THESIS

THE PERCEIVED VALUE OF USING BIM FOR ENERGY SIMULATION

Submitted by

Anderson M. Lewis

Department of Construction Management

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Master's Committee:

Advisor: Rodolfo Valdes-Vasquez

Caroline Clevenger
Rebecca Atadero

ABSTRACT

THE PERCEIVED VALUE OF USING BIM FOR ENERGY SIMULATION

Building Information Modeling (BIM) is becoming an increasingly important tool in the Architectural, Engineering & Construction (AEC) industries. Some of the benefits associated with BIM include but are not limited to cost and time savings through greater trade and design coordination, and more accurate estimating take-offs. BIM is a virtual 3D, parametric design software that allows users to store information of a model within and can be used as a communication platform between project stakeholders. Likewise, energy simulation is an integral tool for predicting and optimizing a building's performance during design. Creating energy models and running energy simulations can be a time consuming activity due to the large number of parameters and assumptions that must be addressed to achieve reasonably accurate results. However, leveraging information imbedded within Building Information Models (BIMs) has the potential to increase accuracy and reduce the amount of time required to run energy simulations and can facilitate continuous energy simulations throughout the design process, thus optimizing building performance.

Although some literature exists on how design stakeholders perceive the benefits associated with leveraging BIM for energy simulation, little is known about how perceptions associated with leveraging BIM for energy simulation differ between various green design stakeholder user groups. Through an e-survey instrument, this study seeks to determine how perceptions of using BIMs to inform energy simulation differ among distinct design stakeholder groups, which include BIM-only users, energy simulation-only users and BIM and energy

simulation users. Additionally, this study seeks to determine what design stakeholders perceive as the main barriers and benefits of implementing BIM-based energy simulation.

Results from this study suggest that little to no correlation exists between green design stakeholders' perceptions of the value associated with using information from BIMs to inform energy simulation and their engagement level with BIM and/or energy simulation. However, green design stakeholder perceptions of the value associated with using information from BIMs to inform energy simulation and their engagement with BIM and/or energy simulation may differ between different user groups (i.e. BIM users only, energy simulation users only, and BIM and energy simulation users). For example, the BIM-only user groups appeared to have a strong positive correlation between the perceptions of the value associated with using information from BIMs to inform energy simulation and their engagement with BIM. Additionally, this study suggests that the top perceived benefits of using BIMs to inform energy simulations among green design stakeholders are: facilitation of communication, reducing of process related costs, and giving users the ability examine more design options. The main perceived barrier of using BIMs to inform energy simulations among green design stakeholders was a lack of BIM standards for model integration with multidisciplinary teams.

Results from this study will help readers understand how to better implement BIM-based energy simulation while mitigating barriers and optimizing benefits. Additionally, examining discrepancies between user groups can lead the identification and improvement of shortfalls in current BIM-based energy simulation processes. Understanding how perceptions and engagement levels differ among different software user groups will help in developing a strategies for implementing BIM-based energy simulation that are tailored to each specific user group.

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DEFINITION OF TERMS

The following terms and definitions are referenced in this research study:

*Building Information Models (BIMs)**:** "*a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility" (Ernstrom, 2006, p. 3)

Building Information Modeling (BIM): "the development and use of a computer software model to simulate the construction and operation of a facility, which results in a Building Information Model" (Ernstrom, 2006, p. 3)

Energy Model: The computerized representation of a building and its properties that are used to perform energy simulation calculations

Energy Simulation: The process of quantitatively predicting a buildings energy performance through software analysis.

Green Design Stakeholder(s) - a person who holds an interest in the design of a project that is slated to achieve greater levels of energy efficiency, produce less carbon and/or minimize environmental impact more than an average building.

Interoperability: the ability of multiple software programs to work together.

Leveraging: using in a way to provide an advantage.

Middleware: software that is used to translate BIM information into a form that is readable by energy modeling software.

CHAPTER I

SCOPE OF THE RESEARCH

Leveraging BIMs for energy simulation provides designers with an opportunity to maximize building performance through design. Although the term "building performance" can be used to describe a variety of metrics pertaining to a building's functionality, in this paper it will be used to describe energy performance. Leveraging information imbedded in BIMs to run energy simulations is beginning to gain traction within the Architectural, Engineering and Construction (AEC) industries. However, sparse research exists on how design stakeholders perceive the value associated with using BIMs for energy simulation and even less is known about how perceptions different software among distinct user groups. To address this need, an e-survey was developed to uncover green design stakeholders' perceptions of levering BIM for energy simulation. For the purpose of this study, a green design stakeholder is defined as "a person who holds an interest in the design of a project that is slated to achieve greater levels of energy efficiency, produce less carbon and/or minimize environmental impact more than an average building." This study aims to identify design stakeholders' main perceived barriers associated with implementing BIM-based energy simulation. The hypothesis of this study is that design stakeholder engagement with BIM and/or energy simulation programs will influence how they perceive the value associated with BIM-based building performance analysis. The purpose of this chapter is to: (1) introduce the context of the research problem; (2) provide information on overarching research efforts; and (3) identify the impacts of this study.

Research Context

BIM is a parametric, virtual representation of a building that is capable of storing imbedded information about a project (Schluter & Thessling, 2009). Multiple benefits of using BIM in the construction process have been identified, some of which contribute to the overall energy performance of a project. Among other benefits, BIM gives designers the opportunity to preform clash detection to ensure MEP plans do not intersect, to perform quick and accurate quantity takeoffs for estimating, and extract and analyze large quantities of data about a building design, which allows designers to inform their decision-making process based on this information (Azhar, 2011). One major benefit of storing information in BIMs is that it can be leveraged to inform energy simulations, which are predictions of a design's energy performance through software analysis.

An increased awareness of climate change, increasingly stringent building codes, and rising energy costs are leading to a surge in global demand for better performing buildings, which has incited designers to pay more attention to building performance. Sustainable design principles can improve the overall performance of a building using strategies such as passive solar design, increased insulation, and by tuning windows properly. However, difficulty exists in knowing the exact implications that a design change will have on the overall performance of a building or knowing how these changes will impact other building systems and if they could potentially produce undesirable effects. In order to get a better idea of how design changes impact building performance, designers often rely on using energy simulations.

Energy simulation is a process frequently used by design stakeholders' for predicting a building's energy performance through software analysis (Mokhtar, 2013). Computer-based energy simulations are based off of complex calculations, which consider such factors as location, climate, building orientation, and material properties. Although the use of energy simulation software is considerably faster than predicting building performance through manual calculations, the process of gathering and entering information into energy models can be tedious and time consuming (Schluter & Thessling, 2009). A slew of energy simulation software products are currently available on the market such as: Trane TRACE, eQUEST, Green Building Studio and many more. While some energy simulation products are used to predict specific aspects of building performance (such as daylighting, mechanical system performance etc.), others (such as massing based energy simulation) are meant to give overall building performance predictions. Energy simulation programs require a thorough, accurate set of data and assumptions to produce reasonably accurate results, and as a general rule, more accurate feedback usually comes from a more complete set of data inputs. Energy simulation results provide designers with useful information to guide design related decision-making processes (Stumpf, Kim, & Jenicek, 2009).

Since BIMs are capable of storing and updating data about a building throughout the design process that can be extracted and analyzed to improve the decision making process (Azhar, Brown, & Farooqui, 2009), this creates an opportune situation to leverage information stored in these models to inform energy simulations. When BIM software is used in conjunction with energy simulation software, it allows for building performance measures to continuously be analyzed throughout the design process, ensuring that performance criteria are enhanced (Azhar, Carlton, Olsen, & Ahmad, 2011). Energy simulation results give users the predicted performance of different designs and can help designers choose a design that maximizes functionality and building performance. Additionally, energy simulation can be performed at any point during the design process. However, the earlier an energy simulation is performed in the design process the greater potential it has for improving a building's eventual operating performance (Attia & De Herde, 2011). While energy simulations are not crucial in designing buildings that have high levels of performance, they minimize the guesswork associated with this process and give designers well-founded information from which to base their decisions. Modeling multiple design options, BIM-based energy simulation can rapidly produce predicted energy usage outputs that enable a design team to choose the most energy efficient and cost effective options (Schade, Olofsson, & Schreyer, 2011). However, uncertainty exists on how green design stakeholders perceive the benefits/ barriers to leveraging the BIMs to inform their energy models or how their engagement levels with BIM and energy simulation software correlate with this overall perception.

Problem Statement

Architectural, Engineering, and Construction (AEC) industries are quickly adopting BIM as a project management and design tool. A report from McGraw-Hill (2012) indicates BIM adoption increased from 28% in 2007 to 71% in 2012. Multiple studies have identified the project benefits, trends, risks, challenges and perceptions of BIM (Azhar, 2011; Bryde, Broquetas, & Volm, 2013; McGraw-Hill, 2012). Likewise, green design stakeholders frequently use energy simulation tools to inform their decision-making process and to validate previous design decisions on projects where building performance is of high importance. **Sparse literature exists that identifies green design stakeholders' perceptions on using BIM to aid in the creation of energy models and running energy simulations.** In addition, even less literature exists that identifies green design stakeholders main perceived **benefits and barriers** pertaining to using BIM to create energy simulations. This research aims to identify the main perceived barriers and benefits associated with using BIM for energy simulations. Additionally, this research investigation seeks to confirm a positive correlation between green design stakeholders' engagement levels with BIM and energy simulation software programs and their overall perception of leveraging BIM for energy simulation.

Goals and Objectives

The goal of this study is to identify green design stakeholders' overall perceptions of the value associated with leveraging BIM for energy simulation and to determine how these perceptions differ among distinct user groups. The following objectives were accomplished in pursuit of this goal:

O1 – To identify previous studies pertaining to the benefits and barriers associated with both BIM and energy simulation software programs. This extensive literature review also looked into the perceptions of design stakeholders surrounding BIM and energy simulation. Although sparse literature exists pertaining to how design stakeholders perceive the value associated with BIM-based energy simulations, even less literature exists on examining green design stakeholders perceptions of the barriers and benefits associated with using BIM-based energy simulations.

O2 – To develop a survey instrument and determine respondents' perceptions on leveraging BIM for energy simulation while observing characteristics about these respondents including demographic data, firm type and size, and experience level with BIM software and energy simulation software. This survey instrument is based on previous studies including Azhar & Brown (2009) and McGraw-Hill (2012). The study by (Azhar et al., 2009) helped shape several survey items that measure respondents perceptions related to the cost and timesavings implications of BIM-based energy simulatin. Additionally, a BIM engagement index was taken from a McGraw-Hill (2012) study to measure respondents' engagement with BIM. This engagement index was also adapted to measure respondents' engagement levels with energy simulation and BIM-based energy simulation. Survey questions were crafted to further identify demographic information about respondents and to better gauge their perceptions pertaining to BIM-based energy simulation. This survey was sent out to green design stakeholders to examine their perceptions surrounding leveraging BIM for energy simulation.

O3 – To analyze data from the survey instrument using a variety of statistical analysis. Descriptive statistics including mean, mode and standard deviation, were run for data collected from seven-point Likert scales. Bivariate Pearson correlations were performed so that the relationship between energy simulation/ BIM engagement scores and respondents perceptions of the value associated with using BIMs to inform simulation could be observed. Additionally, scatterplots were created to illustrate high levels of correlation between the previously mentioned items. A Cronbach's Alpha tests were run to determine the reliability of both the BIM and energy simulation engagement score indexes. T-tests were run to determine the significance levels in the differences in mean values between different user groups overall perception of the value associated with using information from BIMs to inform energy simulation and their perceptions of the how accurate energy simulation is at predicting an actual buildings performance.

O4 – To identify what green design stakeholders perceive as the main barriers and benefits to leveraging BIM for energy simulation and to determine how BIM and energy simulation engagement scores impact green design stakeholders overall perceptions of using BIM for energy simulation. In addition, the analysis of the results recognizes perceptual trends between different software user groups (for example, BIM users, energy simulation users, or BIM and energy simulation users) among the green design stakeholders. This study is meant to help the researcher determine how to encourage further use of information from BIMs for energy simulation. In addition, further research opportunities were identified, including how respondents' demographic information such as age, sex, and certifications correlate with respondents' perceptions of BIM-based energy simulation. Further research opportunities also exist in identifying strategies to help distinct user groups implement BIM-for energy simulation, to develop a more accurate protocol for sharing information between design stakeholders so that modelers have a comprehensive set of data from which to create models, and to determine how to increase BIM users knowledge on how to create comprehensive, accurate models that are usable by energy modelers.

According to a study by (McGraw-Hill, 2008, p. 3) "the ability to leverage data analysis comes with experience as experts are twice as likely to use BIM data for quantity takeoff, scheduling and estimating compared to beginners." This statement from industry experts leads the researcher to hypothesize that those who are more experienced with BIM and/or energy simulation programs are more likely to use BIM for energy simulation and have more positive perception of it. This study correlates the perception(s) of green design stakeholders with their overall engagement level with both BIM and energy simulation. Additionally, this study also measures how design stakeholders' perceive different benefits and barriers to leveraging BIM for energy simulations.

Research Questions

The following questions shaped this study:

RQ1: What are green design stakeholders' overall perceptions of the value associated with using information from BIMs to inform energy simulation?

RQ2: How do green design stakeholders' engagement levels with BIM, energy simulation and BIM-based energy simulation impact their perceptions of leveraging BIM for energy simulation?

RQ3: What do green design stakeholders perceive as the greatest barriers and benefits to implementing BIM-based energy simulations?

Delimitations

Participants in this study currently work in the U.S. This study also does not identify how BIM or energy simulation usage is structured within a firm or identify which types of energy simulation each respondent's firm performs (energy analysis, solar analysis, acoustic analysis, etc.).

Limitations

The e-survey instrument was distributed to respondents using a convenience sample. A request was included both in the email and at the end of each e-survey for respondents to forward this survey to any contacts that also met the description of a "green design stakeholder." Although this survey was distributed and forwarded to green design stakeholders in different regions of the U.S. it still cannot be considered a truly random sample of the population because it does not evenly represent green design stakeholders throughout the U.S. Therefore, results from this study have the potential for regional bias.

Assumptions

As a part of both the BIM and energy simulation engagement indices, respondents who used these programs were asked to self-report their skill level with these respective software programs. In these questions skill level is broken down into the following categories: Beginner, Moderate, Advanced, and Expert. In this study, green design stakeholders are assumed to have a similar frame of reference for what constitutes each of the aforementioned categories.

Researchers Perspective

Constructing sustainable buildings has become increasingly important as green building codes and green legislation become more stringent, and as the implications of global climate change become more evident (Azhar et al., 2009). The construction industry is synonymous with waste and is typically slower to adapt to change and innovation than other industries (such as manufacturing) due to a fractured industry, less standardization, and non-controlled work environments (Franklin Associates, 1998). Close to 40% of the energy usage in the U.S. is attributable to the operation of commercial and residential buildings (U.S. DOE, 2012). Therefore, the construction industry has the potential to have a large impact on reducing future U.S. energy needs through building and remodeling more energy efficient structures.

Two promising technologies are currently transforming the landscape of the AEC industries are BIM and energy simulation software programs. Properly utilizing BIM and energy simulation on construction projects can help improve building performance and help reduce waste. However, few firms have completely figured out how to leverage BIM for energy simulation to its fullest extent due to a number of limiting factors and barriers. I believe that the synergistic benefits of leveraging BIM to perform energy simulations have the potential to lead to the design of buildings with higher levels of performance that are better tailored for their intended functionality and that have minimal negative environmental impacts. This is why I am interested in determining what barriers may be preventing green design stakeholders from leveraging this synergistic relationship to its fullest extent. I am also interested in discovering how design stakeholder engagement levels with BIM and/or energy simulation impact their overall perceptions of the value associated with using BIMs to inform energy simulations.

Readers Guide

This study investigates how green design stakeholders perceive the value associated with using BIM models to inform energy simulation and to understand what green design stakeholders perceive as the main barriers and benefits associated with using BIM models to inform energy simulation. The remainder of this document describes the steps that were taken to carry out this study. Chapter II provides a summary of the previous research and knowledge related to the uses, benefits and barriers of BIM and energy simulation and how the former can be leveraged for the later. Chapter III includes the discussion of the research approach, which consists of defining the population for this study, survey development, pilot testing, and the approval process for the e-survey. In Chapter IV, the data gathered from this survey is analyzed through various statistical analysis methods and the results are discussed. Lastly, Chapter V serves as a point of exploration for future studies that will support the work of academics and other industry professionals.

CHAPTER II

REVIEW OF BIM FOR ENERGY SIMULATION

The first objective towards accomplishing the research goal was to gain a broad understanding of BIM, energy simulation and using information from BIMs to inform the energy simulation process. To do so, this investigation included the review of salient research pertaining to each of the previously mentioned topics. Reviewing and analyzing these concepts and background information provided a base for identifying the need for this study and identified areas that merit further exploration. In particular, this study identifies green design stakeholders' main perceived barriers and benefits to leveraging BIM for energy simulation. This will allow readers to better understand how to mitigate barriers while enhancing benefits associated with leveraging BIM for energy simulation. In addition, determining if a correlation exists between design stakeholders' perceptions of the value associated with leveraging BIM for energy simulations and their engagement levels with BIM and/or energy simulation can help explain the discrepancies between different design stakeholders' perceptions. This Chapter covers the benefits, challenges, and other trends associated with using BIM, energy simulation and BIM-based energy simulation.

BIM

The General Services Administration (GSA) defines BIM as:

The development and use of a multi-faceted computer software data model to, not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs *can be extracted and analyzed to generate feedback and improvement of the facility design.* (Gordon, Azambuja, & Werner, 2009).

In short, BIM is a process in addition to software and using it requires making significant changes to the work flow and project delivery process (Azhar, 2011).

BIMs represent the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, and project schedules (Azhar, 2011). BIM software allows users to efficiently produce and update geometric models (Welle, Haymaker, & Rogers, 2011). Unlike drafting tools such as AutoCAD, BIM allows for drawings to be completed more efficiently, it utilizes parametric change technology and can have robust information imbedded within the model (Azhar et al., 2009). Parametric change technology maintains model consistency by automatically updating the elements of the model that are immediately impacted by the change made. For example, if walls in a model are attached to the roof, increasing the height of a wall will also increase the elevation of the roof. The parametric functionality of BIM has considerable time saving implications.

BIM is also useful in that it can demonstrate the entire life cycle of a building virtually. From the conceptual stage of design, BIM can help inform the shape and size of a building based on the owner’s functionality requirements and budget. BIM facilitates in the production of an accurate, consistent drawing sets, early collaboration in both design and construction planning, clash detection, prefabrication, the support of lean construction techniques, and streamlined supply chain management (Becerik-Gerber & Rice, 2010). BIM also improves documentation reliability by providing a platform for multiple stakeholders to access and update information. In addition, fixing a problem in a computer model costs only a fraction of what it would cost to fix the mistake in the field (Smith & Tardif, 2012).

Despite the view held by some that BIM is still not totally proven and that the cost does not completely justify its use (Bryde et al., 2013), the AEC industries and sophisticated owners are quickly adopting BIM as a project management and design tool because, when used correctly, it can positively impact productivity and increase revenue. Among other applications, BIM is used by the owner to understand project needs, by the design team to analyze, design and develop a project, by the contractor to manage the construction of the project and by the facilities manager during the operation and decommissioning phases (Bryde et al., 2013).

Adopters of BIM

BIM adoption rates have increased in the last decade. A study carried out by McGraw-Hill (2012) investigates BIM user trends and user perceptions on value over a five year period between 2007 and 2012. According to this study and the BIM adoption has gone from 28% in 2007 to 71% in 2012. This study found that as BIM adoption continues to rise BIM users are beginning to use BIM more heavily. This study also found that in 2009, only 27% of those who adopted BIM were heavy users, however, the number of heavy users is forecasted to approach 60% of users by 2014. Additionally, it was found that architects were the "early adopters" of BIM and for years had the most users of BIM industry wide, but architects were surpassed by contractors in their adoption of BIM in 2012 This fact substantiates claims made by a McGraw-Hill (2008, p. 3) study, saying that "contractors had the most positive view of BIM." Due to spatial coordination and constructability analysis among other things, BIM use by contractors has now surpassed that of architects, however, architects still have the most "very heavy users" of BIM (McGraw-Hill, 2012).

Benefits

The benefits of BIM usage have been widely recognized in the AEC industry and the rapid and continuous adoption helps affirm these benefits are real. According to Russell, Cho, and Cylwik (2014) the most widely recognized indirect benefits to using BIM are: increased safety, enhanced quality, reduced schedules, cost savings, lower labor costs, and waste reduction. The benefits associated with using software tools to manage construction fall into three main areas: tangible benefits (quantifiable in monetary terms), semi-tangible benefits (quantifiable, but not in monetary terms) and intangible benefits (non-quantifiable) (Becerik & Pollalis, 2006). When used correctly BIM has the potential to benefit each of the previously mentioned areas. Becerik-Gerber and Rice (2010) argued that most studies only have anecdotal evidence that BIM makes the building process more efficient and effective and that few studies provide insight for singular situations, provide a comprehensive list of benefits and associated costs, or assign quantitative values to benefits. Part of the reason that there is a lack of hard data on the true financial benefit of BIM is because few organizations employ a formal methodology to evaluate the benefit of IT investments and cost-benefit analysis are rarely used (Becerik-Gerber & Rice, 2010).

Despite the fact that Becerik-Gerber and Rice (2010) believed evidence supporting claims that the tangible benefits of using BIM are largely anecdotal, strong evidence already exists that when BIM is used correctly it can provide significant financial benefit to projects. A McGraw-Hill (2008) study shows that 44% of BIM experts frequently track their ROI. Of the 48 companies who actively tracked their ROI for using BIM on projects showed initial ROIs of 300 to 500% (McGraw-Hill, 2008). This same study also showed that firms that make an effort to track the ROI perceive BIM to be a higher value than those who do not (McGraw-Hill, 2008).

Positive Perceptions of BIM

In addition to hard financial data supporting BIM benefits, AEC professionals' opinions generally back up these claims. Through industry-wide surveys (with a sample size of 302), McGraw Hill Construction (2008) has discovered that AEC industry holds a very positive perception of integrating BIM into their workflows, with over half of BIM users believing that, in general, BIM had a very positive impact on their company. In fact, 82% of BIM users believe that BIM had a "very positive" impact on their company's productivity a (McGraw-Hill, 2008). Similarly, 66% percent of the BIM users surveyed also believed that BIM increased their chances of winning projects (McGraw-Hill, 2008). Since 2009, perceptions of BIM users who consider benefits of BIM of high/ very high value is growing (McGraw-Hill, 2012). For example, the percentage of BIM users who perceived a very high value of "increase in profits" as a result of using BIM grew from 21% to 36%. In addition, as users gain experience with BIM, their view of its impact improves significantly (McGraw-Hill, 2008). As such, 52% of firms who had high levels of engagement with BIM perceived a very high value of "increase in profits," as opposed to the 36% of all BIM users who held this perception (McGraw-Hill, 2012).

Business Case for BIM

The construction industry is known for producing large amounts of waste, both physical and monetary alike. In 1998, Franklin Associates estimated that the construction industry produced over 135 trillion tons of waste. In addition, Thurairajah (2013) estimates that $600 billion of the $1.288 trillion (or 57%) a year building industry are wasted each year. The fragmentation, lack of standardization and non-controlled work environments, among other factors, make it highly unlikely that waste will ever be completely eliminated from the construction process. However, there is potential to greatly reduce the amount of waste that stems from the construction industry, which can translate directly into higher levels of profit. BIM can help companies reduce waste and increase profit by improving process efficiency and design efficiency. BIM can also help estimators create more accurate quantity takeoffs, which translates into more accurate purchase orders and less wasted materials.

The 3D visualization function of BIM provides users with an infinite number of vantage points of a model allowing project stakeholders to gain a fuller understanding of a projects design and can help designers to convey their intent to other project stakeholders. This allows cost consultants to make fewer assumptions, gives clients the ability to view multiple design options to speed up their decision making, and allows for fewer cost revisions (Thurairajah, 2013). In addition, 3D models are a useful marketing tool to help contractors win bids. As more nontraditional companies continue to adopt BIM, it will create more BIM-based career paths for AEC professionals (Uddin & Khanzode, 2014).

BIM has the potential to play a significant role in improving building performance through design, construction and operation. BIMs are capable of storing information that pertains to sustainable aspects of design that can be pulled out of models and analyzed. BIM models can carry a wealth of information about sustainable design aspects of projects that can also assist in the facilitation of the achievement of up to 20 points toward LEED certification (Azhar, Brown, & Sattineni, 2010). If properly stored in a model, schedules of building components can be obtained from a model to determine the percent of materials reused, recycled or salvaged.

Barriers to implementation

Factors affecting BIM adoption can be grouped into two different categories: technical tool function requirements and needs, and non-technical strategic issues (Gu & London, 2010). Technical barriers can include interoperability issues, lack of BIM standards, errors and accuracy issues. Interoperability is the smooth sharing of information among stakeholders across platforms to share data (Bryde et al., 2013). While BIM standards such as IFC and gbXML schema do exit, no information infrastructure has been unanimously adopted across the entire AEC industry.

Non-technical strategic issues include cost, lack of management buy in, stakeholder reluctance, time constraints, learning curve/ lack of skilled personnel, organizational issues, contractual and legal concerns. The fact that 90% of medium and large firms engage with BIM while less than half of small firms do suggests that cost can be a very real barrier to small firms (McGraw-Hill, 2012). Management must first think the price of BIM justifies the benefit of its use before they buy in to the idea of BIM. A multitude of BIM products are currently available on the market. However, buying in to one does not guarantee that other stakeholders will have the capability to collaborate. Other stakeholders may use different BIM products, diminishing the effectiveness and benefit of using BIM as a communication tool. Since BIM is relatively new in the construction field there is a lack of skilled personnel capable of using it. Training employees is an expensive investment. Employees at the bottom of the learning curing using BIM will inevitably take more time to perform a task than an employee that is well versed in the same software program. Another major non-technical barrier to implementing BIM are the process related risks, such as, ownership of design/ data, model protection, and standardizing a process for updating the model (Azhar, Khalfan, & Maqsood, 2012).

Best Types of Projects for BIM

While BIM can be beneficial on all types of construction projects, certain types of projects have been identified in which BIM usage can provide greater benefits than others. Multiple sources cite IPD as being the most effective project delivery method in facilitating the use of BIM for construction projects. IPD creates a collaborative atmosphere conducive for the most comprehensive use of BIM by aligning the goals of all the stakeholders and incentivizing them to work together throughout the project (Becerik-Gerber & Rice, 2010; Zhang, Tan, & Zhang, 2013). This collaborative atmosphere allows users on IPD projects to use BIM applications as a communication platform. Design Build (DB) projects are also more well suited for using BIM that Design-Bid-Build (DBB) projects (Zhang et al., 2013) because on design-build projects, designers are typically employed by a general contractor. This makes for a contractual relationship that is less adversarial and allows for greater levels of collaboration than do DBB projects. DBB projects, while not optimal for utilizing BIM to its fullest extent, can still benefit from using BIM. However, much of the opportunity to use BIM as a communication/ collaboration platform among stakeholders is lost on DBB projects.

Energy Simulation

For the purpose of this research, *energy simulation* will refer to the process of predicting a building's energy performance through software analysis, while an *energy model* refers to a computerized representation of a building and its properties that are used to perform energy simulation calculations.

Overview of Energy Simulation

Energy simulations are comprised of many complex computations that are based on the system parameters of a building (thermal properties, orientation, geometries, etc.). Traditionally, energy simulation calculations were performed by designers who used a range of disparate calculation techniques to quantify and assess building performance in the design stage (Clarke, 2001). Because of the complexity and burdensome nature of energy simulation calculations, designers were forced to take a piecemeal approach that involved simplifying assumptions and the omission of certain system parameters (Clarke, 2001).

Real-world building performance is a function of numerous, interdependent internal and external factors, such as material selection, mechanical and electrical systems, solar orientation, climate, and occupant usage. Building energy simulation programs are capable of evaluating energy impacts across dynamic interrelated systems in a rapid manner, which make them an invaluable tool for design and construction professionals who have goals of achieving high levels of building performance. Providing energy analysis results to the design team early in the design is essential so they can identify energy-saving improvements against this baseline while the design was being modified (Stumpf, Kim, & Jenicek, 2009).

A variety of energy simulation software products exist. Some energy simulation software, such as Autodesk's Vasari, allows for the examination of parameters such as thermal properties, orientation, weather data, and HVAC systems, to predict the general performance of a building. Other energy simulation software programs are able to perform more specific analysis on single aspects of building design (such as daylighting or mechanical systems). Energy simulations, when used properly, have the potential to lead to more efficient designs, lower costs and result in better value for a building's owner by allowing the energy implications of multiple designs to be efficiently compared and examined.

In general, different types of analysis occur at different phases in a project. A study by Stumpf et al. (2009) refers to the energy analysis process occurring in three phases. In the conceptual design phase basic energy simulations are most appropriate. These early stage simulations measure the expected energy use based on a building's geometry, climate, building type, and mechanical systems (Stumpf et al., 2009). These high-level results are used to optimize the form and orientation of a building. During the detailed design phase of a building, energy analysis is geared towards building elements such as size, shape, and material of wall penetrations (Stumpf et al., 2009). This low-level analysis of building elements allow designers to analyze how different materials, minor design detail changes, and mechanical systems will impact the overall performance of the building. The final step is refinement, in which validation of results between a distinct, independent energy modeling software program is needed (Stumpf et al., 2009). Although uncommonly practiced on projects other than those with the loftiest sustainability goals, the third step of refinement and validation may increase overall accuracy of results (Stumpf et al., 2009).

Continuous building performance analysis during the design process leads to more comprehensive feedback on the performance implications of different design variations, which can lead to more energy efficient designs. Early design and preconstruction stages of a project are the most critical phases to make decisions on designs and features that impact energy performance (Azhar et al., 2012). However, the ability to quickly analyze and compare design alternatives is especially important in the early preconstruction and early design phases of a project. In fact, Attia and De Herde (2011, p. 3) go as far as to say "20% of the design decisions taken subsequently, influence 80% of all design decision." Therefore, the ability to optimize design decisions in the early design stages of project impacts a designers ability to make future design decisions that further optimize building performance in later stages of design.

The Value of Energy Simulation

Rising energy costs, increasingly stringent building codes and voluntary green building rating systems continue raise the bar for building performance. Leadership in Energy and Environmental Design (LEED) is perhaps the most well-known green building rating system in the U.S and continues to gain popularity internationally, with over 2 billion SF of building space certified under this program as of June 2012 (USGBC, 2012). Certain LEED rating systems, such as LEED-NC v2009 (among others), provide users with compliance paths for receiving credits that use energy modeling. For example, the LEED Energy and Atmosphere prerequisite 2 (EAp2) and the credit associated with it (Energy and Atmosphere credit 1) allow users to demonstrate their modeled building's predicted performance is a certain percentage over a specific code's requirement, in this case ASHRAE Standard 90.1-2007 or California Title 24-2005 Part 6.

Contractors, construction managers and designers who want to provide better value to their clients can also benefit from the use of energy simulation software programs. Energy simulation programs allow users to compare the building performance implications of alternative building forms, designs, materials, and mechanical systems. When cost information and the estimated product lifecycle information of different materials are accounted for, it allows stakeholders to perform a cost benefit analysis to determine if the benefits of an alternative justify its upfront costs. Contractors and construction managers can utilize energy simulation to guide or validate the value engineering (VE) process to ensure that their VE suggestions add to (or at very least, do not detract from) the designer's initial intent in regards to building performance.

Challenges of Energy Simulation

Implementing energy analysis on projects is not without challenges. Prior to the 1970s less consideration was given to building energy efficiency (Geller, Harrington, Rosenfeld, Tanishima, & Unander, 2006). Architects largely ignored energy implications of design to meet aesthetic and functional goals while engineers were content to use previously proven precedents and that leaned towards oversizing building systems. Part of the reason for this shortfall in attention to energy performance was the availability of cheap energy, a lack of correlation between using fossil fuels and negative environmental impacts, insufficient attention and knowledge related to energy efficient building concepts, and the large amount of time that it took to perform energy analysis (Schurr, 1980; McMichael & Anthony, 2004). Traditional building performance analysis, which is based on information from physical models, drawings and CAD, requires a great deal of human intervention, which makes analysis too time consuming and costly for most designers to justify (Azhar et al., 2009).

Now numerous computer-based energy simulation programs exist that are capable of performing calculations in short periods of time. In fact, so many energy simulation tools are available that deciding among them is difficult. The DOE website has over 389 building performance simulation tools listed and of these tools less than 40 are targeted for architects to use in the early design phase of a project (Attia & De Herde, 2011).

A recent study by Attia and De Herde (2011) revealed that architects most important selection criteria for building performance analysis tools is "intelligence," or the ability to inform decision making on both performance and cost. These architects indicated a lack of intelligence among energy simulation tools they compared. However, software programs with greater levels of intelligence are beginning to emerge. One such tool is "BeOpt" (short for Building Energy Optimization), which was developed by the National Renewable Energy Laboratories (NREL) to optimize cost effectiveness in achieving desired levels of building performance for residential building designs.

As mentioned earlier, a lack of continuous building performance analysis throughout the planning and design phase leads to an inefficient process of retroactively modifying design to achieve desired performance criteria (Schluter & Thessling, 2009). However, a study carried out by Welle et al. (2011) indicated that the design professionals surveyed spent less than half of their time doing “value adding” design and analytic work, and used simulation tools primarily to validate a chosen design alternative, not to explore multiple alternatives to guide design decisions. This means many design professionals are missing the full potential to optimize building performance. In addition, improving the sustainability of a building through energy analysis can be a difficult process due to the difficulty of assessing one improvement verses another, especially when designers change more than one building element at a time (Bank, 2010).

Despite the fact energy simulation software has become increasingly user-friendly and time efficient to use, these software programs can still require considerable time to complete with high levels of precision. The large number of parameters needed for running an energy simulation for a whole building and lack of information about buildings early in the design process can yield a vast, under-determined parameter space (Raftery, Keane, & O’Donnell, 2011). Assumptions are used to fill in this under-determined parameter space. Inaccurate assumptions lead to inaccuracies in building performance simulations, which ultimately leads to unreliable energy simulation results to base decisions on. In addition, buildings are often designed by multiple stakeholders, which are all in charge of distinct subsystems. Ineffective communication channels among stakeholders can result in incomplete information or further delay the transfer of information needed to run an energy simulation.

Some design stakeholders may find it hard to integrate building performance simulation into the design process. A study by Attia and De Herde (2011) found that architects and non-specialist users had a hard time integrating building performance simulations into the design process for net-zero energy buildings. This could be partially due to unfamiliarity with software programs used or difficulty changing design processes to aid the energy simulation process.

Lastly, multiple studies have shown that significant improvements need to be made for whole building energy simulation to become a more reliable decision making tool in the design process (Raftery et al., 2011). In the same study, Raftery et al. (2011, p. 2356) were quoted saying “there are significant discrepancies between simulation results and the actual measured consumption of a real building.” However, multiple factors may attribute to the discrepancies between energy simulation results and a buildings actual performance. For example, if a project is not constructed to the designer’s original intent, this can exacerbate the discrepancy between an energy simulations results and the actual buildings performance. However, even moderately accurate energy simulation results can be useful during the decision-making process as it still allows for a comparative analysis of the energy implications of the different design options.

BIM and Energy Simulation

Lack of continuous building performance analysis during the design process can lead to less efficient designs, which can require retroactively modifying designs to achieve desired performance criteria. Since BIM is capable of storing and updating data about a building throughout the design process that can be extracted and analyzed to improve the decision-making process (Azhar et al., 2009), an ideal opportunity exists to leverage the information stored in these models to inform energy simulations. However, few firms have completely figured out how to leverage BIM for energy simulation to its fullest extent due to a number of limiting factors and barriers including contract structure, process standardization for updating BIMs among interdisciplinary teams, and interoperability issues. The use of BIM-based energy simulation tools can simplify the burdensome, arduous process of running simulations (Azhar & Brown, 2009). BIM software used in conjunction with energy simulation software allows for building performance measures of a structure to continuously be analyzed throughout the design process, ensuring that performance criteria are maximized (Azhar et al., 2011). Since BIM-based energy simulation allows users to rapidly predict performance of different designs, it can help designers choose a building design that maximizes functionality, cost and performance (Schade et al., 2011).

BIM and Energy Simulation: Opportunities

Building performance analysis in the design stage is not an uncommon practice on projects where environmental performance or reducing energy usage is of high concern. Using BIM-based energy simulation tools gives designers access to feedback on design alternatives early in the design process (Azhar & Brown, 2009). However, in order to assess a buildings predicted performance early in the design or preconstruction phase, access to a comprehensive set of information regarding the proposed buildings form, materials, location and technical systems are required (Azhar et al., 2010). Since BIM allows for multi-disciplinary information to be stored in one location it creates an ideal opportunity for sustainability measures and performance analysis to be performed throughout the design process (Azhar et al., 2010). While traditional CAD programs do not support the possibly of early decision-making based on building performance analysis (Azhar et al., 2009), today's virtual design software (BIM) give users the opportunity to explore different energy saving options more easily while avoiding the time-consuming process of re-entering information pertaining to building components, geometry, etc. (Stumpf et al., 2009).

Integrating BIM with energy simulations can greatly simplify the cumbersome energy analysis processes and allows for energy simulations to be performed more frequently throughout the design process (Azhar et al., 2009). BIM can reduce costs associated with traditional energy analysis by making information needed for the energy analysis process routinely available as a byproduct of standard design process (Azhar et al., 2009). In addition, existing information databases can help inform assumptions about energy simulations in order to make them more accurately represent an actual buildings operation and potentially improve accuracy of a building model (GSA, 2012). BIM software also allow for the creation of thermal zones, making it unnecessary for modelers to create thermal zones within an energy model (GSA, 2012).

BIM and Energy Simulation: When to use it

Leveraging multidisciplinary BIM-based energy simulation is becoming more important with the current emphasis on energy efficient buildings (Welle et al., 2011). Energy simulation can be performed at any point during the design process. However, to achieve maximum building performance, energy simulation should commence early in the design process and continue throughout a projects design stages (Attia & De Herde, 2011). According to Azhar et al. (2009), "… lack of integration of building performance analysis during the design process leads to an inefficient process of retroactively modifying the design to achieve a set of performance criteria." Fortunately, practitioners who do use BIM-based sustainability analysis typically used it in the planning and early design stages (Azhar et al., 2009). BIM provides the opportunity to perform continual analysis throughout a project's conception, design, construction and post occupancy phases, while traditional design tools require a separate energy analysis at the end of design, reducing opportunities for early modifications that can improve a building's performance (Azhar et al., 2009).

BIM for Energy Simulation: Who can Benefit from it

Many project stakeholders can benefit from the leveraging BIM for energy analysis, including: Architects, Engineers, Contractors, Subcontractors, as well as owners (Azhar, & Brown, J. , 2009). Architects and design build firms make up the majority of practitioners using BIM-based sustainability analysis (Azhar, & Brown, 2009). Architects are able to quickly use information stored within BIM models to more time efficiently run energy simulations. The results from these simulations are invaluable in guiding decisions about the aesthetics, functionality and performance implications of different design variations such as form, envelope, glazing, and orientation. Engineers can leverage BIM information to inform their designs to further reduce energy demands by comparing implications of HVAC systems and they can use 3D models to calculate light reflectance and penetration (Azhar & Brown, 2009). Skilled contractors and construction managers can also investigate the potential implications of various value-engineering options for an owner. Lastly, owners can benefit from being able to more accurately determine the long-term maintainability and energy usage (Azhar et al., 2012) of a building and weigh that against its upfront costs and determine how design changes impact overall building aesthetics and functionality.

BIM to Energy Simulation: Data Exchange

To date, no fully automated data exchange infrastructure has been unanimously adopted across the entire AEC industry (Hitchcock & Wong, 2011). Current common practice is for design to initially take place from the perspective of an architect. Energy modelers must then work with the information provided by the architect to manually transform it and fill in assumption about the model to create a different BIM model for energy simulation (Hitchcock & Wong, 2011). According to Hitchcock and Wong (2011, p. 1) there is a "lack of commercially available software robustly supporting" the process of converting information within BIMs into information that is usable by energy simulation programs. Contributing to this is the fact that BIM software vendors are not interested in producing third party tools for robust data exchange. Instead, they prefer to embed energy simulation programs into their own products to support business goals (Hitchcock & Wong, 2011). However, two prevalent informational infrastructures exits in the AEC industry, Industry Foundation Class (IFC) and Green Building Extensible Markup Language (gbXML) (Hitchcock & Wong, 2011). Both of these information infrastructures translate data between different BIM and energy simulation programs through a common language (GSA, 2012). A report by the GSA (2012) argues that these informational infrastructures increase transparency in the process of energy simulation and also reduces the need of rebuilding models. However, Kim, Oh, Park, Kim, and Kim (2011) suggest that using either of these informational infrastructures reduces the certainty that information is getting sent among software programs precisely.

The IFC information exchange protocol was established to help improve processes and to help with the sharing of information in the construction industry and facilities management industries (Dong, Lam, Huang, & Dobbs, 2007). IFC data exchange protocol has a "top-down" data schema that is highly organized and represents relational data (Dong et al., 2007). In other words, IFC is structured in layers that build upon each other. For example, a wall is an object, which is a subtype of an *IfcBuildingElement,* which is a subtype of an *IfcElement* (i.e. walls, doors, windows, etc.), an element is a subtype of an *IfcProduct* (Dong et al., 2007). The *IfcProduct* has two attributes that represent its overall location and shape.

Similar to the IFC information exchange protocol, the gbXML information exchange protocol facilitates the exchange of data between CAD tools and energy simulation tools (Dong et al., 2007). According to Dong et al. (2007, p. 1531), “gbXML is developed based on the XML (Extensible Markup Language) format, which provides a robust, non-proprietary, persistent, and verifiable file format for the storage and transmission of text and data both on and off the Web.” Since the gbXML schema is so robust yet realatively simple it allows for quicker implementation of schema expansion for new design purposes (Dong et al., 2007).

BIM and Energy Simulation: What to use it for

Energy simulation can be used to analyze many aspects of building performance. BIM-based energy simulation can aid in multiple facets of sustainable design, including building orientation, building massing, daylight analysis, energy analysis, water harvesting, and green materials selection (Krygiel & Nies, 2008). Geometries can be extracted directly from preexisting BIM models to help populate energy models, resulting in time savings (GSA, 2012). BIM-based energy simulation can also be used to help optimize passive solar strategies, such as building orientation, tuning overhangs and windows. Massing helps to optimize the overall size and form of a building to meet functionality requirements and minimize energy consumption. Daylighting analysis predicts how much of a space can be naturally illuminated with day light, thus reducing lighting related energy usage and costs. Energy analysis can predict a building’s energy usage, allow designers to analyze the energy impacts of alternative design options to reduce energy needs and help determine renewable energy requirements.

BIM-based energy simulation is also a valuable tool for performing value analysis. According to Dell'Isola (2003) value analysis is “an organized effort directed at analyzing the functions of systems, equipment, facilities, services, and supplies for the purpose of achieving essential functions at the lowest life-cycle cost consistent with the required performance, reliability, quality, and safety.” However as the formula for value (Value = Functional benefits ÷

Cost) implies that value could be increased in more than one way. For example, costs could be raised and if functional benefits were raised by a larger amount than the overall value would still be improved over the original design. When BIM is integrated with energy simulation tools, it can be used to quickly analyze the impact of a specific value added recommendation (Dell'Isola, 2003). As with the rest of the design process, BIM can help stakeholders collaborate and share information during the VA stage of a project.

BIM and Energy Simulation: Proof that it works

Few companies have taken the time to actually track the benefits associated with leveraging BIM for energy simulations. However, more are beginning to and many are reporting positive results. For example, SmithGroup used BIM tools to redesign buildings to be more energy efficient and were able to achieve energy savings of 19.6%, which resulted in a cost savings of 22.4% (McGraw-Hill, 2008). This energy savings was “primarily achieved through lowering space cooling, lighting, and through exchange of pumping and heating energy usage.” (McGraw-Hill, 2008).

A study carried out by Azhar and Brown (2009) sought to determine the current state and benefits of three BIM-based building performance analysis software programs. A questionnaire survey instrument was sent out to design and construction firms who use BIM technology and/or sustainable design/ construction practices in most of their projects. This survey showed that “Practitioners implementing BIM-based sustainability analyses are realizing some-to-significant time and cost savings as compared to the traditional methods.” In addition, the authors proved that practitioners were experiencing some to high degree of satisfaction with using BIM-based sustainability analysis over traditional energy analysis products. This study suggests that, in general, design stakeholders who use BIM-based energy analysis perceive a positive value associated with its use. This study, however, does not explain all of the barriers and benefits associated with BIM-based energy simulation that influence design stakeholders' perceptions of the value associated with using BIM-based analysis. Like if experience with BIM and/ or energy simulation software programs is correlated to design stakeholder's overall perceptions of value related to using BIM-based energy simulation.

According to a second study by Azhar et al. (2010) the construction company DPR Construction was able to save time and money for itself and stakeholders by utilizing BIM-based energy analysis tools. This same study also shows that DRP realizes $28,000/ year in energy savings from utilizing energy simulation on the design of their headquarters building. Although this savings resulted from non-BIM based simulation, DPR analyzed both software programs and concluded that the BIM-based methods they used perform as well, if not better, than the actual results. This study confirms that BIM-based energy simulation can be used as a tool to make cost saving decisions about a building's design.

BIM and Energy Simulation: Future Implications

While leveraging BIM for energy simulation is far from a widespread practice in the AEC industry, its use is growing. Results from a survey by Ku and Taiebat (2011) that was administered to construction companies indicates that while the companies surveyed do not perceive an immediate need to use BIM for environmental/ sustainability analysis, that it would become increasingly important in the near and far future. Since BIM enables rapid analysis of different building scenarios related to performance, it has the potential to benefit project outcomes (Schade et al., 2011). In addition, Bryde et al. (2013, p. 2) speculated that "BIM will eventually lead to a virtual project design and construction approach, with a project being completely simulated before being undertaken for real."

Barriers to BIM energy simulation

In addition to the barriers for implementing BIM and energy simulation within an organization respectively, using BIM-based building performance analysis presents its own set of risks and challenges. According to Azhar et al. (2010, p. 221) these risks and challenges include: "lack of interoperability between various BIM-based applications, the relative slowness of the mechanical design community in adopting BIM, and lack of BIM-based analyses applications certified by the California Energy Commission." Interoperability issues can create inadequate data exchange between BIM and energy simulation programs, making it difficult to realize the full potential benefit of leveraging BIM for energy simulation (Kim & Woo, 2011). Since data sets required to build an accurate energy model are so complex, to achieve accurate energy simulation results, integrated simulation tools should be used (Motawa & Carter, 2013). Green BIM tools integrate the BIM model and the energy simulation tools, which can improve analysis accuracy and minimizes data handling errors (Azhar et al., 2011). However, a study by (Kim & Woo, 2011) showed that results varied as much as 30% from actual building performance and that BIM-based energy simulations were less accurate when it came to at predicting HVAC performance than standard energy simulation.

Unreliable assumptions or estimated values of loads can result in unreliable energy simulation results. The modeler sometimes makes assumptions, while other assumptions are "deterministic" in nature, meaning that they are assumptions made by the energy simulation software (Kim et al., 2011). However, difficulty exists in accounting for assumptions made by the software. Sharing and utilizing data from previous, similar projects that are already operational can help mitigate this problem by improving assumptions on behalf of the modeler (Motawa & Carter, 2013). Inaccurate input variables can have a large impact on the accuracy of energy simulation results so ensuring that inputs reflect the probabilistic nature of real world situations is important in order to achieve reasonably accurate and useful results (Kim et al., 2011).

While leveraging BIM for energy simulation is gaining popularity, a number of barriers still exist that prevent it from being used to its full extent. As previously mentioned, certain contract types and interoperability issues can both act as barriers to BIM-based energy simulation. Additionally, a lack of proficiency with BIM, energy simulation tools or the process of leveraging BIM for energy simulation can impact the potential maximize the effectiveness of leveraging BIM for energy simulation. Similarly to interoperability issues, a lack of proficiency with any of the aforementioned tools can lead to increased time required to complete a model and perform a simulation, the cost associated with of the extra time needed to perform the BIM-based energy simulation process and the potential for a decreased level of accuracy (Ku & Taiebat, 2011).

Other barriers to implementing BIM-based energy simulation that are more specific to each software are cost (software, hardware, and training), lack of management buy in to either, lack of BIM standards for model integration, lack of motivation to change current processes, and lack of others capabilities to collaborate. Lastly, an energy model is only as accurate as the information that is constructed with, thus, if building elements are not accurately constructed in BIM model it can negatively impact the accuracy of an energy simulation. The inability to calibrate models for future use with actual building energy usage prevents future models from becoming more accurate (GSA, 2012).

Need for Research

As this discussion implies there is a need to better understand design stakeholders' perceptions of the value associated with using BIM-based energy simulation as a decision making tool and how these perceptions differ among user groups. Additionally, there is a need to better understand if experience with BIM and/ or energy simulation software programs is correlated to design stakeholder's overall perceptions of value related to using BIM-based energy simulation. While some research exits on design stakeholders' perceptions of using BIM-based energy simulation, a need exists to correlate these perceptions to individuals overall engagement with both BIM and energy simulation tools. A past study by McGraw-Hill (2008) indicates that users perceptions of BIM improved as they gained more experience with it and that BIM users are twice as likely to see BIM as helpful on green projects as compared to beginners. Likewise, the possibility exists that a users' engagement with both BIM and energy simulation are positively correlated to their perception of its value for leveraging BIM for energy simulation. After all, difficulty exists in knowing the value associated with something without first understanding how to use it to its full potential.

CHAPTER III

RESEARCH APPROACH

Sparse literature exists that identifies the perceptions that design stakeholders' have on using BIM to aid in the creation of energy models and running energy simulations. Even less literature exists that identifies the factors that affect design stakeholders' perceptions pertaining to using BIM to create energy simulations. This study seeks to confirm a positive correlation between green design stakeholders' engagement levels and their perception of leveraging BIM for energy simulation. To answer these questions, an e-survey was developed to quantitatively and qualitatively measure perceptions of green design stakeholders as well as the demographics of these stakeholders.

Research Strategy

Method of Data Collection

The e-survey was distributed using Qualtrics, an online survey design and distribution tool. The goal of this survey was to determine respondents' perceptions on leveraging BIM for energy simulation while observing characteristics about these respondents, such as: demographic data, firm type and size, and experience level with BIM software and energy simulation software. This survey allows the researcher to identify the factors that impact how green design stakeholders' engagement levels with BIM and/or energy simulation impacts their overall perceptions of leveraging BIM for energy simulation.

Sample

Responses were collected from various green design stakeholders. The population of this study consists of all green design stakeholders located in the U.S that use BIM and/or energy simulation software as a part of their job. The stakeholders in this study mainly consist of architects, engineers, and energy modelers, although the survey instrument accommodates anyone who meets the description of green design stakeholder. Other stakeholders could include, but are not limited to: Construction managers, general contractors, sustainability/energy consultants, project owners, etc.

The sample started off as a convenience sample that was then allowed to "snowball" to the contacts of those in the initial convenience sample. The initial convenience sample was formed through a variety of channels and was comprised of approximately 210 contacts who were asked to also forward the survey along to any of their contacts who met the criteria of a "green design stakeholder." First, the author developed a list of green design stakeholders that were past and present clients of a local sustainable consulting firm. This list yielded approximately 120 contacts, many of which are located in the Midwest Region (primarily in Colorado). Second, the survey instrument was sent to a contact at BIMforum.org who volunteered to distribute this survey to his contacts that met the definition of green design stakeholders. The BIMforum.org contact indicated that he distributed this survey instrument to approximately 60 contacts. Third, this survey was distributed to a well-respected construction management professor who has influenced this study through his past works. This construction management professor forwarded the survey along to 20 green design stakeholders. Fourth, this survey was sent to approximately 50 respondents from ENR's Top Green Contractors from 2011 and 20 more from the 2013 list. Lastly, this survey was distributed among the researcher's personal contacts so that they could forward it along. The researcher's personal contacts included Colorado State University (CSU) professors, an Autodesk representative, and other industry contacts. This survey is estimated to have been sent out to more than 270 primary and secondary contacts, but because snowball sampling was used to expand upon the pool of respondents, there is no way of knowing how many people this survey was distributed to.

Survey Development

This survey instrument used for this research was developed with information derived from interviewing design and construction professionals and from researching and reviewing existing literature on this topic as described in Chapter 2. The initial questions were revised and updated though multiple meetings with various professors from the CSU Department of Construction Management.

Pilot Test

This survey was distributed among eight academics and industry professionals to check for conciseness, clarity, and to provide general feedback during two rounds of piloting that took place during March of 2014. The survey was revised based on the feedback received from the survey pilot round. In addition, approximately 12 graduate students took the survey and provided the researcher with open-ended feedback on the length, clarity and conciseness of the survey.

Survey Sections

The survey instrument is broken down into five sections: *Introduction*, *Demographics*, *BIM Aptitude*, *Energy Simulation Aptitude*, and *How BIM and Energy Simulation Work Together*. Skip logic questions were inserted as the first question of the first three sections, so that respondents did not have to answer questions that were not applicable to them. For instance, respondents were asked if they "use BIM as a part of their job?" The respondents who indicated that they did not use BIM as a part of their job skipped past questions pertaining to their BIM engagement levels.

Demographics

The demographics section gauges the firm type, position title, company size, company zip code, and the breakdown of work type for each respondent. Respondents were given the option to choose from a list of company types, including architectural, engineering, construction management, general contractor, energy modeling and sustainability/ energy consulting firms. Respondents also had the option of selecting owner or specifying their own company type if none of the previous options fit their job title. Each respondent was asked to fill in a box indicating his or her position title. Respondents were then asked to indicate their company size.

Size ranges for this question were used directly from McGraw-Hill (2012), which distinguishes company sizes by annual revenue. McGraw-Hill also breaks down company size by firm type. For example, architects and engineers are defined as small firms if they produce less than $500,000 of annual net revenue, while contractors and owners are defined as small firms if they produce less than 25 million dollars of annual revenue. Because McGraw-Hill did not include revenue for the additional positions addressed in this study, energy simulation firms, sustainability/ energy consulting firms and the option for "other, please specify" were grouped in with the architect, engineer and owner company sizes, while construction management firm sizes were grouped with the general contractor and construction management firm company sizes.

The revenue ranges from this study are only three years old, and therefore still assumed to be relevant for use in this research. An illustration of the company size ranges for architects and engineers as well as contractors and owners is broken down in Tables 1 and 2 below.

Table 1: ***Company size breakdown by revenue (design related)***

Firms Types: Architects, Engineers, Energy Modelers, Energy Consultant, Owner & Other (design related)	
Small firms	Less than $500,000
Small to medium firms	$500,000 to less than $5 million
Medium to large firms	$5 million to less than $10 million
Large firms	$10 million or more

Table 2: ***Company size breakdown by revenue (construction related)***

Firms Types: Construction Managers, General Contractors	
Small firms	Less than $25 million
Small to medium firms	$25 million to less than $100 million
Medium to large firms	$100 million to less than $500 million
Large firms	$500 million or more

Lastly, respondents were asked to indicate the ZIP code in which their company was located and asked to give an estimate of the percentage of work their company performed by work type. Work type selection was broken down into *commercial, residential, institutional, and industrial*. In addition "other" was added as a response, which allowed the respondents to fill in their own work type.

BIM Aptitude

The BIM aptitude section determined whether respondents used BIM as a part of their job and measured respondents' engagement levels with BIM. The engagement index was adapted from a McGraw-Hill (2012) study. The engagement index is out of 27 points, where 27 indicates very high engagement scores, 19-26 indicates high engagement scores, 11-18 indicates a medium engagement score and 3-10 indicates a low engagement score. This engagement index is comprised of three categories: user experience, user expertise and firm implementation levels. These three categories are all self-reported by respondents. Experience measures the number of years a respondent has been using BIM. Expertise indicates the level each respondent selected as best representing his or her personal skills with BIM. Implementation measures the percentage of projects being done in BIM by the respondents firm. This engagement index is illustrated in Tables 3 and 4 below.

Table 3: ***Engagement index point structure***

Experience		Expertise		Implementation	
1 year	1 point	Beginner	1 point	Light (<15%)	1 point
2 years	2 points	Moderate	3 points	Moderate (15%-30%)	3 points
3 years	3 points	Advanced	6 points	Heavy (31%-60%)	5 points
4 years	4 points	Expert	10 points	Very heavy (Over 60%)	8 points
5 years	5 points				
> 5 years	9 points				

Note: Adapted from " The business value of BIM in North America: Multi-year trend analysis and user ratings (2007-2012)" by Mc-Graw Hill Construction, p. 8 Copyright 2012 by McGraw Hill Construction. Adapted with permission. -

Table 4: ***Engagement classification level***

Tier of BIM engagement (E-Level)	Range of scores for each E-Level
Very High	27
High	19 to 26
Medium	11 to 18
Low	3 to 10

Note: Adapted from " The business value of BIM in North America: Multi-year trend analysis and user ratings (2007-2012)" by Mc-Graw Hill Construction, p. 8 Copyright 2012 by McGraw Hill Construction. Adapted with permission.

In addition, this survey inquires which BIM software program(s) each respondent uses. Respondents are able to select multiple BIM products from a list of 19 BIM software programs. This list was taken from a CAD-Addict.com list of BIM software products and providers. Respondents also have the option to select "Other, please specify," if their software program(s) were not on the list, giving them the opportunity to list their BIM software manually to ensure that no software programs were overlooked.

Energy Simulation Aptitude

The *Energy Simulation Aptitude* section measures respondent's engagement levels with energy simulation. The same engagement index for BIM was adapted to measure respondents' engagement levels with energy simulation. The exact same values were used as with the BIM engagement index. The engagement index is out of 27 points, where 27 indicates very high engagement scores, 19-26 indicates high engagement scores, 11-18 indicates a medium engagement score and 3-10 indicates a low engagement score. This engagement index is comprised of three categories: user experience, user expertise and firm implementation levels. These three categories are all self-reported by respondents. Respondents were also asked to indicate which energy simulation software program(s) they use. A list of 20 options was given with an "Other, please specify" option. These energy simulation software programs were found through an exhaustive literature review and though web searches. Respondents were also asked how accurate they perceive their energy simulation results to be compared to actual building operation energy usage.

How BIM and Energy Simulation Work Together

This section of the survey measures if respondents use BIM models to inform their energy simulation(s) and it measures respondents overall perceptions of using BIM models to inform energy simulations. Additionally, this survey section investigates respondents' overall perceptions of benefits and barriers associated with leveraging BIM for energy simulation. Major benefits of and barriers to leveraging BIM for energy simulations were identified though a review of relevant literature. Respondents were asked to indicate their level of agreement/ disagreement with a series of statements about benefits and barriers associated with using BIM for energy simulation, respectively. The responses from this section of questions will allow the researcher to determine which barriers are perceived as the greatest to implementing BIM-based energy simulation and what potential benefits are perceived as the greatest. At the end of this section, respondents are provided with a text box so that they may qualitatively describe additional barriers that may have accidentally been excluded of the survey instrument.

Human Research Approval

The survey for this study was sent to the Research Integrity & Compliance Review Office's Institutional Review Board for approval. Since this study maintains confidentiality and was deemed of minimal risk to respondents, it was exempt from the requirements of the human subjects protections regulations as described in 45 CFR 46.101(b)(2). See Appendix **B.**

Data Analysis Methods

Nominal, ordinal, and ratio data were collected from this survey instrument, leading the researcher to draw from a range of descriptive statistics to examine frequencies, mean, median, mode, distribution and standard deviation. Bivariate Pearson correlations were performed so that the relationship between energy simulation/ BIM engagement scores and respondents perceptions of the value associated with using BIMs to inform simulation could be observed. Scatterplots were created to help a visual representation of the relationships between different independent and dependent variables. Cronbach's Alpha tests were run to determine the reliability of both the BIM and energy simulation engagement score indexes. Additionally, t-tests were run to determine the significance levels in the differences in mean values between different user groups overall perceptions of the value associated with using information from BIMs to inform energy simulation and their perceptions of the how accurate energy simulation is at predicting an actual buildings performance. The findings and analysis of these statistical analyses are presented in Chapter IV.

CHAPTER IV

FINDINGS AND ANALYSIS

Data was collected via e-survey (see Appendix C). The questions in this survey instrument are meant to directly address the research questions of this study. In particular, to determine green design stakeholders' perceptions associated with leveraging BIM for energy simulation and what factors impact these overall perceptions. Results from the e-survey are presented in the following sections, which covers: respondent demographics, BIM and energy simulation engagement scores, and perceptions related to BIM-based energy simulation.

The E-Survey Results

Response Rate

Respondents of this study are all green design stakeholders who work for companies located in the U.S. that have experience with either BIM, energy simulation or both. Initially the survey instrument was distributed to approximately 210 primary contacts from a convenience sample. Requests that respondents forward the survey to additional contacts that met the definition of a green design stakeholder were included in both the introduction email and survey. Informal follow up emails were sent to select primary contacts that had only volunteered to forward the survey to secondary contacts. These primary contacts indicated that they had forwarded the survey to as many as 60 secondary contacts total, meaning the number of individuals who received this survey was approximately 270, however the exact number is unknown. The survey was left open for two weeks and received 85 responses. However, a total of 34 respondent results were removed from analysis because they were either insufficiently complete or because respondents did not meet the criteria of the population being observed. Those who did not meet the criteria of the study's population were either not located in the U.S., had no experience with BIM or energy simulation programs, or did not meet the definition of a green design stakeholder. The final survey sample size analyzed for this study is 51. The response rate is estimated to be approximately 19%. However, this number is based on the purposive sampling population of 270, making it impossible to determine how many individuals actually received this survey though the snowball sample. Additionally, because some questions did not pertain to every respondent or were omitted by respondents, the number of respondents varies for certain survey items. In every instance where the sample is less than 51, the number of respondents is stated.

Respondent Profile

Respondents surveyed work at a variety of different firm types, which include: engineering, architectural, general contracting, construction management, energy consulting firms, and "other." The "other" category was comprised of two energy services companies, a modeling/software company, and a firm that specialized in architecture, engineering, energy modeling, and sustainability consulting. The breakdown of firm types is illustrated in Figure 1.

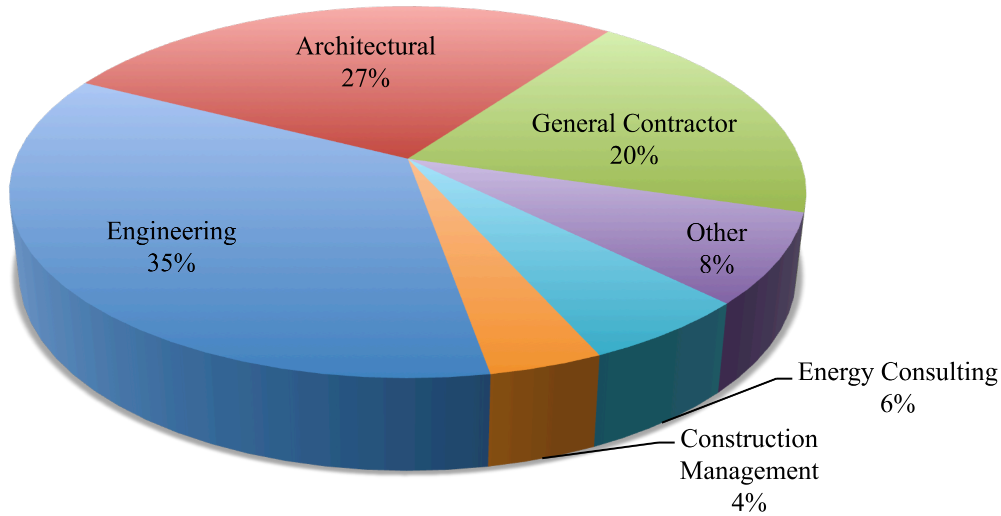

Figure 1: Breakdown of respondents by company type (n=51)

Respondents reported a wide range of position titles within their respective firms. Since respondents used a text box to indicate their position titles, some variation exists in the name for similar/ equivalent titles. These titles were logically grouped together to reduce the number of similar responses names for the ease in displaying the results. For example "owner" was grouped in with "Principal," "ARCHIII" was grouped with "architects," while "Mechanical Designers" were grouped in with "Mechanical Engineers." Figure 2 shows an illustration of position titles held by respondents.

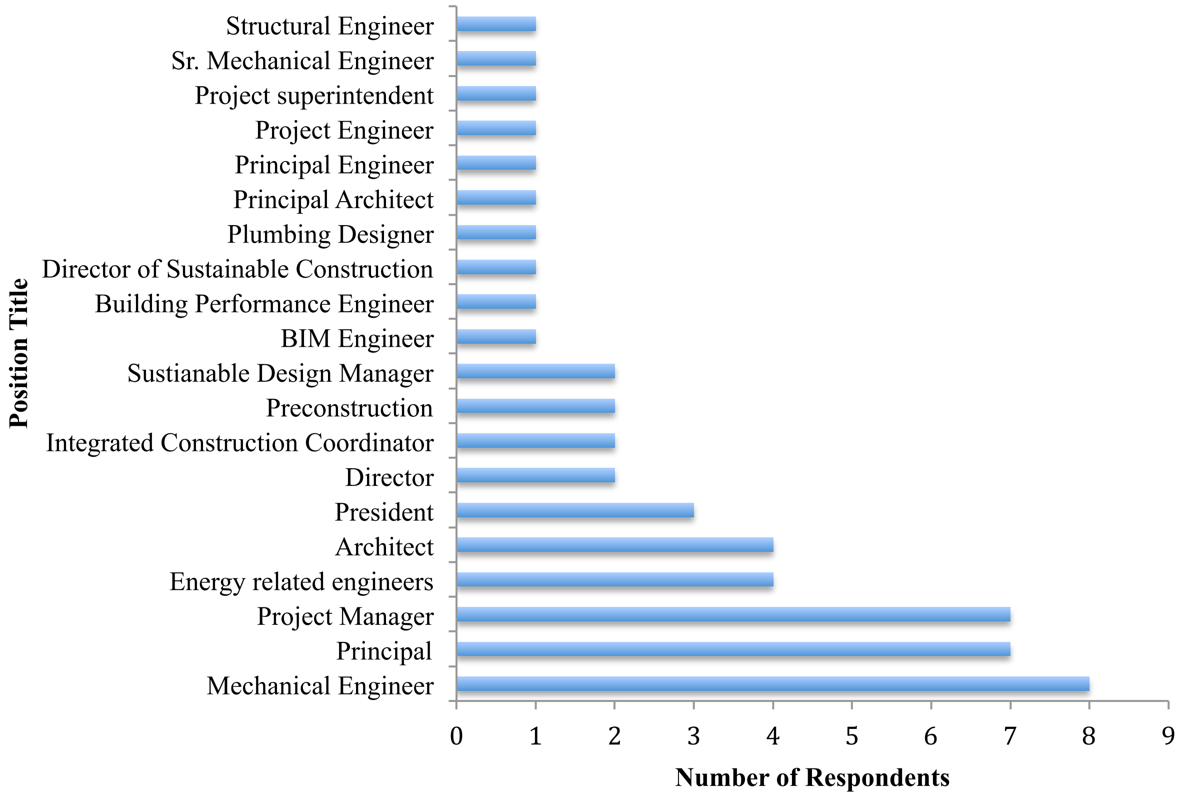

Figure 2: Position title of respondents (n=51)

As a whole, respondents indicated that 43% of their work was comprised of institutional projects, 39% commercial, 10% residential, 7% industrial and 1% other. "Other" work types as indicated by respondents include hospitality, military, sports, LEED, master planning, and civil.

Respondents' firm sizes were measured based on their company type and total net revenue in 2014. The breakdown of respondent firm sizes is listed below for design related and construction related firms in Figures 3 and 4 respectively.

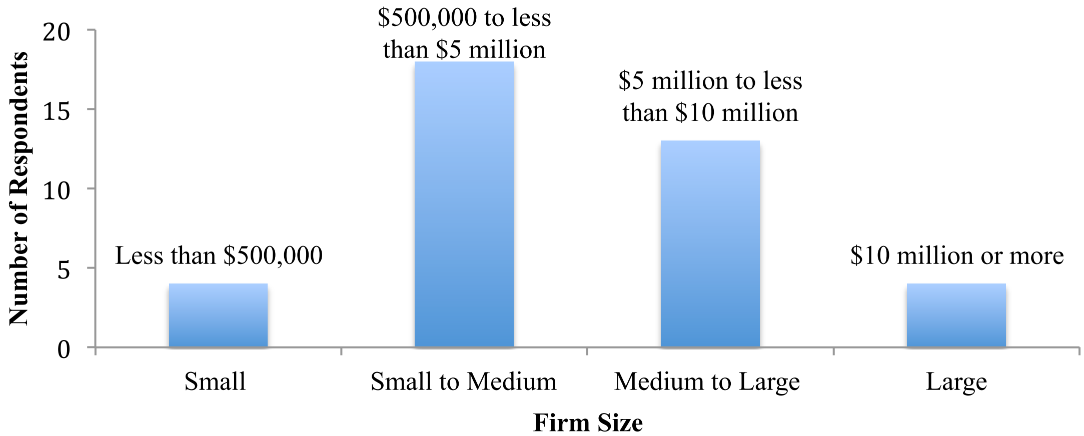

Figure 3: Design related firm size breakdown (n=39)

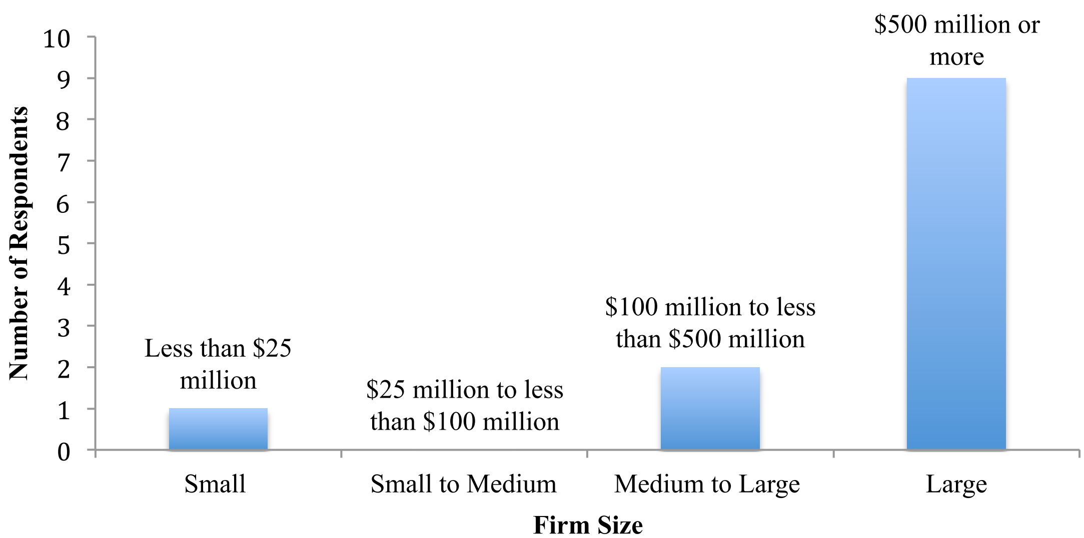

Figure 4: Construction related firm size breakdown (n=12)

Firm Size and BIM-based Energy Simulation

A McGraw-Hill (2012) study showed that 90% of medium and large firms engage with BIM while less than half of small firms do, which suggests that cost can be a very real barrier to small firms. However, this trend only appears to be partially true for firms that use BIMs to inform their energy simulation. For design based firms (architects, engineers, energy modelers, consultants, owners and other) “small” firms comprised 5.2% of the BIM based-based energy simulation users, while “small to medium” made up 31.5%, “medium to large” made up 52.6 and “large” made up 10.5%. Only five construction-related firms used BIM for energy simulation, and of these five, one was a small firm while the other four were large firms.

Respondents reported company zip codes from all over the U.S. However, the vast majority of respondents (n=38) reported that their company was located in Colorado. Table 5 shows the number of respondent’s company locations by state.

Table 5: ***Location of respondent companies by state***

State	Frequency
Arizona	1
California	2
Colorado	38
Georgia	1
Minnesota	3
New York	1
Ohio	1
Pennsylvania	1
South Carolina	1
Washington	1
Washington DC	1
Virginia	1
Wyoming	2
Total	51

Respondent Software User Groups

Survey respondents have mixed background with the software programs that they use. While respondents that did not use either BIM or energy simulation programs were omitted from the data analysis, the remainder of respondents engaged with BIM, energy simulation or both software programs to some degree. Respondents who only used BIM comprised the largest segment of respondents, with 24 of 51 (or 47% of respondents) falling into this category. Users of BIM and energy simulation comprised the second highest group of users with 22 of 51 (43% of respondents) using it, while those who only used energy simulation comprised the smallest group of people with only 5 of 51 (or 10% of respondents). Figure 5 illustrates the breakdown of respondent user groups.

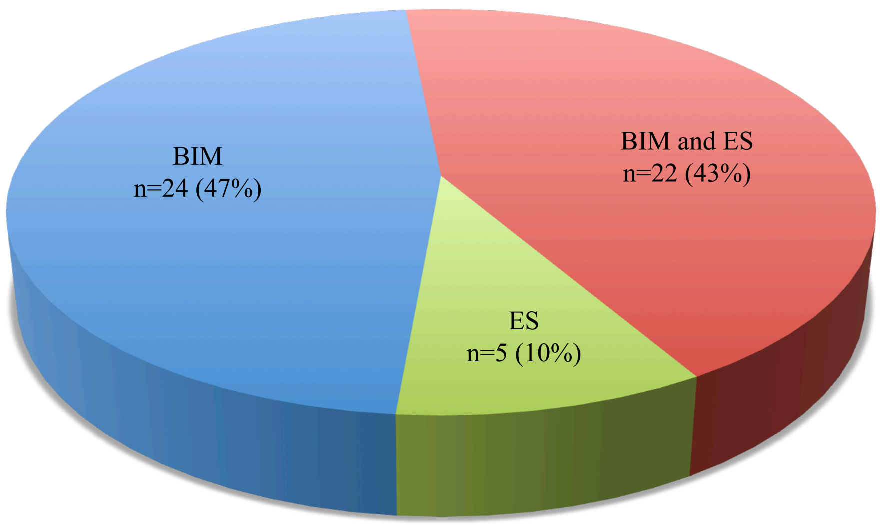

Figure 5: Breakdown of respondent user groups

Reliability of Engagement Scores

A Cronbach's Alpha test was run to determine the reliability of both engagement scales. Each scale is comprised of only three items. For the BIM engagement index a Cronbach's Alpha score of 0.638 was calculated (see Appendix E), indicating that the BIM engagement score is a fairly reliable scale give that there are only three items comprising the engagement index. Likewise, a Cronbach's Alpha test was run to determine the reliability of the energy simulation engagement scale (see Appendix F). The reliability test for energy simulation engagement score yielded a Cronbach's Alpha score of 0.765, indicating a good reliability of this scale.

BIM Engagement

Overall BIM engagement levels were measured for all respondents who use BIM (n=46). The engagement index (mentioned in Chapter III), which was borrowed from a McGraw-Hill (2012) study, is comprised of three different categories: Experience, skill level and percentage of projects used on. For example one respondent indicated that he or she had been 3 years of experience with BIM (3 points), had an advanced level of expertise with BIM (6 points), and was very heavy on implementation (8 points), therefore this respondent had an overall BIM engagement score of 17. The engagement index was previously mentioned and is illustrated in Tables 3 and 4 located in Chapter III.

Of the 46 respondents that used BIM, engagement scores varied widely. The minimum and maximum scores were 4 and 27, respectively (on a 3-27 point scale). BIM software engagement scores were fairly evenly distributed, however, because the engagement level groups are not even it appears as though respondents' engagement levels are on the lower end. The mean score of all BIM engagement scores was 15.04 with a standard deviation (SD) of 6.128. Since the engagement score goes from 3-27, if this scale were to be adjusted from 0-24 the mean of all engagement scores would fall in the middle at 12.04. Table 6 shows the respondent BIM engagement classification breakdown.

Table 6: ***BIM engagement score break down (n=46)***

Engagement Level	Point Range	Number of Respondents
Low	3-10	11
Medium	11-18	24
High	19-26	7
Very High	27	4

Respondents indicated that their firms used a wide variety of BIM software products. An "other" section was left blank in case a respondent did not see their BIM software program listed as an option on the survey. Responses in the "other" section included: Trimble Sketched, Informatics MicroGDS, Solibri, Vasari Beta 3 and Syncho. Multiple respondents indicated that their firm used multiple BIM products, with nine being the highest number of distinct software programs being used by a single firm. Other firms indicated that they only used one BIM software program. On average, each firm used 2.3 different software programs. Figure 6 illustrates all the BIM software programs us

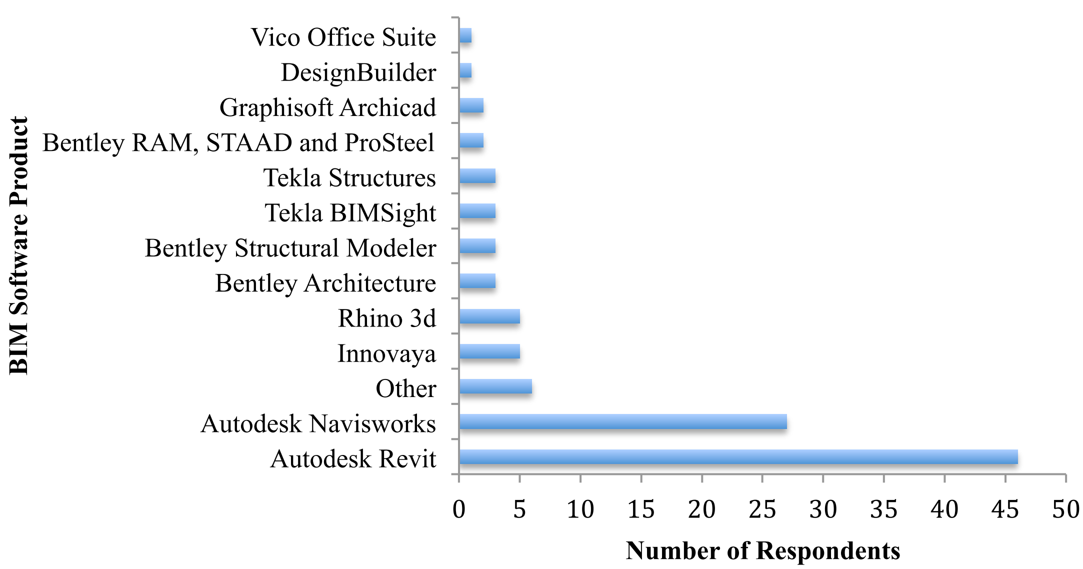

Figure 6: Most common BIM software programs used by respondent companies

Energy Simulation Engagement

Similarly to the BIM engagement index, energy simulation engagement was measured using the same 27-point index. However, the BIM engagement score index from McGraw-Hill (2012) was adapted to reflect respondent experience levels, skill levels and percentage of projects used on as they pertain to energy simulation instead of BIM. For example, one respondent had over five years of experience (9 points), an expertise level of expert (10 points), and had heavy implementation levels of BIM (8 points), giving this user an overall BIM engagement score of 27. A total of 27 respondents used energy simulation as a part of their job. Energy simulation software user engagement scores were fairly evenly distributed. The minimum and maximum scores were 3 and 27, respectively (on a 3-27 point scale). The mean score of all engagement scores was 15.85 with a SD of 7.655. Table 7 shows the respondent energy simulation engagement classification breakdown.

Table 7: ***Energy simulation engagement score break down (n=27)***

Engagement Level	Point Range	Number of Respondents
Low	3-10	8
Medium	11-18	7
High	19-26	9
Very High	27	3

Respondents indicated that their firms use a wide variety of energy simulation software products. Multiple respondents also indicated that their firm uses multiple energy simulation products, with 11 being the highest number of distinct software programs being used by a single firm. Other respondents indicated that their firm only uses one energy simulation software program. The “other” section was left blank in case a respondent did not see their energy simulation software program listed. Included in this section was Trane TRACE, Passive House Planning Package (PHPP), Carrier HAP, and one respondent was “unsure”. Trane TRACE was written in the “other” nine times, making it the second most popular energy simulation software program used by respondents. Figure 7 shows the breakdown of energy simulation programs used by respondent firms.

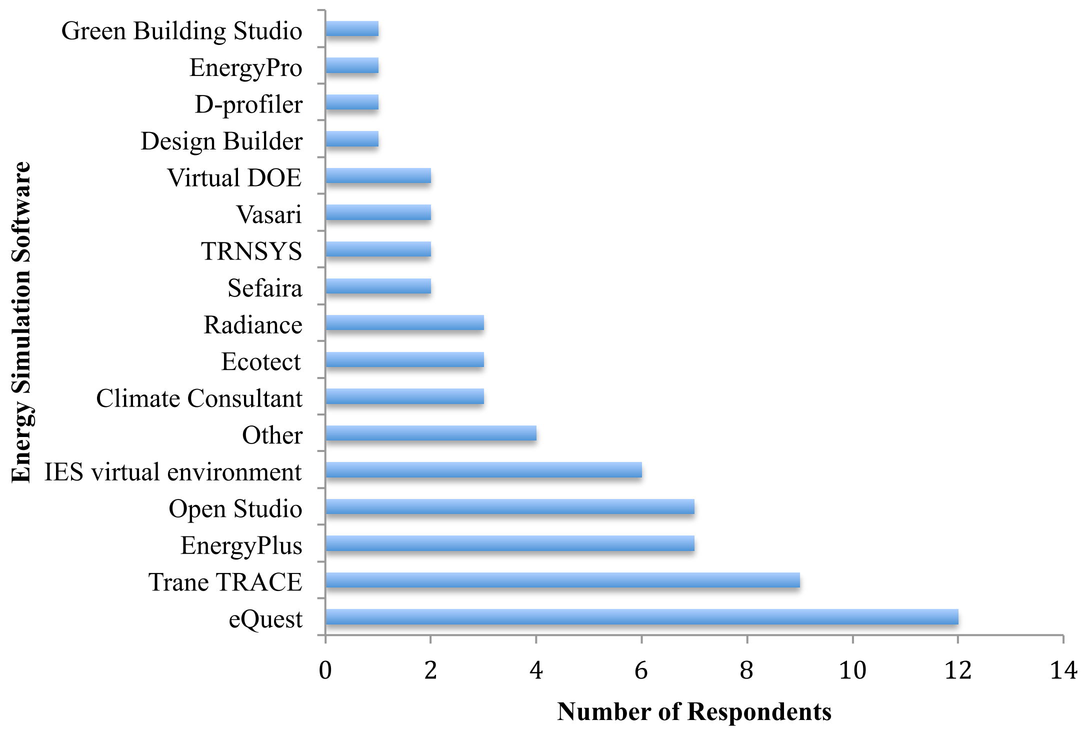

Figure 7: Most common energy simulation software programs used by respondent companies

When the respondents who indicated they used energy simulation programs (n=27) were asked to choose which “more accurately describes how you use energy simulation results?” the majority (78%) of them indicated that they use energy simulation results *to guide the design decision making process pertaining to improving building performance*. Only two respondents indicated that they used the energy simulation results *to validate previously made design decisions pertaining to building performance*, while four respondents chose *Other, please specify.* The answers written into this option included: “research to support energy code development, to quantify saving for facility improvement measures, LEED certification programs, and both of the above & LEED documentation."

Perceptions of Energy Simulation Accuracy

Fifty respondents (n=50) answered the question, *How accurate do you perceive energy simulation in predicting a building's actual operating energy usage?* In general, the respondents had a slightly positive perceptions of the accuracy in which energy simulations predict a building's actual operating energy usage. On a seven-point Likert scale (one being most negative, four being neutral, and seven being most positive) the mean for the response group was 4.66 with a standard deviation of 1.12. The large range of responses on accuracy support claims by Raferty et al. (2011) that significant improvements need to be made before energy simulations become a reliable decision making tool. Figure 8 shows the distribution of respondents' answers for this question.

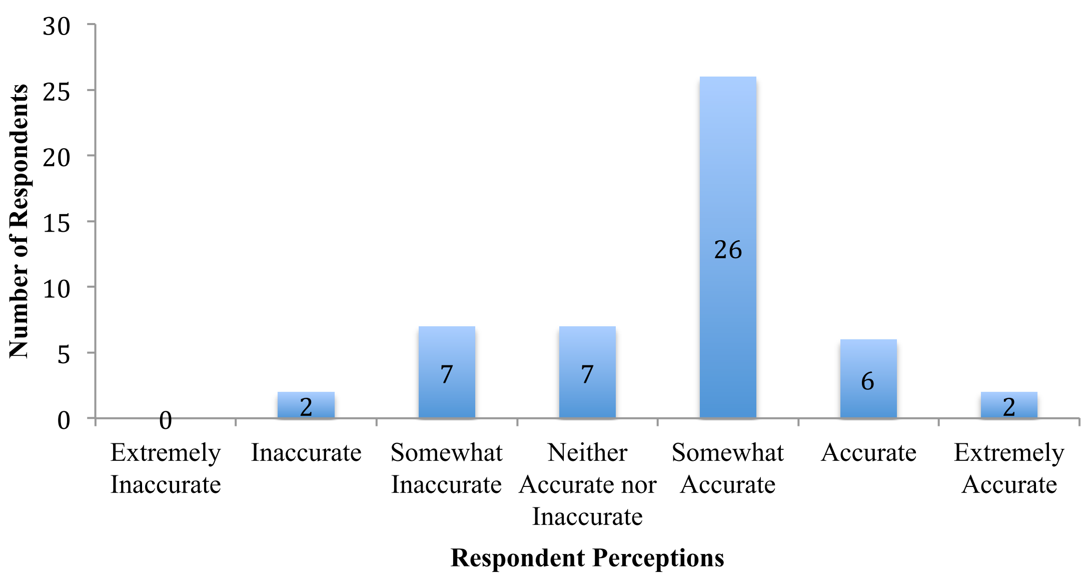

Figure 8: Breakdown of respondents' perceptions of energy simulation accuracy

When asked their level of agreement with the statement "*there is significant room for improvement in the process by which stakeholders provide me with information pertaining to the creation of an Energy Model,"* respondents (n=51) were in the range of "slightly agree" to "agree" with an average score of 5.37 for the response group. Figure 9 shows the distribution of respondents' answers for this question.

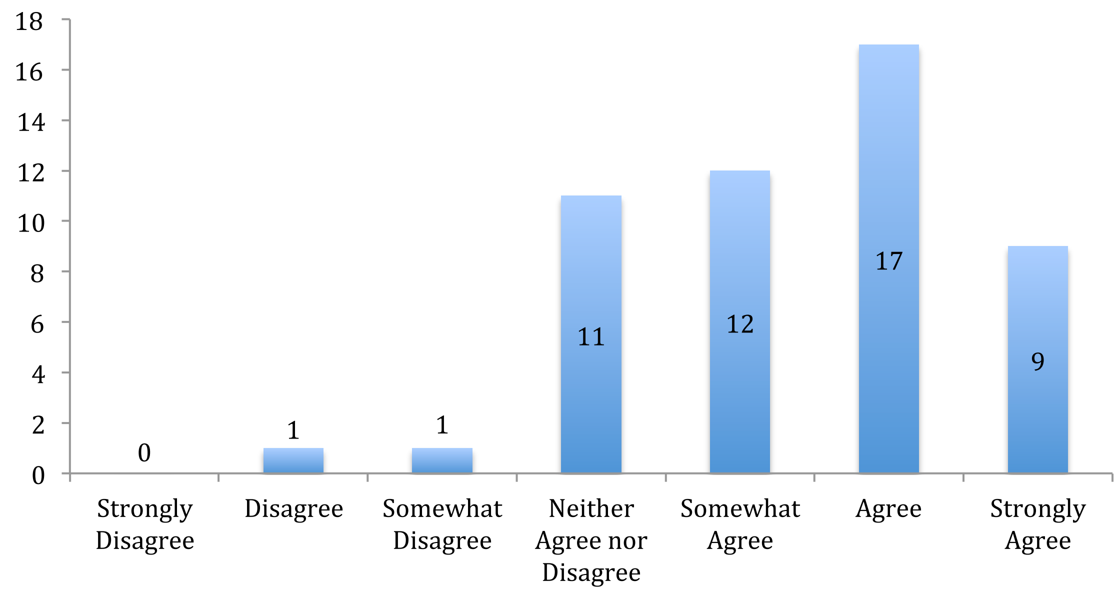

Figure 9: Agreement that the process for providing information pertaining energy models can be improved.

Next, respondents were asked if **their company** *used BIM for the energy simulation process*, which 24 respondents indicated that their company did in fact use BIM for the energy simulation process. This is distinct from earlier in the paper when respondents were asked if they **personally** used BIM and if they **personally** used energy simulation (where 22 had used both).

Respondents who indicated that their company did use BIM for the energy simulation process (n=24) were then asked *how their company uses BIM information in the energy simulation process*. Respondents were given four choices, including:

- *We use BIM based/ integrated energy simulation software that pulls information directly from a BIM software file.*
- *We use a "middleware" to pull info from a BIM model and translate info to other simulation software programs.*
- *We manually pull info from a BIM project file and enter into EM.*
- *Other, please Specify.*

Only one respondent selected "Other, Please Specify" and wrote in that "Depending on how well an architect has created a model we will either pull directly from the BIM model into our energy simulation software or will manually pull information from the BIM model." Figure 10 illustrates the breakdown of how respondents' companies use BIM info in the energy simulation process.

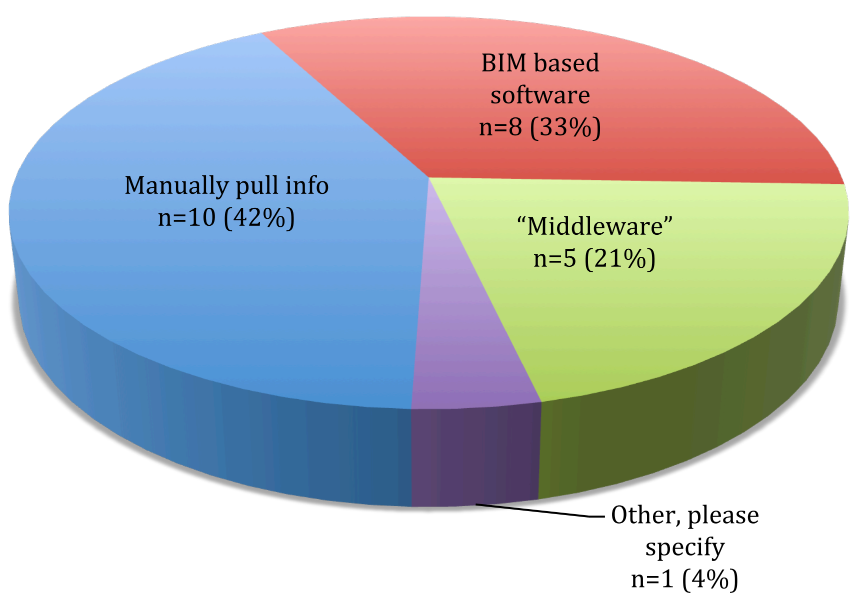

Figure 10: How companies leverage information from BIMs for energy simulation (n=24)

Little agreement existed between the five respondents who indicated that their company used "middleware" in their confidence of the middleware's ability to accurately translate information from their BIM software to their energy simulation software program. One respondent was extremely unconfident, one was unconfident, one was somewhat unconfident, one was somewhat confident, and one was confident in their middleware's ability to accurately translate information from their BIMs to their energy simulation program.

Perceived Value of BIM for Energy Simulation

Using a seven-point Likert scale (where 1 *very low value*, 4 is *neither high nor low value* and 7 is *very high value*), respondents were asked to indicate their *overall perception of the* ***value*** *associated with using information from BIMs to inform energy simulation.* The average score of the respondent group (n=51) was between "neither low nor high value" and "somewhat high-value," with a mean score of 4.39 and a SD of 1.662. Figure 11 illustrates respondents' perceptions of the **value** associated with using information from BIMs to inform energy simulation.

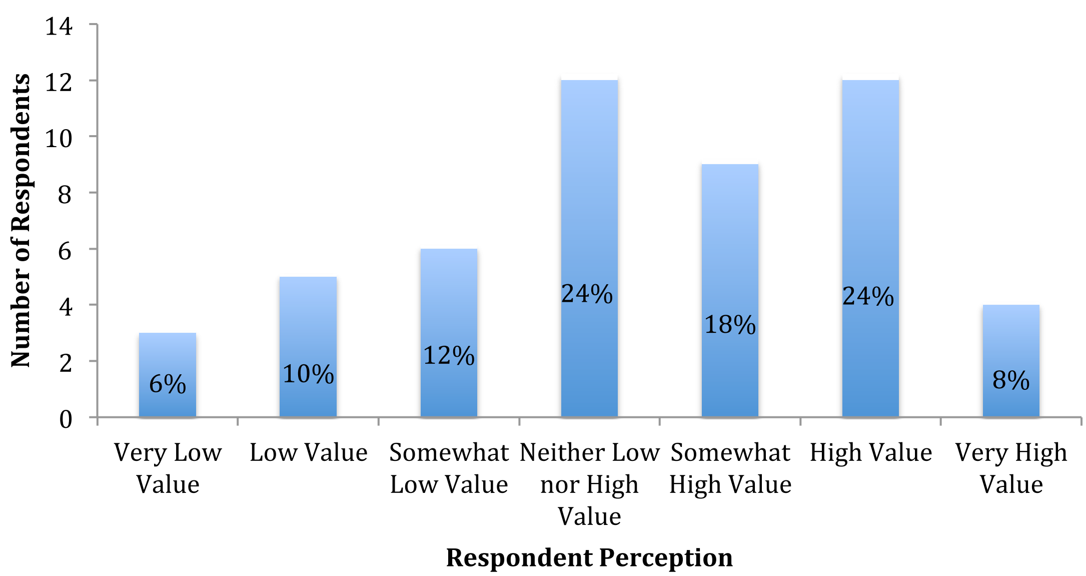

Figure 11: Respondent perceptions of the value associated with BIM information to inform energy simulation.

Perceptions of Benefits

Respondents were asked to what degree they agreed or disagreed with how a series of items pertaining to using BIM information for energy simulations were benefits. Each item used a seven-point Likert rating scale where 1 represents "strongly disagree," 4 represents "neither agree nor disagree" and 7 represents "strongly disagree." Table 8 shows the averages of how much each of the following items are perceived benefits realized from using BIM information for the energy simulation process.

Table 8: ***Respondents perception of benefits using BIM to inform energy simulation (n=51)***

Benefit Items	Mean	Std. Dev.	Agreement Levels						
			StD	D	SwD	N	SwA	A	StA
Facilitates communication	5.14	1.40	1.96%	3.92%	1.96%	25.49%	19.61%	31.37%	15.69%
Reduced Process Related Costs	5.04	1.36	1.96%	5.88%	1.96%	15.69%	37.25%	25.49%	11.76%
Ability to Examine More Design Options	5.04	1.66	3.92%	7.84%	1.96%	17.65%	27.45%	17.65%	23.53%
Time Savings	4.39	1.70	5.88%	11.76%	9.80%	21.57%	21.57%	19.67%	9.80%
Increased Accuracy	4.24	1.41	1.96%	15.69%	0.00%	45.10%	19.61%	11.76%	5.88%
Technical Ease	3.75	1.40	9.80%	9.80%	13.73%	39.22%	17.64%	9.80%	0.00%

Note: StD=Strongly Disagree, D=Disagree, SwD=Somewhat Disagree, N=Neither Agree Nor Disagree, SwA=Somewhat Agree, A=Agree, StA=Strongly Agree

Benefits to using BIM for energy simulation

When asked to indicate their overall agreement levels that certain items act as benefits to using information in BIMs to inform energy simulation, three main items stood out. On average, all respondents (n=51) have the highest level of agreement with the statement *Integrating BIM with Energy Simulation tools facilitates greater levels of communication among design stakeholders*. In addition, respondents highly agreed that *reduced process related costs* and *the ability to examine more design options* were all benefits associated with using BIM for energy simulation. Respondents were slightly above neutral in their agreement levels with the statements that *increased accuracy* and *time* savings were benefits of using BIM. Lastly, on average respondents slightly disagreed that *technical ease* of using BIM for energy simulation was a benefit.

After the question-set pertaining to respondents' perceptions of the benefits associated with using BIM for energy simulation, a blank text box was left encouraging respondents to leave additional comments on the benefits associated with using BIM for energy simulation based on their experience. Nearly a third of respondents decided to leave a comment (n=16) and many had overlapping themes. However, the majority of the comments addressed barriers instead of benefits. Half of the respondents (n=8) that commented stressed the fact that BIM models are rarely constructed accurately enough for it to be useful to energy modelers. Additionally, over a third of the respondents who left comments (n=6) stated in some way that time was a limiting factor in their abilities to create a BIM model to use for energy simulation. Lastly, one respondent stated, "BIM platform providers are not incentivized to support a wide number of energy simulation tools and tend to focus on their company's products."

Perceptions of Barriers

Respondents were also asked to what degree they agreed or disagreed with how a series of items act as barriers for using BIM information for energy simulations. Each item used a seven-point Likert rating scale where 1 represents "strongly disagree," 4 represents "neither agree nor disagree" and 7 represents "strongly disagree." On average respondents agreed to some extent that all the items listed below (aside from "hardware costs") acted as barriers to implementing BIM-based energy simulation, the highest level of agreement was still in-between somewhat agree and agree. Lack of BIM standards for model integration with multidisciplinary teams had the highest level of agreement as acting as a barrier to BIM-based energy simulation. The only other two barrier survey items that were to the level of "slightly agree" or higher were *learning curve* and *software functionality.* Table 9 shows the averages of how much each of the following items are perceived barriers of using BIM information for the energy simulation process.

Table 9: ***Respondents perception of barriers of using BIM to inform energy simulation (n=51)***

Benefit Items	Mean	Std. Dev.	Agreement Levels						
			StD	D	SwD	N	SwA	A	StA
Lack of BIM standards for model integration with multi-disciplinary teams	5.37	1.45	0.00%	1.96%	3.92%	19.61%	17.65%	43.14%	13.73%
Learning Curve	5.04	1.69	0.00%	11.76%	1.96%	15.69%	27.45%	27.45%	15.69%
Software Functionality	5.00	1.55	1.96%	5.88%	5.88%	17.65%	25.49%	31.37%	11.76%
Additional time needed to build the model	4.92	1.71	1.96%	5.88%	7.84%	15.69%	31.37%	25.49%	11.76%
Interoperability issues	4.82	1.61	0.00%	3.92%	11.76%	31.37%	15.69%	25.49%	11.76%
Training Cost	4.76	1.34	0.00%	9.80%	3.92%	25.49%	27.45%	27.45%	5.88%
Lack of others' capability to collaborate on a BIM model	4.75	1.37	0.00%	13.73%	7.84%	21.57%	19.61%	21.57%	15.69%
Lack of management buy in	4.51	1.44	1.96%	17.65%	5.88%	25.49%	11.76%	25.49%	11.76%
Software cost	4.41	1.44	3.92%	11.76%	7.84%	27.45%	17.65%	27.45%	3.92%
Lack of motivation to change current processes	4.29	1.50	1.96%	17.65%	13.73%	23.53%	11.76%	21.57%	9.80%
Hardware cost	3.71	1.18	5.88%	21.57%	7.84%	39.22%	11.76%	13.73%	0.00%

Note: StD=Strongly Disagree, D=Disagree, SwD=Somewhat Disagree, N=Neither Agree Nor Disagree, SwA=Somewhat Agree, A=Agree, StA=Strongly Agree

Expected Results

Based on research from the literature review presented in this study, it was believed that a positive correlation would exist between respondents' engagement scores with BIM and energy simulation and their perceptions of the value associated with using BIM for energy simulation. However based on the results of the e-survey, these expected results were not upheld. The statistical findings are explained in the next sections.

Engagement Scores and Perceptions of Value

The initial hypothesis of this study was that there would be a positive correlation between respondents' engagement levels with BIM and energy simulation and their overall perception of the value associated with using BIMs to inform energy simulation. Bivariate Pearson correlation tests were run to determine the level of correlation between respondents' BIM/ energy simulation engagement scores and their overall perception of the value associated with using BIMs to inform energy simulation. The results are presented in Table 10.

Table 10: ***Correlation between engagement scores and perceptions of value***

Correlations

		ES Engagement Score	BIM Engagement Score
Perception of Value	Pearson Correlation	-.285*	.297*
	Sig. (2-tailed)	.043	.034
	N	51	51

* Correlation is significant at the 0.05 level (2-tailed).

As the results above show, there is actually a weak negative relationship between the energy simulation engagement scores and perception of value associated with using information from BIMs to inform energy simulation (at the 0.05 significance level). Additionally, a weak positive relationship exists between the BIM engagement scores and perception of value associated with using information from BIMs to inform energy simulation (at the 0.05 significance level). Scatter plots were created (see Appendices C and D) for both energy simulation engagement scores and BIM engagement scores located on the x-axis (respectively) and the perception of value associated with using information from BIMs to inform energy simulation located on the y-axis. These scatter plots provided a visual confirmation that further investigation into the correlation between BIM and energy simulation engagement scores and the perception of value associated with using information from BIMs to inform energy simulation would be trivial at best. However, the researcher decided to breakdown the respondent pool in to distinct user groups to determine if there were differences in perception between these different groups. The distinct groups consisted of those who only used BIM software, those who only used energy simulation software, and those who used BIM and energy simulation software programs.

Perceptions Between Different User Groups

As mentioned earlier in this section, the mean value for "overall perception of the value associated with using BIMs to inform energy simulation" of the entire respondent pool was 4.39 (which is between neutral and somewhat high value) with a standard deviation of 1.662 and two modes of 4 and 6, with twelve responses each. However, when broken down into distinct user groups of those who only use BIM, those who only use energy simulation and those who use both BIM and energy simulation, trends began to emerge. For example, respondents that only use BIM (n=24) tended to have the highest overall perception of the value associated with using BIM to inform energy simulations with a group mean score of 4.88 and a standard deviation of 1.484. Users of BIM and energy simulation programs (n=22) perceived the value associated with using BIM to inform energy simulations at slightly above *neither low nor high value or* mean value of 4.18 (SD of 1.651), while those who only used energy simulations (n=5) had the lowest perceptions with a mean value of 3.00 and a SD of1.871. However, since there were only five respondents that only used energy simulation, inferring valid conclusions from their responses is not possible.

A t-test was run to determine if there was a significant difference between the mean values of BIM-only users and BIM and energy simulation users because they had the largest difference in means (aside from energy simulation only users, who only had five respondents) and a significance value of 0.514 was obtained, indicating that there was no significant difference between the two user groups. The breakdown of the average perceptions of these user groups on the value of BIM for energy simulation is shown in Table 11.

Table 11: User group perceptions on the value of BIM for energy simulation

	Number	Mean	SD
All Respondents	n=51	4.39	1.662
BIM users ONLY	n=24	4.88	1.484
BIM and Energy Simulation users	n=22	4.18	1.651
Energy Simulation users only	n=5	3.00	1.871

Barriers to using BIM for energy simulation

When asked to indicate their overall agreement levels that certain items act as barriers to implementing BIM for energy simulation, one item stood out. On average respondents most strongly agreed that *a lack of BIM standards for model integration with multidisciplinary teams* was the largest barrier to BIM-based energy simulation. This perception that a *lack of BIM standards for model integration with multidisciplinary teams* is further backed by a level of agreement with the statement that *There is significant room for improvement in the process by which stakeholders provide me with information pertaining to the creation of an Energy Model.* This suggests that improving processes of information communication in the BIM and energy simulation creation process could help mitigate this barrier. Other barrier items that were one point or more above neutral for perceptions of barriers to using BIM for energy simulation include: learning curve and software functionality. Despite the literature review mentioning interoperability as a barrier when leveraging BIM for energy simulation, respondents were below slightly agree (4.82) that interoperability is a barrier to BIM-based energy simulation (Hitchcock & Wong, 2011). Additionally, Attia and De Herde (2011) found that architects and non-specialist users had a hard time integrating building performance simulations into the design process for net-zero energy buildings. However, this could be partially due to unfamiliarity with software programs used or difficulty changing design processes to aid the building performance simulation process.

Likewise, when the entire respondent pool was broken down into distinct user groups of those who only use BIM, those who only use energy simulation, and those who use both BIM and energy simulation, stronger correlations began to become more evident for certain user groups. Although for the BIM **and** energy simulation user group (n=22) little to no correlation existed among BIM and energy simulation engagement scores and the perception of value associated with using information from BIMs to inform energy simulation (shown in table 12), the other two remaining groups showed a strong correlation.

Table 12: ***BIM and energy simulation user correlation scores***

		ES Engagement Score	BIM Engagement Score
Perception of value	Pearson Correlation	0.047	-0.156
	Sig. (2-tailed)	0.834	0.488
	N	22	22

For those who only had experience using BIM (n=24), a moderate positive correlation of 0.418 (significant at the .05 level) existed between the overall perception of the value associated with using BIMs to inform energy simulation and their BIM engagement scores. This implies that those respondents who only had experience with BIM are more likely to have a higher overall perception of the value associated with using BIMs to inform energy simulation as their engagement levels with BIM increase. Table 13 illustrates the breakdown of the correlation between engagement scores and respondent perceptions of value pertaining to BIM-based energy simulation for all user groups.

Table 13: Correlation breakdown of all user groups

		ES Engagement Score	BIM Engagement Score
Perception of value	BIM & ES (n=22)	0.047	-0.156
	BIM-only (n=24)	--	0.418*
	ES-only (n=5)	-0.8	--

* Correlation is Significant at the .05 level (2-tailed)

Figure 12 illustrates the relationship between BIM engagement scores and the perceptions of value associated with using BIM for energy for energy simulation within the BIM-only user group (n=24).

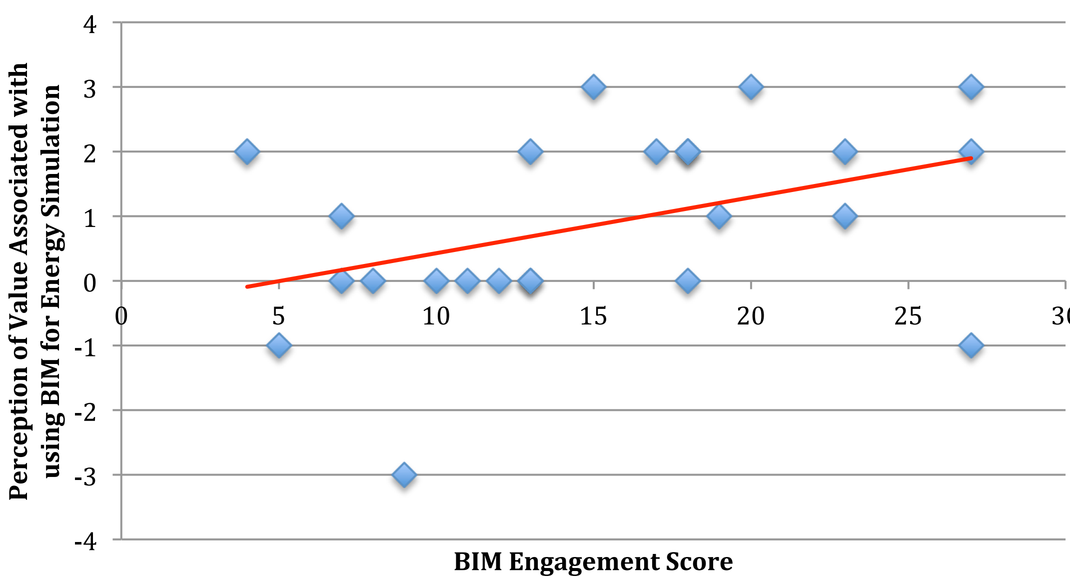

Figure 12: BIM-only user group correlation between BIM engagement and perception of value associated with using BIM for energy simulation

The user group that only used energy simulation had a very strong negative correlation between energy simulation engagement scores and perception of value associated with using

BIM for energy simulation with a Pearson Correlation value of -0.800 (with a 0.104 level of significance). However, because only five respondents fell into this user group these results are not significant. If energy simulators perceptions of the value associated with using information from BIMs to inform energy simulation do actually decrease as their engagement level with energy simulation products increase, it may be because they become more aware of the inputs that are needed to construct an accurate energy model and have come to the realization that few BIMs are constructed correctly for this use. Backing this up is that a total of eight respondents commented that BIM models are rarely constructed with great enough accuracy to be of much use in forming energy models.

Information Conveyance Process Improvement

Additionally, when asked to indicate their level of agreement/disagreement with the statement "*there is significant room for improvement in the process by which stakeholders provide me with information pertaining to the creation of an Energy Model*," the average response from all survey participants was 5.37 with a SD of 1.183. In other words, all respondents fell between *somewhat agree* and *agree*. For this survey question those who only used energy simulation software products had the lowest agreement with the statement "*there is significant room for improvement in the process by which stakeholders provide me with information pertaining to the creation of an Energy Model*." However, there were only five respondents in this group and the standard deviation was high (SD= 1.949). Respondents who only used BIM (n=25) had a level of agreement with the previous statement that was close to the overall respondent average, with a mean of 5.33 and a SD of 1.167. However, the user group that use both BIM and energy simulation had the highest level of agreement with the previous statement, with a mean value of 5.59 and a SD of .959. Table 14 shows the breakdown of the agreement levels that different respondent user groups with the statement *"there is significant room for improvement in the process by which stakeholders provide me with information pertaining to the creation of an Energy Model*."

Table 14: ***User group agreement with ability to improve information sharing process between stakeholders***

	Number	Mean	SD
All Respondents	n=51	5.37	1.183
BIM users ONLY	n=24	5.33	1.167
BIM and Energy Simulation users	n=22	5.59	0.959
Energy Simulation users only	n=5	4.6	1.949

Perceived Accuracy of energy simulation

When asked about how accurate they perceived energy simulation in predicting a building's actual operating energy usage the average of all respondents fell between *neither accurate or inaccurate* and *somewhat accurate*. This finding coincides with the beliefs of Raftery et al. (2011) that significant discrepancies exist between energy simulations and a buildings actual performance. BIM-only users had the highest overall perceptions with a mean value of 4.87 and a SD of 1.014. However, after running a t-test of the means of BIM-only users and BIM and energy simulation users, a significance level of .400 was calculated, indicating that there is not significant difference between these two mean values. Table 15 below shows the breakdown of the perceptions that different respondent user groups had about the accuracy of energy simulation in predicting a building's actual operating energy usage.

Table 15: ***User group perceptions on energy simulation accuracy***

	Number	Mean	SD
All Respondents	n=51	4.66	1.118
BIM users ONLY	n=23	4.87	1.014
BIM and Energy Simulation users	n=22	4.45	1.057
Energy Simulation users only	n=5	4.6	1.817

Perceptions of Benefits (BIM and ES users)

When the benefit related items were examined for the BIM and energy simulation user group, there were some discrepancies between the overall group and the BIM and energy simulation group in importance of each benefit related item. However, each item maintained the same order of importance between the two groups. Table 16 (below) shows the averages and distribution of how much each of the following benefits are perceived benefits realized from using BIM information for the energy simulation process.

Table 16: ***BIM & ES user perception of benefits of using BIM to inform energy simulation (n=22)***

Benefit Items	Mean	Std. Dev.	Agreement Levels StD	D	SD	N	SA	A	StA
Facilitates communication	5.45	1.37	0.00%	4.55%	0.00%	22.73%	18.18%	27.27%	27.27%
Reduced Process Related Costs	5.36	1.36	0.00%	9.09%	0.00%	4.55%	36.36%	31.82%	18.18%
Ability to Examine More Design Options	4.91	1.85	4.55%	13.64%	0.00%	13.64%	31.82%	9.09%	27.27%
Time Savings	4.05	1.89	9.09%	18.18%	13.64%	13.64%	18.18%	18.18%	9.09%
Increased Accuracy	4.00	1.51	0.00%	27.27%	0.00%	40.91%	13.64%	13.64%	4.55%
Technical Ease	3.64	1.79	13.64%	22.73%	9.09%	13.64%	22.73%	18.18%	0.00%

Note: StD=Strongly Disagree, D=Disagree, SD=Somewhat Disagree, N=Neither Agree Nor Disagree, SA=Somewhat Agree, A=Agree, StA=Strongly Agree

Perceptions of Benefits (BIM users only)

The perceptions of BIM-only users were also examined as separate from the entire respondent pool. The BIM-only user group did not believe that BIM-based energy simulation communication facilitation was a nearly as large of a benefit BIM as energy simulation groups did. Similarly, the BIM-only users had a higher level of agreement that BIM-based energy simulation allowed for more design options to be examined. Interestingly BIM-only users had a much more positive perception of time savings (5.04) and technical ease (4.75) compared with BIM and energy simulation users at 4.05 and 3.64 respectively. This further shows that BIM-only users may have overly optimistic perceptions of leveraging BIM for energy simulation. Table 17 outlines BIM-only user perceptions on benefits items to using BIM for energy simulation.

Table 17: ***BIM-only user perception of benefits of using BIM to inform energy simulation (n=24)***

Benefit Items	Mean	Std. Dev.	Agreement Levels						
			StD	D	SD	N	SA	A	StA
Allows for examination of more design options	5.29	1.40	0.00%	4.17%	4.17%	20.83%	25.00%	20.83%	25.00%
Facilitates communication	5.08	1.25	0.00%	4.17%	4.17%	25.00%	20.83%	37.50%	8.33%
Time Savings	5.04	1.12	0.00%	0.00%	4.17%	33.33%	29.17%	20.83%	12.50%
	4.88	1.15	0.00%	4.17%	4.17%	25.00%	41.67%	16.67%	8.33%
Technical Ease	4.75	0.99	0.00%	0.00%	0.00%	54.17%	25.00%	12.50%	8.33%
Increased Accuracy	4.08	0.72	0.00%	0.00%	16.67%	62.50%	16.67%	4.17%	0.00%

Note: StD=Strongly Disagree, D=Disagree, SD=Somewhat Disagree, N=Neither Agree Nor Disagree, SA=Somewhat Agree, A=Agree, StA=Strongly Agree

Two of the largest discrepancies between BIM and ES users and BIM-only users on their perception of benefits associated with using BIM to inform energy simulation were *increased time savings* and *technical ease.* BIM-only users had a much higher average agreement that BIM-based energy simulation provided significant time savings over traditional energy simulation, with an average score of 5.04 and 4.05 respectively. This may be because they only have to create a BIM without necessarily knowing everything that is required from the energy modeler's perspective, whereas those in the BIM and energy simulation user group have a better understanding of the level of detail required of the BIMs to be useful in informing the energy model. Additionally, the BIM-only user group had a much higher agreement level that *pulling information from BIMs to inform energy simulation is easy to do* that did the BIM and energy simulation user group, with averages of 4.75 and 3.64 respectively. This may be because those who use BIM and energy simulation are the ones who actually have to transfer information between the two programs and have experienced a greater level of technical difficulty with this process in the past. Table 18 provides a comparison of the average benefit related perceptions of then entire respondent group and compares it to the average scores of the BIM and ES user group and the BIM-only user group respectively.

Table 18: Average perceptions of all user groups on BIM-based energy simulation benefits

Benefit Items	All users (n=51)		BIM & ES users		BIM-only users	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Facilitates communication	5.14	1.4	5.45	1.37	5.08	1.25
Reduced Process Related Costs	5.04	1.36	5.36	1.36	4.88	1.15
Ability to Examine More Design Options	5.04	1.66	4.91	1.85	5.29	1.40
Time Savings	4.39	1.7	4.05	1.89	5.04	1.12
Increased Accuracy	4.24	1.41	4	1.51	4.08	0.72
Technical Ease	3.75	1.4	3.64	1.79	4.75	0.99

Perceptions of Barriers (BIM and ES users)

Likewise, BIM and energy simulation users were looked at as separate from the entire respondent group in their perceptions of the barriers of using BIM for energy simulation. The order of perceived barriers of BIM and ES users were largely representative of the entire respondent groups aside from the fact that they viewed interoperability to be less of an issue. Table 19 shows the breakdown of BIM and energy simulation users perceptions on the barrier items listed below.

Table 19: ***Respondents perception of barriers of using BIM to inform energy simulation (n=22)***

Barrier Items	Mean	Std. Dev.	Agreement Levels						
			StD	D	SD	N	SA	A	StA
Lack of BIM standards for model integration with multi-disciplinary teams	5.50	1.26	0.00%	4.55%	4.55%	9.09%	13.64%	54.55%	13.64%
Learning Curve	5.32	1.81	0.00%	18.18%	0.00%	4.55%	18.18%	27.27%	31.82%
Additional time needed to build the model	5.32	1.52	4.55%	4.55%	4.55%	0.00%	27.27%	45.45%	13.64%
Software functionality	5.05	1.65	4.55%	9.09%	0.00%	13.64%	22.73%	36.36%	13.64%
Training Cost	4.95	1.53	0.00%	13.64%	0.00%	18.18%	27.27%	27.27%	13.64%
Lack of others' capability to collaborate on a BIM model	4.91	1.72	0.00%	13.64%	9.09%	13.64%	22.73%	18.18%	22.73%
Interoperability Issues	4.86	1.46	0.00%	4.55%	13.64 %	27.27%	13.64%	27.27%	13.64%
Software cost	4.64	1.59	0.00%	18.18%	0.00%	27.27%	18.18%	27.27%	9.09%
Lack of management buy in	4.14	1.86	4.55%	27.27%	0.00%	22.73%	22.73%	9.09%	13.64%
Lack of motivation to change current processes	4.14	1.83	4.55%	22.73%	9.09%	22.73%	9.09%	22.73%	9.09%
Hardware cost	3.68	1.36	0.00%	31.82%	4.55%	36.36%	18.18%	9.09%	0.00%

Note: StD=Strongly Disagree, D=Disagree, SD=Somewhat Disagree, N=Neither Agree Nor Disagree, SA=Somewhat Agree, A=Agree, StA=Strongly Agree

Perceptions of Barriers (BIM users only)

Lastly, the BIM-only user group was separated out of the entire pool of respondents and their perceptions of distinct barriers to BIM-based energy simulation were examined. On average BIM-only users perceived that lack of management buy in was a much larger barrier to BIM-based energy simulation than BIM and energy simulation users. This makes sense as it is assumed that if a respondent is already using both software programs then their management has already bought into both of these products separately and is more likely to leverage their synergies to the fullest extent. Additionally, BIM users and BIM and energy simulation users had different perceptions on how the amount of time that it takes to build a BIM model acts as a barrier to BIM-based energy simulation, with BIM-only users mean score at 4.50, while BIM and energy simulation users were at 5.32.

Table 20: ***BIM user perception of barriers of using BIM to inform energy simulation (n=24)***

Barrier Items			Agreement Levels						
	Mean	Std. Dev.	StD	D	SD	N	SA	A	StA
Lack of BIM standards for model integration	5.21	1.14	0.00%	4.17%	12.50%	29.17%	4.17%	37.50%	12.50%
Lack of management buy in	4.96	1.46	0.00%	4.17%	12.50%	29.17%	4.17%	37.50%	12.50%
Learning curve	4.92	1.14	0.00%	4.17%	4.17%	25.00%	33.33%	29.17%	4.17%
Software Functionality	4.79	1.28	0.00%	4.17%	12.50%	20.83%	33.33%	20.83%	8.33%
Lack of others' capability to collaborate on a BIM model	4.75	1.57	0.00%	12.50%	8.33%	20.83%	20.83%	25.00%	12.50%
Interoperability Issues	4.67	1.31	0.00%	4.17%	12.50%	33.33%	20.83%	20.83%	8.33%
Training costs	4.63	1.10	0.00%	4.17%	8.33%	33.33%	29.17%	25.00%	0.00%
Lack of motivation to change current processes	4.54	1.61	0.00%	12.50%	16.67%	20.83%	16.67%	20.83%	12.50%
Additional time needed to build the model	4.50	1.22	0.00%	8.33%	8.33%	29.17%	37.50%	12.50%	4.17%
Software cost	4.29	1.49	4.17%	8.33%	16.67%	25.00%	16.67%	29.17%	0.00%
Hardware cost	3.88	1.42	8.33%	8.33%	12.50%	45.83%	8.33%	16.67%	0.00%

Note: StD=Strongly Disagree, D=Disagree, SD=Somewhat Disagree, N=Neither Agree Nor Disagree, SA=Somewhat Agree, A=Agree, StA=Strongly Agree

Compared to BIM and energy simulation users, BIM-only users have a much lower perception of *additional time needed to build a model,* with mean values of 5.32 (above slightly agree and 4.5 (between neither agree nor disagree) respectively. This could be due to the fact that BIM-only users are not completely familiar with all of the information that must be included in a BIM model to create a complete energy model. Additionally, BIM only users perceived *lack of management buy-in* as a much larger barrier than BIM and energy simulation users. This makes sense as it is assumed that BIM and energy simulation users' firms already have *bought in* to both of these software programs and therefore are more likely to use BIM models to inform energy simulation. Table 21 provides a comparison of the average barrier related perceptions of then entire respondent group and compares it to the average scores of the BIM and ES user group and the BIM-only user group respectively.

Table 21: Average perceptions of all user groups on BIM-based energy simulation barriers

Benefit Items	All users (n=51)		BIM & ES users (n=22)		BIM- Only users (n=24)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Lack of BIM standards for model integration with multi-disciplinary teams	5.37	1.45	5.5	1.26	5.21	1.14
Learning Curve	5.04	1.69	5.32	1.81	4.92	1.14
Software Functionality	5	1.55	5.05	1.65	4.79	1.28
Additional time needed to build the model	4.92	1.71	5.32	1.52	4.5	1.22
Interoperability issues	4.82	1.61	4.86	1.46	4.67	1.31
Training Cost	4.76	1.34	4.95	1.53	4.63	1.1
Lack of others' capability to collaborate on a BIM model	4.75	1.37	4.91	1.72	4.75	1.57
Lack of management buy in	4.51	1.44	4.14-9	1.86	4.96	1.46
Software cost	4.41	1.44	4.64	1.59	4.29	1.49
Lack of motivation to change current processes	4.29	1.5	4.14	1.83	4.54	1.61
Hardware cost	3.71	1.18	3.68	1.36	3.88	1.42

Chapter Summary

This study offers several findings on how the perceptions of green design stakeholders vary among different software user groups pertaining to the value associated with using information from BIMs to inform energy simulation. In addition, this study shows that different user group engagement scores with BIM and/or energy simulation software programs seem to vary in their correlation to their perceptions on the value associated with using information from

BIMs to inform energy simulation. Lastly, this chapter identifies green design stakeholders' largest perceived barriers and benefits to implementing BIM-based energy simulation. The following chapter includes the synthesis of the findings presented in this chapter and conclusions that can be drawn from them.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The overall goal of this study is to determine what green design stakeholders perceive as the main barriers and benefits to leveraging BIM for energy simulation and to determine how BIM and energy simulation engagement scores impact green design stakeholders' overall perceptions of the value associated with using BIM for energy simulation. An extensive literature review was undertaken to identify previous research on BIM-based energy simulation. An e-survey instrument was developed to gather green design stakeholders perceptions pertaining to leveraging BIM for energy simulations. A variety of statistical analysis methods were used to analyze this data. The implications of this study, limitations, future research and final remarks are discussed in this Chapter. This new knowledge is useful in understanding if a BIM-based energy simulation is likely to become perceived as more valuable by green design stakeholders as their engagement levels with BIM and/ or energy simulation increase.

Importance of the study

By identifying the main perceived barriers and benefits associated with using BIMs to inform the energy simulation process it is possible for firms who intend to implement BIM-based energy simulation to maximize benefits while minimizing associated barriers. Correlating green design stakeholder perceptions on the value associated with BIM-based energy simulation and BIM and energy simulation engagement scores allows researchers to observe if engagement with either (or both) tools is likely to increase their perceptions of BIM-based energy simulation. After all, difficulty exists in knowing the value associated with something without first understanding how to use it to its full potential.

Additionally, determining how perceptions and engagement levels differ between different software user groups can help in developing strategies for implementing BIM-based energy simulation that are custom tailored to each group. Lastly, examining discrepancies between user groups can lead the identification shortfalls in current BIM-based energy simulation processes and help to improve them.

Addressing the Research Questions

This study sought to determine green design stakeholders' overall perceptions of the value associated with using information from BIMs to inform energy simulation, the results indicate that the average perception of the entire respondent group was between *neither low nor high value* and *somewhat high-value* with a mean score of 4.39. Respondents average perceptions on the value of BIM-based energy simulation only partially supports claims by McGraw-Hill (2008) that the AEC industries have positive perceptions of integrating BIM into workflows and that it adds value to their company. However, when user groups within the respondent pool were compared, it was found that BIM-only users tended to have the highest perception of value associated with using BIM to inform energy simulations while those who only used energy simulation had the lowest.

On average, BIM-only users perceived value of using BIM-based energy simulation to be approaching *somewhat high value* with a mean of 4.88. A strong positive correlation value of 0.418 (significant at the .05 level) existed between the overall perception of the value associated with using BIMs to inform energy simulation and their BIM engagement scores. This shows that as BIM-only users become more familiar with using BIM they appear to perceive higher levels of value associated with using information from BIMs to inform energy simulation, which is likely because they become more confident in their ability to construct better models. However, BIM users may not know exactly what information is required of BIM models on the energy simulation side of things and may be overly confident in their model's usability for energy simulation purposes. After all, some energy simulation programs are only capable of using certain types of information from BIM models (such as geometry). Further substantiating the claim that *BIM-only users may have over optimistic expectations of the capabilities of energy simulation,* is the fact that BIM users had the highest perceptions of an energy simulation program's ability to accurately predict a buildings performance with a mean value of 4.88. This helps partially back claims made by Azhar and Brown (2009, p. 283) that "in general, design stakeholders who use BIM-based energy analysis perceive a positive value associated with its use." However, the BIM and energy simulation user group had an average perception of 4.18 regarding BIM-based energy simulation, which is slightly above neutral.

When investigating how green design stakeholders' engagement levels with BIM/ energy simulation impact their perceptions on the value of using information from BIMs to inform energy simulation, little correlation was found for the overall respondent group. However, when broken down into distinct user groups it was found that there was a positive correlation between BIM user engagement scores and their overall perceptions of the value associated with BIM-based energy simulation. Likewise, the energy simulation user group has a very strong negative correlation (-0.800) between energy simulation engagement scores and their overall perceptions of the value associated with BIM-based energy simulation. This large discrepancy in perception indicates that BIM-only users might be overly optimistic in their ability to produce usable, accurate models for energy simulation and that they may not know exactly what is required of the energy simulation software. Additionally, the potential exists that those who only use energy simulation have lower perceptions of the value associated with using BIM for energy simulation because they do not fully understand the capabilities of BIM have only been given inaccurate or incomplete models to work with in the past.

It was also found that different user groups had different perceptions of the greatest benefits and barriers associated with using BIM-based energy simulation. Interestingly BIM-only users had a much a more positive perception of time-savings (5.04) and technical ease (4.75) compared with BIM and energy simulation users at 4.05 and 3.64 respectively. This helps reinforce that BIM-only users may be overly optimistic in their ability to create models that are usable for energy simulators or that energy simulators may only have incomplete or inaccurate models to work with. When working with a designer who only uses BIM it might be helpful to focus their training on how to create a model that more accurately represents the needs of the energy simulators.

Lack of BIM standards for model integration with multidisciplinary teams, *learning curve* and *software functionality* were the only other barrier items that were above or at *somewhat agree* for perceived barriers to using BIM for energy simulation. Despite the literature review mentioning interoperability as a barrier when leveraging BIM for energy simulation, respondents were below slightly agree (4.82) that interoperability is a barrier to BIM-based energy simulation (Hitchcock & Wong, 2011). When asked to indicate their overall agreement levels that certain items act as benefits to using information in BIMs to inform energy simulation, three main items stood out among the entire respondent pool. On average respondents had the highest level of agreement with the statement "*Integrating BIM with energy simulation tools facilitates greater levels of communication among design stakeholders.*" In addition, respondents highly agreed that "reduced process related costs" and "the ability to examine more design options" were all benefits associated with using BIM for energy simulation.

Limitations

This was a cross-sectional study that offers a descriptive analysis of the perceptions of the green design stakeholders surveyed on the value of leveraging BIM for energy simulation and the main barriers and benefits associated with leveraging BIM for energy simulation. While the sample contained respondents that were located across the U.S., the majority of respondents (n=38) were located in Colorado, meaning that these results are not generalizable across the U.S. Additionally, respondents experience levels (that comprise engagement scores) were based on self-reported values so it is assumed that each respondent has a similar frame-of-reference for answering this item.

Recommendations for Future Research

This research is largely exploratory in nature and a need for additional research on this topic exists. In future studies the sample size should be larger and more evenly distributed throughout the U.S. and should include more energy modelers so that more valid conclusions can be drawn from the data. This could be achieved by leaving the e-survey open longer or by providing incentives to those who do take the survey. Opportunities also exist to examine demographic data about respondents in more detail to identify trends that develop from different demographic groups and determine if any of these factors are tied to perception. This demographic data could include: sex, age, contract type, and level of building performance targeted. Although the engagement indexes used were determined to be reliable instruments, additional tests could be run or a new engagement index that better represents engagement scores could be created. Further research on this topic should investigate education level and training experience of the green design stakeholders who use BIM for energy simulation.

To go beyond this study, additional research could also focus on different strategies to get distinct user groups to implement BIM for energy simulation. Additionally, further research should look into creating a protocol for sharing information between design stakeholders so that BIM models are complete and accurate before energy simulations are run. For example, a checklist could be created for the BIM design process that makes sure all the information necessary for the energy model is imbedded within the BIM. Lastly, future studies could look at reasons why BIM-only users had higher perceptions of leveraging BIM for energy simulation than other user groups.

Final Remarks

As more emphasis is put on constructing buildings with higher levels of performance, green design stakeholders need to draw from their entire bag of tools to reach designs with greater levels of building performance. Additionally, it will become more important for green design stakeholders to develop processes and communication channels that allow them to more easily share, integrate and leverage information from other design stakeholders, allowing them to better inform their designs and decisions. Since BIM has the capability to act as a communication platform among stakeholders and its information can be leveraged to inform energy simulations, BIM-based energy simulation should be viewed as a viable means of evaluating a design's performance implications in order to inform a designer's decision making process accurately and in a time efficient manner.

This research identifies how green design stakeholders perceive the value associated with leveraging BIM for energy simulation. Identifying discrepancies in perceptions among different users is useful in determining steps that should be taken when implementing BIM-based energy simulation to do so more successfully. When used correctly energy simulation is a tool that has the potential to reduce energy needs and operational costs of buildings through better design. Leveraging BIM to inform energy simulation has the potential to reduce time, cost and rework associated with the energy simulation. In short, BIM-based energy simulation is a tool can help design teams provide owners with a better value and help building reduce energy needs through informed design.

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APPENDIX A: IRB Research Integrity & Compliance Review Office's Institutional Review Board exemption form

Colorado State University

Research Integrity & Compliance Review Office
Office of Vice President for Research
Fort Collins, CO 80523-2011
(970) 491-1553
FAX (970) 491-2293

DATE: April 18, 2014

TO: Rodolfo Valdes-Vasquez, Construction Management
Anderson Lewis, Construction Management

Janell Barker

FROM: Janell Barker, IRB Coordinator
Research Integrity & Compliance Review Office

TITLE: The Perceived Value of Using BIM for Energy Simulation

IRB ID: 074-15H **Review Date:** April 18, 2014
This project is valid from three years from the review date.

The Institutional Review Board (IRB) Coordinator has reviewed this project and has declared the study exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b)(1): Research conducted in established or commonly accepted education settings, involving normal education practices, such as a) research on regular and special education strategies, or 2) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods. The IRB determination of exemption means that:

- **This project is valid for three years from the initial review.** After the three years, the file will be closed and no further research should be conducted. If the research needs to continue, please let the IRB Coordinator know before the end of the three years. You do not need to submit an application for annual continuing review.

- You must carry out the research as proposed in the Exempt application, including obtaining and documenting (signed) informed consent if stated in your application or if required by the IRB.

- Any modification of this research should be submitted to the IRB through an email to the IRB Coordinator, prior to implementing any changes, to determine if the project still meets the Federal criteria for exemption.

- Please notify the IRB Coordinator if any problems or complaints of the research occur.

Please note that you must submit all research involving human participants for review by the IRB. **Only the IRB or designee may make the determination of exemption**, even if you conduct a similar study in the future.

APPENDIX B: E-Survey Email Recruitment Script

Dear __________________

My name is Anderson Lewis. I am a researcher in the Dept. of Construction Management at Colorado State University. I am requesting your assistance with a survey to investigate the perceptions on using BIM for energy simulation in partial fulfillment of my thesis requirements. The Principal Investigator is Dr. Rodolfo Valdes-Vasquez from the CM Department at CSU and I am the Co-PI.

We would like you to take an anonymous online survey. Participation will take approximately 10 minutes to complete. Your participation in this research is voluntary. Below you will find more details about the participant consent, which was submitted to the Institutional Research Board (IRB) and approved.

To indicate your consent to participate in this study and to continue on to the survey, please click here:

https://qtrial2014.az1.qualtrics.com/SE/?SID=SV_78U3JBjJs37AZQV

We hope to gain more knowledge on how to encourage higher levels of usage of the information imbedded with BIM among design stakeholders.

This Survey will be open until May 5th, 2014, so please respond before then.

Upon completion, if you would like to pass this survey along to any fellow peers that use BIM and/or perform energy simulations, I would greatly appreciate it.

We appreciate your participation and help!

Best Regards,

Anderson M. Lewis, LEED GA
Research Assistant
Dept. of Construction Management
Colorado State University
C: (804) 514-8961 E: Anderson.Lewis@colostate.edu

IRB Participant Consent

If you decide to participate in the study you may withdraw your consent and stop participation at any time without penalty. We will not collect your name or personal identifiers. When we report and share the data we will combine the data from all participants. While there are no direct benefits to you, we hope to gain more knowledge on how to encourage higher levels of usage of the information imbedded with BIM among design stakeholders. There are no known risks in participating in this study. It is not possible to identify all potential risks in research procedures, but the researchers have taken reasonable safeguards to minimize any known and potential, but unknown, risks. If you have any questions about the research, please contact Anderson Lewis at Anderson.lewis@colostate.edu or Dr. Rodolfo Valdes-Vasquez at rvaldes@colostate.edu. If you have any questions about your rights as a volunteer in this research, contact the CSU IRB, at RICRO_IRB@mail.colostate.edu.

APPENDIX C: Survey Instrument

Dear Participant,

My name is Anderson Lewis and I am a graduate student in the Construction Management Department at Colorado State University. I am conducting a research study on the perceptions of green-design stakeholders on using of information imbedded within Building Information Models to inform the energy simulation process.

This survey will take approximately 10 minutes to complete. All results will be anonymous and compiled as general data.

If you have any questions, please feel free to contact me and I will be glad to further inform you of my study. Upon completion, if you would like to pass this survey along to any fellow peers that use BIM and/or perform energy simulations, I would greatly appreciate it.

Thank you for your help and participation.

Anderson M. Lewis Graduate Researcher Department of Construction Management Colorado State University Email: Anderson.Lewis@colostate.edu

DEFINITION OF TERMS

The following terms and definitions are referenced in this survey:

Building Information Model: a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility (America, 2005)

Building Information Modeling (BIM): the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model is a Building Information Model (America, 2005)

Building Performance Analysis: iteratively testing, analyzing, and improving a design. (Autodesk)

Energy Model: The computerized representation of a building and its properties that are used to perform simulation of energy consumption calculations.

Energy Simulation: The process of quantitatively predicting a buildings energy performance through software analysis.

Interoperability: the ability of multiple software programs to work together.

Middleware: software that is used to translate BIM information into a form that is readable by energy modeling software.

Section 1: Demographic Questions

1) Indicate the type of company that you currently work for:
   - ☐ Architectural firm
   - ☐ Engineering firm
   - ☐ Construction Management firm
   - ☐ General Contractor
   - ☐ Energy Simulation/ modeling firm
   - ☐ Sustainability/ Energy Consulting firm
   - ☐ Project Owner
   - ☐ Other, please specify ___________________

2) What is your position title? ________________

3) Provide an estimate of the percentage of your total work in the following categories:

Commercial	______%
Residential	______%
Institutional	______%
Industrial	______%
Other (Specify) ____________	______%
Total	100 %

4) What were your companies total in net Revenue in 2013? (Only answer one of the following questions based on company type)

- Answer here if a design related firm (Architectural, engineering, consulting, or modeling firm)
  ☐ < $500,000 ☐ $500,000 - < 5 million ☐ $5 million -15 million ☐ > $15 million

- Answer here if a construction firm (General contractor, construction management or owner)
  ☐ < $25 million ☐ $25 million - < 100 million ☐ $100 million - < 500 million ☐ >$500million

5) Please provide your company ZIP code: _ _ _ _ _

Section 2: BIM Aptitude

6) Do you use Building Information Modeling (BIM) as a part of your job?
☐ Yes ☐ No

- *IF NO, Please **Skip to question 10!**

7) Please indicate your experience level with BIM:
☐ ≤ 1 year ☐ >1-2 years ☐ >2-3 years ☐ >3-4 years ☐ >4-5 years ☐ ≥ 5 years

8) Which of the following best represents your skill level with BIM software:
☐ Beginner ☐ Moderate ☐ Advanced ☐ Expert

9) Please indicate the percentage of projects that your company uses BIM on:
☐ Light (Under 15%) ☐ Moderate (15% to 30%) ☐ Heavy (31% to 60%) ☐ Very Heavy (Over 60%)

10) Please indicate the BIM software product(s) that your firm uses: (select all that apply)

☐	4MSA IDEA (intelliCAD¨ CADSoft Envisioneer	☐	Bentley RAM, STAAD and ProSteel	☐	Graphisoft Archicad	☐	Softtech Spirit
☐	Autodesk Navisworks	☐	Bentley Structural Modeler	☐	Innovaya	☐	Tekla BIMSight
☐	Autodesk Revit	☐	CypeCAD	☐	Nemetscheck Allplan	☐	Tekla Structures
☐	Autodesk Robot Structural Analysis	☐	DesignBuilder	☐	Nemetschek Scia	☐	Vico Office Suite
☐	Bentley Architecture	☐	Digital Project Designer (Gehry Technologies)	☐	Rhino 3d	☐	Other, Please Specify: _________

Section 3: Energy Simulation Aptitude

Please place a check mark in the appropriate space or fill in the blank. Answer questions based on current information.

11) Do you perform **Energy Simulations** as a part of your job? ☐ Yes ☐ No

- *IF NO - Please **Skip to Question 16!**

12) Please indicate your experience level with Energy Simulation:
☐ ≤ 1 year ☐ >1 year-2 years ☐ >2 years-3 years ☐ >3 years-4 years ☐ >4years-5 years ☐ ≥ 5 years

13) Which of the following best represents your skill level with Energy Simulation software:
☐ Beginner ☐ Moderate ☐ Advanced ☐ Expert

14) Please indicate the percentage of projects that your company uses Energy Simulation?
☐ Light (Under 15%) ☐ Moderate (15% to 30%) ☐ Heavy (31% to 60%) ☐ Very Heavy (Over 60%)

15) Please indicate the Energy Simulation software product(s) that your firm uses: (select all that apply)

☐ Climate Consultant	☐ Energy 10	☐ G-Modeler	☐ Sefaira
☐ Design Builder	☐ EnergyPlus	☐ Green Building Studio	☐ Solar Shoebox
☐ D-profiler	☐ EnergyPro	☐ IES virtual environment	☐ TRNSYS
☐ Ecodesigner Star	☐ eQuest	☐ Open Studio	☐ Vasari
☐ Ecotect	☐ Fluent	☐ Radiance	☐ Virtual DOE

☐ Other, Please Specify____________________

16) Which of the following more accurately describes how you use Energy Simulation results? (Select one)
☐ To guide the design decision making process pertaining to improving building performance
☐ To validate previously made design decisions pertaining to building performance.
☐ Other, Please Specify________________________

17) In general, how accurate do you perceive Energy Simulation in predicting a buildings actual operating energy usage? (please circle)

☐ Extremely Inaccurate
☐ Inaccurate
☐ Somewhat Inaccurate
☐ Neither Accurate nor Inaccurate
☐ Somewhat Accurate
☐ Accurate
☐ Extremely Accurate

18) Please indicate your level of agreement/disagreement with the following statement:

"There is significant room for improvement in the process by which stakeholders provide me with information pertaining to the creation of an Energy Model"

☐ Strongly Disagree
☐ Disagree
☐ Somewhat Disagree
☐ Neither Agree nor Disagree
☐ Somewhat Agree
☐ Agree
☐ Strongly Agree

Section 4: How BIM and Energy Simulation Work Together

19) Does your company use information from BIM for the Energy Simulation process? ☐ Yes ☐ No
If no, Skip to question 21

20) Please indicate which of the following responses **best** represents how your company uses BIM information in the Energy Simulation process. (Select one)
☐ We use BIM based/ integrated Energy Simulation software that pulls info directly from a BIM software file.
☐ We use a "middleware" to pull info from BIM model and translate info to other simulation software programs
☐ We manually pull info from a BIM project file and enter into EM
☐ Other, Please specify ______________________________________

21) Do you use "middleware" to translate your BIM model information from your BIM model to your EM software? (If no, skip 24a)

a) Please indicate the confidence that you have in middleware's ability to accurately translate information to your EM software:
☐ Extremely Unconfident
☐ Unconfident
☐ Somewhat Unconfident
☐ Neither Unconfident nor Confident
☐ Somewhat Confident
☐ Confident
☐ Extremely Confident

22) What is your overall perception of the <u>value</u> associated with using information from Building Information Models to inform Energy Simulation?

☐ Very Low Value
☐ Low Value
☐ Somewhat Low Value
☐ Neither Low nor High Value
☐ Somewhat High Value
☐ High Value
☐ Very High Value

23) Please indicate your agreement/disagreement with the following statements (based on the current state of practice)

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Using information from BIM for Energy Simulation saves significant time in the Energy Simulation process.	☐	☐	☐	☐	☐	☐	☐
Using information from BIM for Energy Simulation dramatically increases the accuracy of Energy Simulation results	☐	☐	☐	☐	☐	☐	☐
Technically speaking, pulling information from BIM to inform Energy Simulations is easy to do.	☐	☐	☐	☐	☐	☐	☐
Using information from BIM for Energy Simulations has the potential to greatly reduce process related costs associated with Energy Simulation	☐	☐	☐	☐	☐	☐	☐
Integrating BIM with Energy Simulation tools allows for more design options to be examined	☐	☐	☐	☐	☐	☐	☐
Integrating BIM with Energy Simulation tools facilitates greater levels of communication among design stakeholders	☐	☐	☐	☐	☐	☐	☐

24) Please provide any further comments regarding existing benefits on using BIM for Energy Simulation based on your experience:

____

____

____

25) Please indicate your level of agreement/disagreement that the following items act as barriers for using BIM information for Energy Simulations.

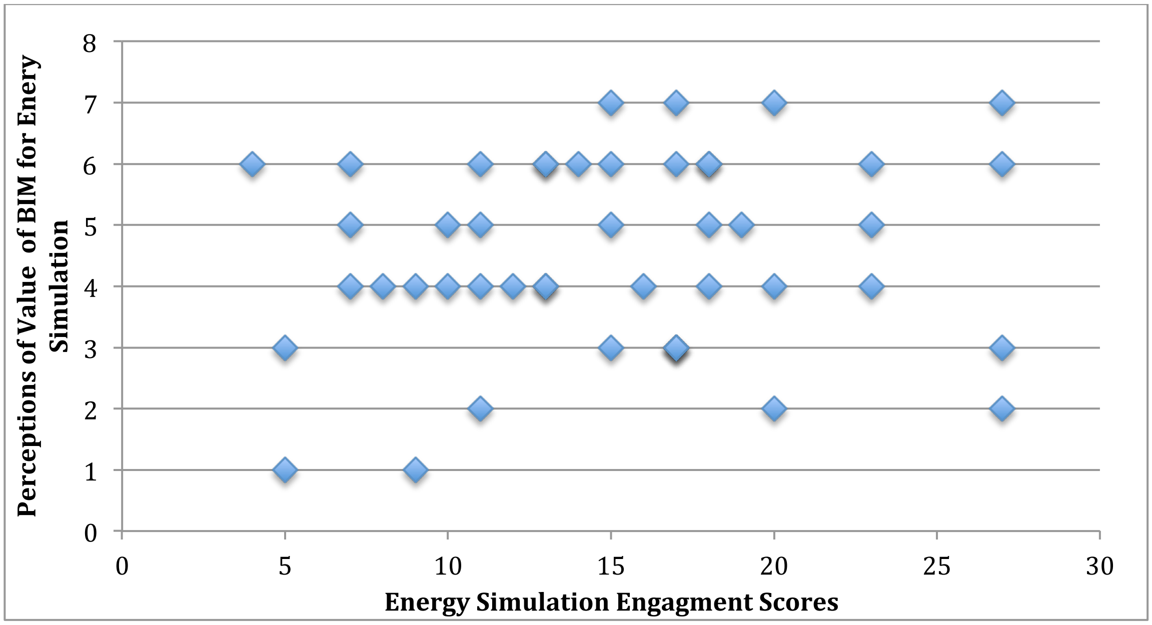
	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Hardware cost	☐	☐	☐	☐	☐	☐	☐
Software cost	☐	☐	☐	☐	☐	☐	☐
Software functionality	☐	☐	☐	☐	☐	☐	☐
Training cost	☐	☐	☐	☐	☐	☐	☐
Learning curve	☐	☐	☐	☐	☐	☐	☐
Lack of management buy in	☐	☐	☐	☐	☐	☐	☐
Lack of BIM standards for model integration with multidisciplinary teams	☐	☐	☐	☐	☐	☐	☐
Additional time needed to build the model	☐	☐	☐	☐	☐	☐	☐
Lack of motivation to change current processes	☐	☐	☐	☐	☐	☐	☐
Lack of others' capability to collaborate on a BIM model	☐	☐	☐	☐	☐	☐	☐
Interoperability issues	☐	☐	☐	☐	☐	☐	☐

26) Please provide any further comments regarding barriers to using BIM for Energy Simulation:
____
____
____

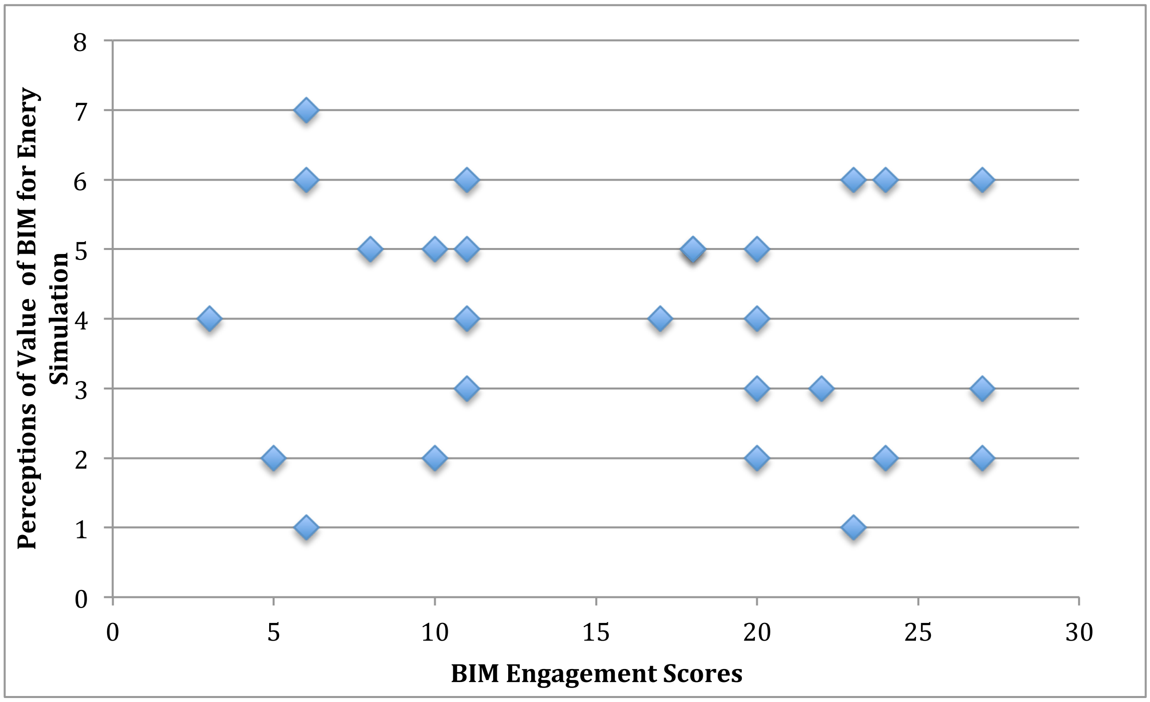
If you would like to elaborate on any of the of the topics covered in this survey, the questionnaire itself, or the survey process, please use the space below:

Thank you for your participation!

APPENDIX D: Scatter plot of BIM users engagement scores and their overall perception of the value of associated with using information from BIM to inform energy simulation (n=46).



Appendix E: Scatter plot of energy simulation users engagement scores and their overall perception of the overall value associated with using information from BIMs to inform energy simulation (n=27).



APPENDIX F: Chronbach's Alpha for the BIM engagement scale.

Reliability Statistics

Cronbach's Alpha	N of Items
.638	3

Case Processing Summary

		N	%
Cases	Valid	46	90.2
	Excluded	5	9.8
	Total	51	100.0

a. List wise deletion based on all variables in the procedure.

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
q8x	9.5217	18.788	.410	.599
q9x	11.1739	18.502	.503	.460
q10x	9.3043	21.505	.437	.557

APPENDIX G: Chronbach's Alpha for energy simulation engagement score.

Reliability Statistics

Cronbach's Alpha	N of Items
.765	3

Case Processing Summary

		N	%
Cases	Valid	27	52.9
	Excluded[a]	24	47.1
	Total	51	100.0

a. Listwise deletion based on all variables in the procedure.

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
q13x	9.8889	25.026	.683	.582
q14x	10.3704	22.319	.749	.492
q15x	11.4444	39.949	.417	.857

APPENDIX H: Permission for adapted use

Subject: RE: Question about BIM SmartMarket Report
Date: Tuesday, May 27, 2014 at 6:23:54 AM Mountain Daylight Time
From: Laquidara-Carr, Donna
To: Lewis,Anderson

Anderson,

Yes, please consider this email permission to adapt the table. Of course, all information drawn from the SmartMarket Report must be cited appropriately.

Donna

McGRAW HILL CONSTRUCTION
McGRAW HILL FINANCIAL

Donna Laquidara-Carr, Ph.D., LEED AP
Manager, Industry Insights and Research Communications

McGraw Hill Construction
34 Crosby Dr, Bedford MA 01730
T 781.430.2010 | F 781.430.2324
www.construction.com

From: Lewis,Anderson [mailto:Anderson.Lewis@colostate.edu]
Sent: Sunday, May 25, 2014 8:08 PM
To: Laquidara-Carr, Donna
Subject: Re: Question about BIM SmartMarket Report

Hello Donna,

I forwarded a previous request to you and never heard back. However, now I wanted to see if I could get permission to adapt a table from "The business value of BIM in North America: multi-year trend analysis and user ratings (2007-2012)." In specific , the "points used to calculate engagement index" and the "classification of Firms into engagement levels" tables. I have recreated them and it is only for use in my thesis.

Thanks!

Best Regards,

Anderson M. Lewis, LEED GA
Research Assistant
Construction Management Dept.
Colorado State University
C: (804) 514-8961 E: Amlax3@gmail.com

From: <Laquidara-Carr>, Donna <donna.laquidara@mhfi.com>
Date: Thursday, April 17, 2014 at 2:54 PM
To: Anderson Lewis <anderson.lewis@colostate.edu>
Subject: Question about BIM SmartMarket Report