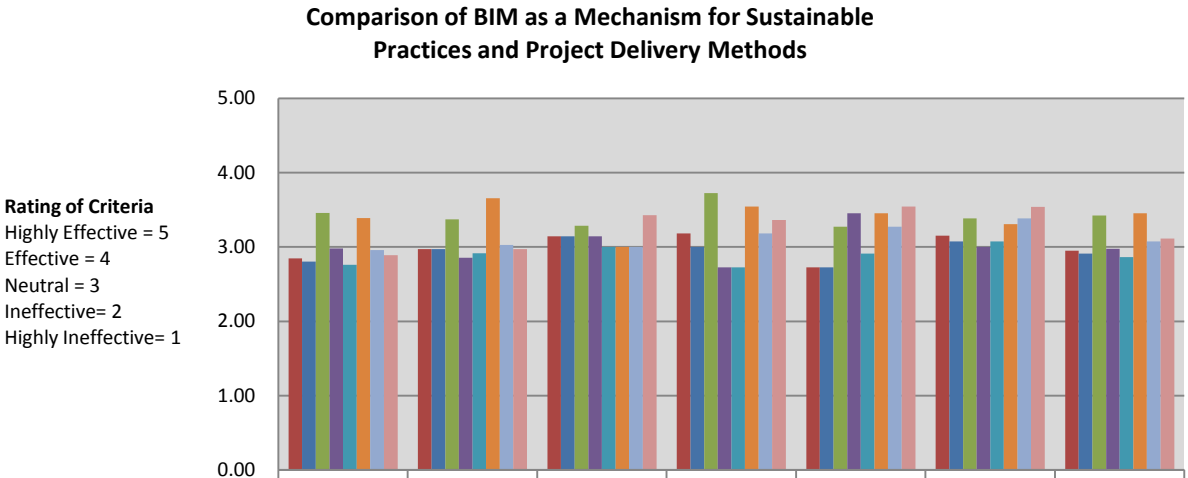


	Architect (25)	Engineer (18)	General Contractor (34)	Subcontractors (18)	Other (28)	Total Participants
Sustainable Site Development	2.7	3.1	3.0	3.0	3.0	3.0
Water Efficiency	2.7	2.9	2.9	3.1	3.0	2.9
Energy Efficiency	3.5	3.5	3.4	3.6	3.3	3.4
Sustainable Materials	3.0	3.2	2.8	3.2	2.9	3.0
Indoor Air Quality	2.8	2.9	2.8	3.1	2.9	2.9
Project Management	3.3	2.9	3.7	3.9	3.4	3.5
Building Commissioning	2.9	3.1	3.1	3.4	3.1	3.1
Post Construction Facility Operations	3.0	3.1	3.0	3.4	3.1	3.1

Figure 5-51. Comparison of BIM as a mechanism for sustainable practices and AEC position roles.

In comparison with project delivery methods, Figure 5-52 indicates that DBD attained lower ratings within all features listed in relation to the average rating, with the

exception of “energy efficiency,” thus viewing BIM as less effective tool in providing sustainable guidelines. CM-R was found to have assigned higher ratings than the average rating, with the exceptions of “sustainable materials” and “indoor air quality.” DB, CM, and IPD each assigned higher and lower ratings than the median of the total population surveyed.

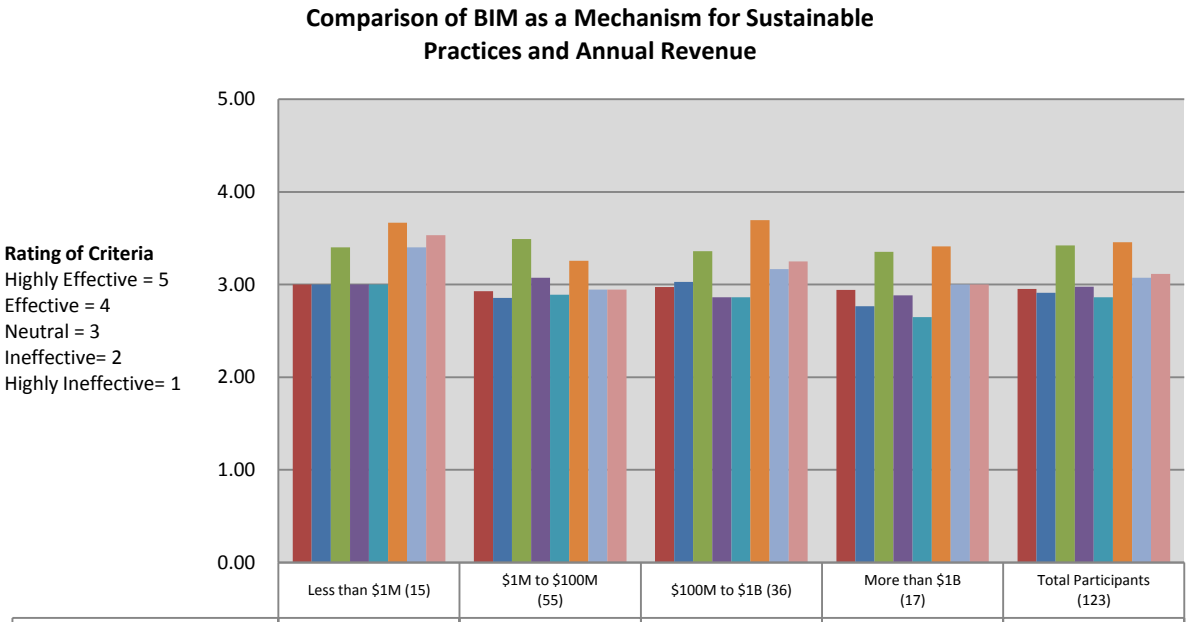


	Design-Bid-Build (46)	Design-Build (35)	Construction Management (7)	Construction Management @ Risk (11)	Integrated Project Design (11)	Other (13)	Total Participants (123)
Sustainable Site Development	2.85	2.97	3.14	3.18	2.73	3.15	2.95
Water Efficiency	2.80	2.97	3.14	3.00	2.73	3.08	2.91
Energy Efficiency	3.46	3.37	3.29	3.73	3.27	3.38	3.42
Sustainable Materials	2.98	2.86	3.14	2.73	3.45	3.00	2.98
Indoor Air Quality	2.76	2.91	3.00	2.73	2.91	3.08	2.86
Project Management	3.39	3.66	3.00	3.55	3.45	3.31	3.46
Building Commissioning	2.96	3.03	3.00	3.18	3.27	3.38	3.07
Post Construction Facility Operations	2.89	2.97	3.43	3.36	3.55	3.54	3.11

Figure 5-52. Comparison of BIM as a mechanism for sustainable practices and project delivery methods.

Through analysis of annual revenue and BIM’s application towards sustainability, it was found that the companies with revenue of ‘More than $1B’ assigned lower ratings than the average rating by all respondents, with respect to all the features listed (see Figure 5-53). Conversely, the companies with revenue of ‘Less than $1M’ attained higher ratings in all features than the average ratings, with the exception of “energy

efficiency." The remaining categories each had higher and lower ratings than the average, however the ratings scores remained near the average, therefore little deviation was found from the norm.

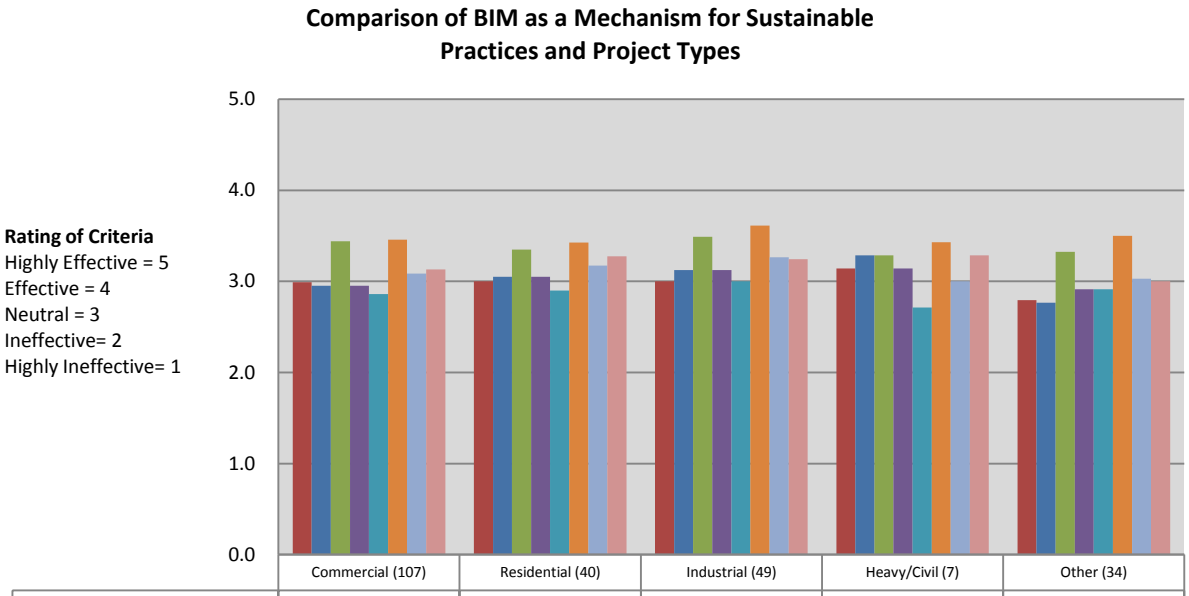


	Less than $1M (15)	$1M to $100M (55)	$100M to $1B (36)	More than $1B (17)	Total Participants (123)
Sustainable Site Development	3.00	2.93	2.97	2.94	2.95
Water Efficiency	3.00	2.85	3.03	2.76	2.91
Energy Efficiency	3.40	3.49	3.36	3.35	3.42
Sustainable Materials	3.00	3.07	2.86	2.88	2.98
Indoor Air Quality	3.00	2.89	2.86	2.65	2.86
Project Management	3.67	3.25	3.69	3.41	3.46
Building Commissioning	3.40	2.95	3.17	3.00	3.07
Post Construction Facility Operations	3.53	2.95	3.25	3.00	3.11

Figure 5-53. Comparison of BIM as a mechanism for sustainable practices and annual revenue

Figure 5-54 provides a comparison between project types and BIM's application to sustainable practices. According to the tabulated data, the Industrial sector assigned higher ratings than the average rating of all the respondents with respect to all the features listed. Conversely, the 'Other' sector attained lower ratings in comparison to the average rating, with the exception of "indoor air quality" and "project management." In addition, the Commercial and Residential sectors each received higher ratings than

the median rating in regards to every feature listed, with the exception of "energy efficiency." Heavy/Civil attained both higher and lower ratings compared to the average with regard to the features listed.



	Commercial (107)	Residential (40)	Industrial (49)	Heavy/Civil (7)	Other (34)
Sustainable Site Development	3.0	3.0	3.0	3.1	2.8
Water Efficiency	3.0	3.1	3.1	3.3	2.8
Energy Efficiency	3.4	3.4	3.5	3.3	3.3
Sustainable Materials	3.0	3.1	3.1	3.1	2.9
Indoor Air Quality	2.9	2.9	3.0	2.7	2.9
Project Management	3.5	3.4	3.6	3.4	3.5
Building Commissioning	3.1	3.2	3.3	3.0	3.0
Post Construction Facility Operations	3.1	3.3	3.2	3.3	3.0

Figure 5-54. Comparison of BIM as a mechanism for sustainable practices and project types.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

The following sections presents the conclusions of this investigation derived from the literature review and survey analysis found in Chapters 2 through 5.

6.1 Conclusions

The utilization of BIM as a catalyst for sustainable design and construction practices is a new development within the AEC industry. Currently, the majority of the AEC industry is utilizing BIM in some form or another due to its ability to support collaborative and distributed work processes as it facilitates project delivery. Although most of the AEC industry seems to believe that BIM is a necessity within project delivery, there are remaining characteristics that determine whether BIM is a viable solution to all project processes, in particular sustainable design. Although the majority of the AEC industry believes that sustainable design and construction practices are of importance within their company's structure, most still believe that it is not a primary application for BIM, that, instead project coordination and visualization are most important.

As the AEC industry has just recently started to implement BIM into their practices (i.e. between 1 to 5 years), it seems that owners are not aware of the capabilities BIM provides to a project, despite the owners having a great deal of influence on the practices of a company, as seen with their influence on demanding green building certification for their project. Therefore, as owners become more aware of the potential benefits provided from BIM, the AEC industry will begin to utilize BIM regularly as a standard process. Just as many municipalities have started requiring green building

certification for projects as standard protocol, the requirement of using BIM on all built projects seems to be a reality in the near future.

As new emergent technologies infiltrate the AEC industry, the application of BIM and auxiliary programs will gradually increase within company practices. This includes the application of environmental analysis software, which currently is not utilized to its fullest capacity. Additionally, due to the relative high costs of obtaining licenses for BIM software, many companies within the AEC industry view it as not cost-effective. Therefore, larger companies are found to use BIM more effectively in their business practices compared to smaller ones. However, as software developers continue to market products at lower costs BIM and supporting software will see increased usage.

With BIM seen as a multidisciplinary tool, problems with interoperability continue to persist among the various sectors of the industry. This includes improving interoperability between BIM platforms and other auxiliary analysis applications like building performance analytical programs. Yet, similar in nature to BIM becoming cost-effective, attempts are being made by software providers to integrate applications within BIM. Therefore, the future of BIM's use within the industry will continue to grow at a gradual pace. This includes utilizing BIM as a mechanism for sustainable design and construction practices.

In terms of project delivery, the majority believe that the move towards Design-Build and Integrated Project Delivery is the optimal method to provide for BIM as a sustainability tool. Because of the internal structure behind the two delivery methods, the transition towards the application of BIM within company practices seems more readily available, whereas, other delivery methods are more segregated and primarily

demand external forms of communication. Thus, as the industry becomes more united and emphasizes the need for collaborative work processes, the use of BIM as a facilitator among sectors will prevail as an essential element.

6.2 Results to Investigation Objectives

As indicated throughout the research, the targeted purpose for this analysis was to understand trends within BIM and sustainability, both as dependent and independent entities within design and construction. The following objectives were used to evaluate any meaningful data derived through the literature review and survey (Chapters 2 through 5): 1) to analyze the current trends and future developments with BIM and sustainable practices within the AEC industry; 2) to assess how BIM is being used as a mechanism for sustainable practices; 3) to understand how BIM is being used today in order to analyze the building performance of a built project; 4) to determine what difficulties with interoperability are seen as potential problems with BIM software, and; 5) to determine what stage in development is BIM thought of as a useful tool in providing sustainable design and/or construction practices.

6.2.1 Objective 1

In identifying certain elements within the AEC industry, understanding the importance of BIM and sustainability were vital in comprehending the nature of the industry as a whole. Though BIM is currently on its way towards becoming a standard within the AEC industry, it is still not utilized to its fullest capacity. At the same time, sustainability is continuing its progression towards standardization in the industry, yet it is not being pursued at optimal levels. As the advancements of technologies continue

to enter the industry, BIM will be an essential element in driving the design and construction practices with respect to sustainability.

6.2.2 Objective 2

Currently, BIM is sought after primarily for its project coordination and visualization capabilities. Although certain available BIM software provides access to allow the user to perform environmental analysis, because it is not specifically internalized within BIM software platforms the majority of the industry does not utilize its capabilities. Thus, auxiliary building performance applications are not seen as tools to drive sustainable practices. Additionally, although not utilized optimally, the industry does view that BIM provides sufficient capabilities for energy, structural, and lighting analysis.

6.2.3 Objective 3

Currently, environmental software is available for users to analyze building efficiencies in the AEC industry however it is not used to its fullest capacity. Platforms such as Ecotect and IES Virtual Environment provide extensive tools to analyze BIM models; however, due to issues with interoperability and the relative cost of the software, companies are not implementing the use of environmental software as part of their company's practices.

6.2.4 Objective 4

The main difficulties seen with interoperability are found with its inability to prevent data loss in translation from software to software. Though recent versions of current BIM software market their products as interoperable through the use of IFC, XML, or similar universal file extensions, the industry indicates that it remains an impediment to the work process. Future BIM software platforms will allow for better interoperability

with the elimination of multiple file formats from single vendors; however, the current status indicates that it does allow for seamless transfer of data.

6.2.5 Objective 5

As viewed by the AEC industry the optimal phase to implement the use of BIM as a tool for providing sustainable measures was determined to be the early schematic or program planning phase. Mainly due to its impact within design decisions, BIM's influence on project planning and coordination allows for greater control than if implemented at later stages during the duration of the project. This in turn allows for direct correlation to sustainable design strategies (e.g. building orientation, solar studies, passive design).

6.3 Improvements to the Survey

The following are improvements that need to be made to further enhance the quality of the survey as well as provide more accurate analysis of the results:

- As this research was intended to assess the AEC industry as a whole, narrowing the targeted audience would have provided more accurate results. Conducting the survey based solely on a particular company role (e.g. architect, engineer, contractor) within the AEC industry would have provided better results.
- When assessing the project type (Q2.1) to the survey questionnaire as part of the sample stratifying method, the results heavily favored the category Commercial due to the nature of the question being multiple-answer. Instead of having the question phrased as a multi-answer response, the question could have been phrased such that the participants select its primary and secondary project type.
- Although the questions as part of the sustainability section of the survey were intended to return information regarding sustainable practices, there should have been more questions regarding LEED or other green building assessment rating systems in order to ascertain relevant data regarding BIM's direct impact on green building rating systems.
- In response to the results of the Likert Scale questions, a forced opinion (i.e. even numbered scale) should have been used instead, as the majority of the

responses hovered around the neutral category, not providing relevant information to evaluate results from.

6.4 Recommendations for Future Research

Future researchers interested in this topic of study should attempt to analyze the owner/proprietor sector of the building industry. As the topic of research is relatively new to the field of design and construction, it would be worth investing time to analyze how often the owner is involved with BIM in relation to sustainable construction, as the owner has direct influence on a project's sustainable design and construction practices. Although this research analyzed various green building assessment systems to understand the sustainable measures used within the industry, further analysis based on BIM's direct correlation to such systems might provide intriguing results.

As the industry has begun to implement BIM and sustainable techniques simultaneously, research investigating academic institutions in regards to software applications used in education and interests in sustainability would provide feedback regarding the future of BIM within the industry. Additionally, education within the industry itself provides for an additional topic of study worth approaching.

APPENDIX A
IRB SURVEY PROPOSAL SUBMITTAL

UFIRB 02 – Social & Behavioral Research

Protocol Submission Form

This form must be typed. Send this form and the supporting documents to IRB02, PO Box 112250, Gainesville, FL 32611. Should you have questions about completing this form, call 352-392-0433.

Title of Protocol:	**Building Information Modeling (BIM) and Its Use to Support Sustainable Design and Building Practices**		
Principal Investigator:	**William Patrick Bynum II**		**UFID #:**
Degree / Title:	**Bachelor of Science in Architecture (University of Virginia)**	**Mailing Address:** (If on campus include PO Box address):	**Email:**
Department:	**Building Construction**		**Telephone #:**
Co-Investigator(s):	**None**	**UFID#: N/A**	**Email: N/A**
Supervisor *(If PI is student)***:**	**Dr. Raymond Issa**	**UFID#:**	
Degree / Title:	**Professor**	**Mailing Address:** (If on campus include PO Box address):	**Email :**
Department:	**Building Construction**		**Telephone #:**
Date of Proposed Research:	**02/15/2010 – 05/01/2010**		
Source of Funding *(A copy of the grant proposal must be submitted with this protocol if funding is involved):*	**None**		

Scientific Purpose of the Study:

The objective of this study is to investigate the current state in which BIM operates and functions towards sustainable design and building practices. The following statements list the three primary goals of the study:

- **To investigate the interoperability of BIM among general contractors, architects, and engineers as**

to way of understanding sustainable developments through the use of virtual prototypes.

- **To evaluate and compare various BIM and building performance software platforms.**
- **To develop a potential scoring matrix for evaluating BIM software in terms of its ability to provide sustainable guidelines.**

Describe the Research Methodology in Non-Technical Language: ***(****Explain what will be done with or to the research participant.****)***

In order to obtain the necessary information for this research an extensive survey will be provided to numerous firms in the architecture-engineering-construction (AEC) industry as a means to collect data regarding BIM systems and their relationship to sustainable design and building practices. The survey participants will be asked to answer a questionnaire consisting of multiple choice, Likert scale matrices, and free response questions. Through the use of statistical analysis the data will be used as a way of rating the various BIM systems as well as developing an evaluative scoring matrix to indicate the positives and negatives of the BIM software being studied.

Describe Potential Benefits:

Based on the results of the survey and if the participant would like to obtain the results, the potential benefits may include understanding how building information modeling (BIM) may be used to support sustainable design and building practices. Therefore, firms in the AEC industry will have the understanding of which software platforms to purchase as well as what building performance analytical software to utilize when considering sustainable design and construction practices.

Describe Potential Risks: (*If risk of physical, psychological or economic harm may be involved, describe the steps taken to protect participant.)*

There are no potential risks involved with this survey.

Describe How Participant(s) Will Be Recruited:

Participants are to be recruited from a registration list generated for the attendees of the Design-Build Institute of America (DBIA) National Conference in Washington DC on November 2009. The participants will be emailed an electronic survey through a survey generator (Zoomerang™).

Maximum Number of Participants (to be approached with consent)	**1500**	**Age Range of Participants:**	**20-80**	**Amount of Compensation/ course credit:**	**None**

Describe the Informed Consent Process. (Attach a Copy of the Informed Consent Document. See http://irb.ufl.edu/irb02/samples.html for examples of consent.)

(SIGNATURE SECTION)		
Principal Investigator(s) Signature:		**Date:**
Supervisor's Signature (if PI is a student):		**Date:**
Department Chair Signature:		**Date:**

APPENDIX B
IRB INFORMED CONSENT DOCUMENT

Informed Consent

Protocol Title:
Building Information Modeling (BIM) and Its Use to Support Sustainable Design and Building Practices

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:

The purpose of this study is to investigate the current state in which building information modeling (BIM) operates and functions towards sustainable design and building practices. The following statements list the three primary goals of the study:

- To investigate the interoperability of BIM among general contractors, architects, and engineers as to way of understanding sustainable developments through the use of virtual prototypes.
- To evaluate and compare various BIM and building performance software platforms.
- To develop a potential scoring matrix for evaluating BIM software in terms of its ability to provide sustainable guidelines.

What you will be asked to do in the study:

As a participant, you will asked to answer a short questionnaire on various topics concerning you and/or your company's perceptions on building information modeling (BIM) and sustainable design and construction practices.

Time required:

10-20 minutes self-administered

Risks and Benefits:

Your involvement with the survey can be potentially beneficial for you and/or your company. If you wish to review the final results of the survey please indicate this by replying to the corresponding question found on the survey form. There are no potential risks involved in participation with this survey.

Compensation:

There is no compensation available other than the ability to obtain an electronic copy of the final results upon request found within the survey form.

Confidentiality:

Your responses will be held in complete confidentiality.

Voluntary participation:

Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:

You have the right to withdraw from the study at anytime without consequence.

Whom to contact if you have questions about the study:

W. Patrick Bynum, Principal Investigator, University of Florida – School of Building Construction
Phone: (xxx) xxx-xxxx
Email: xxxxxxxx@ufl.edu

Dr. R. Raymond Issa, Professor, University of Florida – School of Building Construction
Phone: (xxx) xxx-xxxx
Email: xxxxxxxx@ufl.edu

Whom to contact about your rights as a research participant in the study:

IRB02 Office, Box 112250, University of Florida, Gainesville, FL 32611-2250
Phone: (352) 392-0433
Email: irb2@ufl.edu

APPENDIX C
SURVEY QUESTIONNAIRE

SURVEY 01: Building Information Modeling and Its Impact on Sustainable Building Practices

PART I: Personal Information
The next questions are for classification purposes only. They will only be used to group your answers with others like yourself.

1. Company/Organization Role: (Please select the category that most closely matches the top level description of the position you fill the majority of the time in your professional day-to-day activites.)

- ◯ Execution Roles: (General Contractor, etc)
- ◯ Design Roles: (Architect, Engineer, etc)
- ◯ Utilization Roles: (Facility Mgr., etc)
- ◯ Planning Roles: (Owner, Planner, etc)
- ◯ Suppliers/Vendor (Sub-contractor, etc)
- ◯ Support Roles: (Lawyer, Consultant, etc)
- ◯ Academic Roles: (Professor, Student,etc)
- ◯ Procurement Roles: (Product Rep, etc)
- ◯ Management Roles: (CEO, VP, etc)
- ◯ Software Programmer

2. Are you a LEED Accredited Professional? ◯ Yes ◯ No ◯ Not currently, but plan to be.

3. Number of Years Working as a Professional: (Please select the total combined number of years working in the current industry, including previous related employment, i.e. architect switching to construction mgmt.)

- ◯ 0 - 2 years
- ◯ 3 - 5 years
- ◯ 6 - 10 years
- ◯ 11 - 20 years
- ◯ 21 - 30 years
- ◯ More than 30 years

PART II: Company Information
The next questions are for classification purposes only. They will only be used to group your answers with others like yourself.

1. Company/Organization Project Types: (Please select all that apply.)

- ◯ Commercial
- ◯ Transportation
- ◯ Residential
- ◯ Heavy Civil
- ◯ Industrial
- ◯ Other _____ (please specify)

2. Annual Company/Organization Revenue:

- ◯ Under $500,000
- ◯ $500,000 - $999,999
- ◯ $1,000,000 - $9,999,999
- ◯ $10,000,000 - $49,999,999
- ◯ $50,000,000 - $99,999,999
- ◯ $100,000,000 - $1 Billion
- ◯ $1 Billion - $5 Billion
- ◯ $5 Billion - $10 Billion
- ◯ Over $10 Billion

3. Number of Company/Organization Employees:

- ◯ Less than 10 people
- ◯ 10 - 49 people
- ◯ 50 - 99 people
- ◯ 100 - 149 people
- ◯ 150 - 249 people
- ◯ 250 - 500 people
- ◯ More than 500 people

4. Number of Company/Organization LEED Accredited Professionals:

- ◯ Less than 10 people
- ◯ 10 - 49 people
- ◯ 50 - 99 people
- ◯ 100 - 149 people
- ◯ 150 - 249 people
- ◯ More than 250 people

5. Regional Location of Company/Organization:

- ◯ Northeast (New England)
- ◯ Midwest
- ◯ West (Mountain)
- ◯ Northeast (Mid-Atlantic)
- ◯ South
- ◯ West (Pacific)

PART II: Company Information

The next questions are for classification purposes only. They will only be used to group your answers with others like yourself.

6. Primary Company/Organization Project Delivery Method:

- ◯ Design-Bid-Build (Traditional)
- ◯ Construction Management
- ◯ Construction Management at Risk
- ◯ Design-Build
- ◯ Integrated Project Design
- ◯ Other _____ (please specify)

PART III: Building Information Modeling (BIM)

The next questions are designed to understand your company's use of BIM as part of its current practices. Please respond accordingly.

1. Which of the following BIM software packages does your company/organization utilize, if any?

- ◯ Autodesk Revit
- ◯ Bentley Microstation
- ◯ Graphisoft ArchiCAD
- ◯ VICO Constructor
- ◯ Other _____ (please specify)
- ◯ Beck-Technology dProfiler
- ◯ Gehry Technologies Digital Project
- ◯ Nemetschek Vectorworks
- ◯ Navisworks
- ◯ <None>

2. How long has your company/organization implemented BIM into its practice, if at all?

- ◯ Have yet to implement it.
- ◯ 0 - 1 year
- ◯ 1 - 2 years
- ◯ 3 - 5 years
- ◯ 6 - 9 years
- ◯ 10 - 15 years
- ◯ More than 15 years

3. Approximately what percentage of projects completed by this company/organization have utilized some form of BIM software within the past 5 years?

Total Percentage [ ]

4. Approximately what percentage of projects completed by this company/organization have been required by the owners/stakeholders to utilize BIM software within the past 5 years?

Total Percentage [ ]

5. What role does BIM have within your company/organization, if any? (Please select all that apply.)

- ◯ Project Visualization: *(Displays how the model of a project is visualized and communicated to various stakeholders.)*
- ◯ Project Coordination: *(Organizes the coordination of work with the firm and across the project network.)*
- ◯ Project Analysis: *(Shares electronic files with other firms on projects in order to analyze items such as design changes on cost, pre-construction clash detection, optimizing energy consumption, etc.)*
- ◯ Project Supply/Vendor Integration: *(The BIM model is taken by manufacturing firms to manufacture or order the materials that go into the building.)*
- ◯ <None>
- ◯ Other _____ (please specify)

6. Please respond to the following statements according to your perception of BIM and the skepticism of its use in the industry?

	Strongly Disagree	*Somewhat Disagree*	*Neutral*	*Somewhat Agree*	*Strongly Agree*
a.) BIM is currently too complicated to use.	◯	◯	◯	◯	◯
b.) BIM is currently not a cost-effective measure for the industry.	◯	◯	◯	◯	◯
c.) BIM is currently not designed to be used specifically for my profession.	◯	◯	◯	◯	◯
d.) BIM is currently not a necessity within the industry, therefore there is no need to implement it.	◯	◯	◯	◯	◯
e.) BIM currently does not operate in an optimal standardized format making it difficult to translate data seamlessly.	◯	◯	◯	◯	◯

PART III: Building Information Modeling (BIM)

The next questions are designed to understand your company's use of BIM as part of its current practices. Please respond accordingly.

7. In your opinion, how do you rate the importance of the following features found within BIM software packages? (Please note that "1" ranks as low importance and "7" as high importance.)

	Low 1	2	3	*Neutral* 4	5	6	*High* 7
a.) Direct integration with energy analysis software applications (i.e. Ecotect, IES Virtual Environment).	○	○	○	○	○	○	○
b.) Direct integration with project management software (i.e. Primavera Suretrak, Microsoft Project Planner.)	○	○	○	○	○	○	○
c.) Direct integration for construction related tasks (i.e. estimating costs, scheduling, quantity take-offs)	○	○	○	○	○	○	○
d.) Support to produce construction documents without the need for another application.	○	○	○	○	○	○	○
e.) Standardization of software platforms to facilitate inter-operability in the building industry (i.e. IFC compatible).	○	○	○	○	○	○	○
f.) Multidisciplinary capability (i.e. provides service for architects, engineers, MEP, contractors)	○	○	○	○	○	○	○
g.) Ability to support collaborative and distributed work processes (i.e. multiple team members working on the same project).	○	○	○	○	○	○	○
h.) Relative ease of software adjoined with helpful tutorials, supporting documentation, and other learning resources.	○	○	○	○	○	○	○

SURVEY 01: Building Information Modeling and Its Impact on Sustainable Building Practices

PART IV: Sustainable Building Practices

The next questions are designed to understand the the importance of sustainable building practices within the industry. Please respond accordingly.

1. Approximately what percentage of projects completed by this company/organization has received either a LEED or green building equivalent certification within the past 5 years?

Total Percentage ☐

2. Approximately what percentage of projects completed by this company/organization have been required by the owners/stakeholders to receive either a LEED or green building equivalent certification within the past 5 years?

Total Percentage ☐

3. Please respond to the following statements according to your perception of your company and sustainability?

	Strongly Disagree	*Somewhat Disagree*	*Neutral*	*Somewhat Agree*	*Strongly Agree*
a.) My company finds the role of sustainability to be important.	○	○	○	○	○
b.) My company has been proactive in educating employees on recent sustainable practice developments.	○	○	○	○	○
c.) My company utilizes the latest innovations in technology to enhance our sustainability mechanisms.	○	○	○	○	○
d.) My company actively advises owners/stakeholders to pursue sustainable methods and practices during projects.	○	○	○	○	○
e.) My company provides incentives to encourage sustainable practices during projects.	○	○	○	○	○

4. In your opinion, how do you rate the priority of the following in terms of its potential impact on sustainable construction? (Please note that "1" ranks as low priority and "7" as high priority.)

	Low			*Neutral*			*High*
	1	*2*	*3*	*4*	*5*	*6*	*7*
a.) Sustainable Site Development (i.e. heat island effect, storm water runoff)	○	○	○	○	○	○	○
b.) Water Efficiency (i.e. reduction of potable water usage, limiting irrigation)	○	○	○	○	○	○	○
c.) Energy Efficiency (i.e. reduction of energy consumption, use of renewable energy resources)	○	○	○	○	○	○	○
d.) Sustainable Materials (i.e. use of recycled materials, reduction of waste)	○	○	○	○	○	○	○
e.) Indoor Air Quality (i.e. use of no VOC's, maximize natural ventilation, thermal comfort)	○	○	○	○	○	○	○
f.) Project Management (i.e. elimination of rework)	○	○	○	○	○	○	○
g.) Post Construction Facility Operations (i.e. maintain healthy HVAC systems)	○	○	○	○	○	○	○

SURVEY 01: Building Information Modeling and Its Impact on Sustainable Building Practices

PART V: Building Information Modeling (BIM) and Sustainable Practices

The next questions are designed to understand the correlation between BIM and its usefulness in sustainable design and building practices. Please respond accordingly.

1. In your opinion, at what phase would implementing BIM most likely contribute most to providing sustainable design or construction practices throughout the duration of a project?

- ○ Predesign or Program Phase
- ○ Pre-construction Phase
- ○ Schematic Design Phase
- ○ Construction Administration Phase
- ○ Design Development Phase
- ○ Post-construction Operations Phase
- ○ Construction Documents Phase
- ○ Other _____ (please specify)

2. Which of the following types of computer aided analysis has been utilized by your company/ organization in one form or another, if any? (Please select all that apply.)

- ○ Structural Analysis
- ○ Lighting Analysis/Simulation
- ○ Energy Analysis
- ○ Acoustic Analysis
- ○ MEP Analysis
- ○ Thermal/Air Control
- ○ Building Function Analysis
- ○ <None>
- ○ Other _____ (please specify)

3. Which of the following building performance analysis software has been utilized by your company/ organization in one form or another, if any? (Please select all that apply.)

- ○ Ecotect
- ○ eQUEST
- ○ IES Virtual Environment
- ○ Green Building Studio
- ○ <None>
- ○ Other _____ (please specify)

4. Which of the following project delivery methods provides the best environment for the utilization of BIM software as a mechanism for sustainable design and building practices?

- ○ Design-Bid-Build (Traditional)
- ○ Design-Build
- ○ Construction Management
- ○ Integrated Project Design
- ○ Construction Management at Risk
- ○ Other _____ (please specify)

5. In your opinion, how do you rate the importance of the suggested improvements in terms of its impact within BIM and sustainable design and building practices? (Please note that "1" ranks as low priority and "7" as high priority.)

	Low 1	2	3	*Neutral* 4	5	6	*High* 7
a.) Improvements within interoperability between software packages (e.g. importing/exporting data from BIM software into building performance analysis software).	○	○	○	○	○	○	○
b.) Integration of a carbon accounting tracker (e.g. tracking the carbon emissions of a building from construction to post-construction).	○	○	○	○	○	○	○
c.) Interactivity of weather data (i.e. connecting a BIM model directly to weather databases available online).	○	○	○	○	○	○	○

PART V: Building Information Modeling (BIM) and Sustainable Practices

The next questions are designed to understand the correlation between BIM and its usefulness in sustainable design and building practices. Please respond accordingly.

6. In your opinion, how do you rate current BIM software packages in terms of its effectiveness in achieving the following sustainability categories during a project? (Please mark "Undecided" if unsure about the corresponding query.)

	Highly Ineffective	*Ineffective*	*Neutral*	*Effective*	*Highly Effective*
a.) Sustainable Site Development (i.e. heat island effect, storm water runoff)	○	○	○	○	○
b.) Water Efficiency (i.e. reduction of potable water usage, limiting irrigation)	○	○	○	○	○
c.) Energy Efficiency (i.e. reduction of energy consumption, use of renewable energy resources)	○	○	○	○	○
d.) Sustainable Materials (i.e. use of recycled materials, reduction of waste)	○	○	○	○	○
e.) Indoor Air Quality (i.e. use of no VOC's, maximize natural ventilation, thermal comfort)	○	○	○	○	○
f.) Project Management (i.e. elimination of rework)	○	○	○	○	○
g.) Post Construction Facility Operations (i.e. maintain healthy HVAC systems)	○	○	○	○	○

7. In your own words, how do you feel current BIM software is being used to facilitate sustainable design and construction practices? What changes, if any, need to be made to enhance its ability to support sustainable practices? (Optional)

PART VI: Optional

1. Would you like for us to submit to your company/organization the results of this survey? If so, please provide us with your company's email address.

Email Address

APPENDIX D
QUESTION 5.7 FREE RESPONSE ANSWERS

Question 5.7: In your own words, how do you feel current BIM software is being used to facilitate sustainable design and building practices? What changes, if any, need to be made to enhance its ability to support sustainable practices?

#	Response
1	We are pretty new to BIM so it is hard to say but I think the integration of MEP systems and architectural systems should lead to more efficient environments
2	Needs work. During schematics and pre-design, the tools need to be fast and work with a simple model, nothing too complex. Complexity comes with project development
3	Not familiar with it enough to comment
4	Interoperability and better user interface might help
5	I believe BIM will have a profound impact on the design and construction industries in the next 5 years. Design professions will look to more skilled personnel who can make technical design decisions, thereby impacting the junior / intermediate techs. BIM through IPD and DB will enable and demand conceptual estimating for early feedback on sustainable design, and budget. Contractors and trades will expect the BIM models to be made available to the industry for downstream costing and manufacture.
6	I don't get involved with this area.
7	BIM will eventually become the standard media for design delivery, replacing CAD. The problem currently is twofold: interoperability with estimating, project management, cost tracking software AND availability of software that auto-populates required material submittals based on families (that drag and drop into the design) provided by material suppliers.
8	BIM needs to be integrated with all aspects of construction to eliminate communication and to provide real time updates. The only company that is making this and doing it right is ********** in providence, RI with their iBuild platform. The key to success is know WHAT INFO you need to drive the process not let the process drive the information you get!
9	Better integration with other tools
10	No, BIM should be used more frequently, but unfortunately it's not... Bring more awareness to potential clients on the advantages/capabilities of the BIM tool and what it can do in terms of saving energy/water, LCC calculations, etc.
11	It's not. The architects need to take the initiative rather than trying to pass it on to the contractor as their responsibility. It will grow with time to replace Revit/CAD.
12	I am an electrical contractor, which right now BIM software is not as friendly to as some other trades. I use it extensively and see a huge benefit is design and planning. I hope to see more buy-in from others in the construction business.
13	I think BIM needs to be easier to use and interoperable with other programs. My company has tried BIM on a couple of projects, but so far it seems to be more of a hassle than a benefit.
14	Currently BIM and sustainable design are independent practices; however the use of BIM directly affects sustainable design practices by providing more opportunities to limit waste, build facilities, and test for efficiency prior to even breaking ground. The only limitations are those which the software inherently posses. Standards need to be set so that the software can build the requirements of the standards into their programs so that no matter which program is utilized, the designers, owners, and future maintenance individuals can utilize the BIM model not just for sustainable practices now, but also into the future.
15	Mostly user of UrbaWind to calculate wind-induced natural ventilation, I'd like the software to be directly linked to a weather database for more interactivity and user-friendliness
16	BIM has a lot of potential but only 10% of firms that have some BIM Software are actually using it to its full potential. Lots of teams use it for its graphics and 3d models but really don't use conflict

software, 4d or 5d.

17	Too many to list here.
18	Revit MEP is lacking many capabilities to make it effective. The marketing team for Autodesk is selling a product to owners and architects without understanding the limited capabilities. Additionally, Much of what the architect creates in Revit must be done properly (roofs on buildings, ceilings, correct construction characteristics, etc) in order to make Revit MEP information more useful. Additionally, large scale projects slow Revit significantly. Owners/architects are requiring Revit/BIM without understanding why they want it. Just to say it was completed in Revit does not accomplish much. Additional owners are requesting BIM and allow less of an MEP fee. At this time, it is more time consuming to complete a project in Revit and fewer fees is received.
19	My company is a specialty subcontractor (electrical), so we are rarely, if ever, driving the bus with regard to either sustainability or BIM. That said, my perception is that the software we use barely speaks at all to matters relating to sustainability. Furthermore, my perception of the state of BIM software for the industry as a whole is that we're in the very earliest stages of software development for that functionality.
20	Don't know because I don't use BIM. Therefore, to me, BIM does not facilitate sustainable design in any way. In order to be made effective, it needs to become a mainstream tool. That is terribly difficult during trying economic times. The cost of software and hardware is frustratingly high in an industry (architecture) with a notoriously low return on investment.
21	It doesn't
22	I don't have BIM in my office. How can I rate their use? You ask leading questions that will give predicted results. I don't know what kind of a learning curve is required to be efficient with BIM and if you constantly need to use it to be proficient with the program. What does the program cost and can a small company afford the costs and still survive?
23	It isn't. Firms are too busy trying to learn how to use the BIM software cost effectively, let alone utilize it for sustainability goals.
24	BIM within the AEC community is currently in fashion as design tool. Emphasize the word tool, because it is a means, not an end. Sustainability is an end - and can sustainable design can be attained without use of BIM. Once BIM becomes more useful among owners and building managers (years from now), BIM will be useful in analyzing performance maintaining sustainably-designed facilities. BIM can be used to advance sustainable design. Sustainable design can be accomplished without BIM. BIM is a tool, and can be a means towards improving sustainable design. Site design modeling can be hugely helpful toward analyzing stormwater quality and de-conflicting underground utilities. BIM software's limitations as a detailing tool, lack of interoperability, and high cost of staff retraining/migration currently impede its widespread use. Very little actual construction is 'manufactured' - and BIM continues to be of little, if any, use on most construction projects. Few clients can afford customized, engineered, manufactured building components that require BIM modeling - most opt for standardized, unitized building components in wide production that are accepted among and trade installers (and are warrantable). A premise that BIM and sustainable design are interdependent is somewhat thin and difficult to defend. But unquestionably, BIM, as an emerging and continually improving design tool, can facilitate sustainable design.
25	Someone needs to develop workflows and processes to follow that fit into our current practices as easily as possible. If special modeling techniques are required, what are they?
26	The integration of the LEED data into the BIM platform has quite a ways to go. Software like NavisWorks that can synergize multiple programs is the next plateau. We would like to request the results of this survey or at least the executive summary. Thank you.
27	We utilize at schematic design phase to analyze options to achieve our projects sustainability goals. Better support for IFC (not single vendor solution) would be the best solution.
28	Better utilization of IFC files across all leading software companies. Users should be able to select what platform works best for them and not be forced to go with particular software.

29	Improve ease of use; increase ability of Owners and non-technical team members to view and understand models; Improve ability to link USEFUL information to model elements.
30	BIM still cannot meet our needs in converting scheduled specified items or take off from the BIM documents, all the vendors still have a long way to go to make the systems seamless and "smart"
31	HARDWARE NEEDS TO CATCH UP WITH SOFTWARE- THAT'S THE BIGGEST OBSTACLE WE ARE SEEING.
32	Currently, BIM software is more focused on aspects relating to Project Management and trade integration rather than sustainability. However, because BIM models are typically developed in the pre-design phase, the foundation for further integration of sustainable design and building practices should be easily incorporated and likely effective. In my opinion, the areas of building design and construction that are currently able to be effectively integrated with BIM software include: energy efficiency, project management, building commissioning, and post construction facility operations. Conversely, the areas of building and design that are not currently able to be effectively integrated with BIM software include: sustainable site development, water efficiency, sustainable materials, and indoor environmental quality.
33	Currently, BIM is having an impacted on overall sustainability of a building - mainly in the design & construction phases. We will see a greater impact when BIM is used more on owner/operator side.
34	Trust between AEC team members; legal clarification of each other's risk and responsibilities to the owner
35	We are currently focused on building performance using eQuest. We are in the process of developing our competency in BIM and are looking for the best product in this discipline.
36	Unfortunately, our company has not fully embraced the BIM technology enough to utilize towards sustainable practices. It is a cost/training curve issue.
37	Really little relationship. BIM is still being implemented and needs so much more development to be really integrated. That's the real current focus. Once data can be passed seamlessly, maybe sustainability will receive some attention. LEED checklists being linked is still a manual deal.
38	Don't know.
39	In the construction industry, we have found that the review/approval process vs. BIM drawing submittals is highly problematic. in other words, as a manufacturer we can detail a project in BIM, but to submit the detailing this way does not give the design consultants (Eng. of Record, Architect) a way to 'mark-up' or approve shop drawings. This is especially difficult if multiple types of BIM software are used on a single job. Our business (precast concrete manufacturer) does not have the benefit of a BIM software that a structural steel manufacturer or designer (eng) might have. It has its uses, but integrating wholly into BIM is years away.
40	Needs work. Within Revit, templates can be set up that will assist in documentation. This is done by individual firms. would be helpful if this could be provided as an add-in.

LIST OF REFERENCES

Autodesk, Inc. (2009a). *Autodesk Ecotect Analysis 2010 Questions and Answers*. URL:http://images.autodesk.com/adsk/files/ecotectanalysis10_faq_customer_3.17.09.pdf (Accessed 28 Feb 2010).

Autodesk, Inc. (2009b). *Autodesk NavisWorks Manage 2010 Questions and Answers*. URL:http://www.rand.com/imaginit/1/pdfs/technology/software/navisworksm10_faqanda_reseller_document-final.pdf (Accessed 28 Feb 2010).

Autodesk, Inc. (2009c). *Autodesk Revit Architecture 2010 Getting Started with Revit Architecture*. URL:http://revit.downloads.autodesk.com/download/RAC2009/Documents/ENU/GSGArchitectureENU.pdf (Accessed 28 Feb 2010).

Azhar, S., and Brown, J. (2009). "BIM for Sustainability Analysis." *International Journal of Construction Education and Research*, 5: 276-292.

Cam C., Ong B. (2005). "Building environmental assessment tools and the multi-dimensional pathways towards sustainable architecture." *Proceedings of the 2005 world sustainable building conference* Tokyo, Japan, 1738–45.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2008). *BIM Handbook: A Guide to Building Information Modeling for Owner, Managers, Designers, Engineers, and Contractors*, 1st ed., Wiley, New York.

Energy Design Resources (2009). *eQUEST – The Quick Energy Simulation Tool*. URL: http://www.doe2.com/download/equest/eQUESTv3-Overview.pdf.

Gehry Technologies (2010). *Digital Project Designer*. URL: http://www.gehrytechnologies.com/index.php?option=com_content&task=view&id=50&Itemid=102 (Accessed 26 Feb 2010)

Glavinich, T.E. (2008). *Contractor's Guide to Green Building Construction: Management, Project Delivery, Documentation, and Risk Reduction*. 1st ed., Wiley, New York.

Hardin, B. (2009). *BIM and Construction Management: Proven Tools, Methods, and Workflows*. 1st ed., Sybex, New York.

Hertwich, E. G. and Peters, G. G. (2009). "Carbon Footprint of Nations: A Global, Trade-linked Analysis." *Environmental Science and Technology,* 43(16), 6414-6420.

Holness, G. (2008). "BIM: Gaining Momentum." *ASHRAE Journal,*.6:28-40.

Khemlani, L. (2006). *Visual Estimating: Extending BIM into Construction*, 21 March 2006. URL:http://www.aecbytes.com/buildingthefuture/2006/VisualEstimating.html (Accessed 26 Feb 2010).

Khemlani, L. (2007). *Top Criteria for BIM Solutions: AECBytes Survey Results*, 10 Oct 2007. URL: http://www.aecbytes.com/feature/2007/BIMSurveyReport.html (Accessed 26 Feb 2010).

Khemlani, L. (2008a). *Autodesk NavisWork 2009*, 23 Oct 2008. URL:http://www.aecbytes.com/review/2008/NavisWorks2009.html (Accessed 26 Feb 2010).

Khemlani, L. (2008b). *DProfiler: A 'Macro' BIM Solution*, 22 July 2008. URL:http://www.aecbytes.com/review/2008/DProfiler.html (Accessed 26 Feb 2010).

Khemlani, L. (2008c). *Technology for Construction at World of Concrete 2008*, 31 Jan 2008. URL:http://www.aecbytes.com/newsletter/2008/issue_33.html (Accessed 26 Feb 2010).

Khemlani, L. (2009a). *ArchiCAD 13*, 30 Sept 2009. URL:http://www.aecbytes.com/review/2009/ArchiCAD13.html (Accessed 26 Feb 2010).

Khemlani, L. (2009b). *Bentley Architecture V8i*, 19 Nov 2009. URL:http://www.aecbytes.com/review/2009/BentleyArchV8i.html (Accessed 26 Feb 2010).

Khemlani, L. (2009c). *Revit Architecture 2010*, 9 July 2009. URL:http://www.aecbytes.com/review/2009/RevitArch2010.html (Accessed 26 Feb 2010).

Khemlani, L. (2009d). *Solibri Model Checker*, 31 March 2009. URL:http://www.aecbytes.com/review/2009/SolibriModelChecker.html (Accessed 26 Feb 2010).

Khemlani, L. (2009e). *Tekla Structures 14*, 19 Dec 2009. URL:http://www.aecbytes.com/review/2008/TeklaStructures14.html (Accessed 26 Feb 2010).

Kibert, C.J. (2008). Sustainable Construction: Green Building Design and Delivery. 2nd ed., Wiley: New York.

Krygiel, E. and Nies, B. (2008). *Green BIM: Successful Sustainable Design with Building Information Modeling*, 1st ed., Wiley, New York.

Malin, N. (2007). "Building Information Modeling and Green Design." *Environmental Building News*, 16(5).

Popov, V., Mikalauskas, S., Migilinskas, D., and Vainiunas, P., (2006). "Complex Usage of 4D Information Modeling Concept for Building Design, Estimation, Scheduling, and Determination of Effective Variant."

Thoo, S. (2010). *Graphisoft EcoDesigner*, 11 Feb 2010. URL:http://www.aecbytes.com/review/2010/EcoDesigner.html (Accessed 26 Feb 2010).

Torcellini, P. (2006). Zero energy buildings: A critical look at the definition. *Conference Paper of the 2006 ACEEE Summer Study, American Council for an Energy Efficient Economy*, Washington DC.

Vectorworks, Inc. (2009). *What's New in Vectorworks 2010.* URL:http://download2.nemetschek.net/www_misc/2010/VW2010_whats_new.pdf (Accessed 26 Feb 2010).

Vico Construction Services (2009). *Vico Office Suite,* URL: http://www.vicosoftware.com/Default.aspx?app=LeadgenDownload&shortpath=docs%2fVico+Office+Suite+view.pdf (Accessed 26 Feb 2010).

BIOGRAPHICAL SKETCH

W. Patrick Bynum II earned his master's degree from the M.E. Rinker, Sr. School of Building Construction at the University of Florida. While at the University of Florida he worked for the M.E. Rinker, Sr. School of Building Construction as a graduate teaching assistant for the BCN 2405 Construction Mechanics course. Prior to earning his MSBC degree he earned his bachelor of science in architecture from the University of Virginia School of Architecture. During his studies there he gained experience in the use of digital technology as well as a background on sustainable design techniques and methodologies.

Patrick's research interests are related to seamless communication between the architectural and construction professions through the use of digital technology. He is also interested in the use of technology to perform or enhance sustainable practices within the design and construction processes. He plans to work within the design-build profession with the intent of designing and constructing sustainably built projects.