BUILDING INFORMATION MODELING (BIM) AND ITS POTENTIAL IMPACTS ON SUSTAINABLE BUILDING PROJECT DELIVERY

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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MASTER OF SCIENCE IN BUILDING CONSTRUCTION

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This document is dedicated:

To the entire architecture, engineering, and construction (AEC) community,
in professional practice and in education,
such that we will all continuously assess the environmental benefits and consequences
of the actions and decisions we make.

and

To Edward Mazria, William McDonough, and Michael Braungart,
who helped open my eyes regarding the
environmental impacts of the entire AEC industry.

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By

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August 2009

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Cochair: Robert Ries
Major: Building Construction

The primary purpose of this research is to explore the potential uses of Building Information Modeling (BIM) to achieve environmental sustainability for the architecture / engineering / construction (AEC) industry. This research elaborates on the environmentally detrimental impacts that occur as a result of the construction of the built environment, stressing the need for a reduction or elimination of such impacts. Several third-party rating systems are introduced, rating systems which attempt to measure varying degrees of sustainability for specific building types. The technology referred to as BIM is defined and actual and perceived advantages and disadvantages associated with such software are described. The potential for utilizing BIM software to achieve sustainable design and construction is presented from the perspective of various literature on the subject, as well as from the perspective of surveyed AEC professionals.

As environmental awareness continues to increase, many building owners are asking for more sustainable buildings. Increasing numbers of municipalities now require certain building types to achieve specified levels of sustainable certification. The inherent dilemma within the AEC industry is that most often, every project is unique in many ways, therefore there is never

one single answer to any given issue and/or problem. Many professionals agree that BIM could possibly have the potential to greatly affect the AEC community's ability to design, engineer, and build more sustainable buildings. This research explores Building Information Modeling as one of the potential solutions that the AEC industry can utilize to provide building owners with more sustainable buildings, while simultaneously assisting AEC professionals in making more sustainable decisions.

CHAPTER 1
INTRODUCTION

As the world is entering a new era of environmental consciousness, the architectural / engineering / construction (AEC) professionals of today and tomorrow are obligated more now than ever, morally if not legally, to address the environmental implications of their actions. Buildings, and more broadly, the built environment, are extremely resource dependent, consuming vast amounts of raw materials and energy while generating large volumes of waste throughout construction and operation. Since many resources are not rapidly renewable, current trends cannot continue if humanity expects to anticipate a sustainable future.

Problem Statement

The AEC industry directly and indirectly has the potential to impact environmental disruption more so than any other sector. Therefore, it is imperative that AEC professionals fully understand the environmental consequences of their line of work, and it is critical that they have the tools available to assess and minimize the ecological impacts resulting from the decisions they make. Among the tools currently available, BIM appears to possess extraordinary potential assessing and minimizing the environmental footprint of the AEC industry. There is a need to investigate the use of BIM as the potential technological solution to the sustainability issue by detailing advantages and disadvantages of using BIM, in particular those advantages and disadvantages of using BIM to realize improved sustainability.

Research Objectives

The goal of this research is to explore the methods by which the AEC industry has the capability to mitigate negative environmental impacts of its actions. This research is intended to become a source of information for the AEC industry of today and tomorrow, to assist individuals in identifying the benefits and shortcomings of various methods and technologies, as they strive to improve the sustainability of the buildings they design and build. This research explores BIM as a potential tool capable of assisting the AEC community in making more sustainable decisions. The objectives of this research are as follows:

1. Determine the extent to which sustainability is affecting the AEC industry.
2. Determine the extent to which BIM is being utilized by the AEC community.
3. Determine the perceived and actual advantages and disadvantages to utilizing BIM.
4. Determine various AEC company's perceptions of BIM regarding utilizing BIM in order to achieve sustainability, and the reasoning behind such perceptions.
5. Determine whether or not BIM is changing the traditional methods of project delivery with regard to sustainability, and if so, how and why.

Research Methodology

The scope of this research includes a variety of methods for addressing the research objectives previously introduced. The methods for exploring sustainability and BIM are as follows:

Chapter 2 commences with a discussion of the environmentally detrimental impacts that occur as a result of the constructing the built environment, including: excessive energy consumption, raw materials consumption, and construction and demolition waste (C&D waste), stressing the need for a reduction or elimination of such impacts. Following this is a brief introduction to a variety of third-party rating systems such as LEED (Leadership in Energy and Environmental Design); these rating systems gauge the extent of sustainability for specific building types. Next, the technology referred to as BIM is defined, describing advantages and disadvantages associated with various software applications. Finally, the current and potential future uses of BIM software to achieve sustainable design and construction are presented. Upon concluding the literature review on this topic, it is evident that advances in BIM-related technology could potentially improve the ability of the AEC community to analyze design and construction proposals with regard to improving sustainability. A survey was distributed among 343 AEC companies in order to gain insight into if or how they have integrated sustainable ideologies and/or BIM technologies into their workflow processes. The survey form is reprinted in Appendix F and the responses are reprinted in Appendix G.

Chapter 3 introduces the methodology for composing the survey, and it presents the intentions behind each survey question. The decision to conduct such a survey was critical to this research as a method to compare BIM and sustainability literature with actual data collected from various AEC companies knowledgeable in utilizing BIM for sustainability. The survey was conducted to address the research objectives from a different perspective than that of the literature review.

Chapter 4 presents the analysis of the survey responses. The survey used several open-ended questions in which respondents typically replied in paragraph format. Such responses facilitated first-hand insight regarding the extent of BIM utilization and the benefits realized as a result of using BIM. The analysis resulted from categorizing the type of information included within each response. By surveying individuals from companies with knowledge and expertise of BIM for sustainability, this research provides a beneficial resource to those who wish explore the use of BIM to provide clients with sustainable buildings. A summarized analysis of the survey results concludes Chapter 4.

Chapter 5 presents the conclusions which link the literature review and the survey results. The conclusions recollect the research objectives and address them within the context of the research results. Ultimately, recommendations to the AEC community are suggested, such that companies might achieve a greater understanding of the potential uses of BIM to realize sustainable projects. Additionally, recommendations to BIM software manufacturers are suggested, such that they become aware of potential improvements to BIM which could facilitate its use on projects attempting to attain improvements to sustainability. Recommendations for future research are also suggested.

Summary

The importance or significance of this research is multifaceted: on one hand, it consolidates a wide variety of information into a single resource on BIM in general and BIM for sustainability; on the other hand, survey participants are recommended to provide contact information if they wish to receive a digital copy of this document. The intention of this research is to help increase the awareness of the capabilities of BIM software, such that this research might increase the understanding of the potential for BIM to improve sustainability throughout the AEC industry.

CHAPTER 2
LITERATURE REVIEW

In recent years, issues related to sustainability have begun to migrate from the sidelines into the mainstream. In general, we have begun to become more aware of the environmental consequences of our actions. Consciousness is rising regarding reducing energy consumption, greenhouse gas emission, and raw material consumption, just to name a few topics focused on reducing the ecological footprint resulting from the actions we take.

When assessing energy consumption, the entire economy is typically broken down into four major sectors: industrial, commercial, transportation, and residential, with these sectors representing the primary consumers of energy. The Energy Information Administration (EIA), an agency of the U.S. Department of Energy (USDOE), estimates that within the United States during 2007: the industrial sector consumed about 32% of total energy, followed by transportation at 29%, residential at 22%, and commercial at 18% (Figure 2-1) (EIA 2008). It should also be noted that energy consumption is typically correlated with greenhouse gas emissions, mostly carbon dioxide, methane, and nitrous oxide. This is due to the current predominant use of fossil fuels as energy derivatives (Mazria 2003).

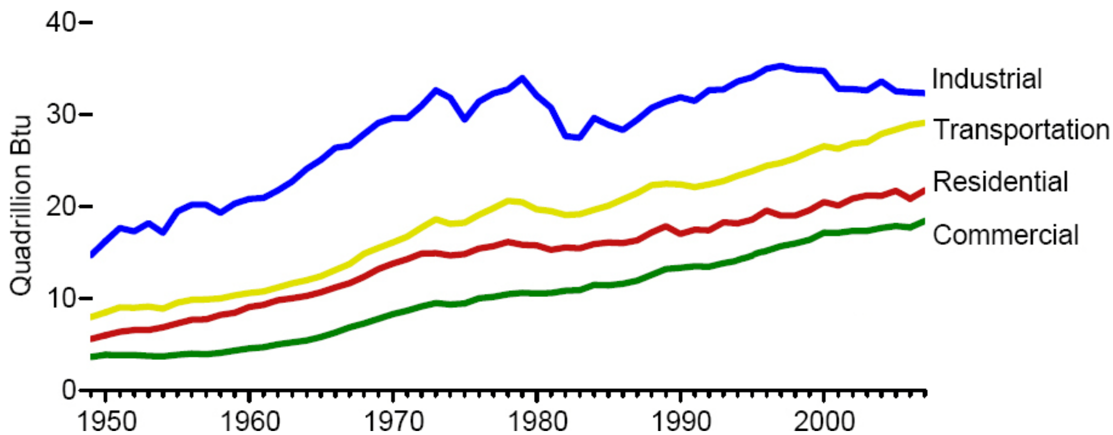

Figure 2-1. U.S. energy consumption by sector

Necessity for Sustainability in the AEC Industry

Mazria (2003) proposes that we should reconsider this model of energy consumption by traditional sectors in order to isolate the architecture and building construction professions, estimating that the AEC industry accounts for 48% of total U.S. energy consumption and 46% carbon dioxide emissions, stating that these are numbers are rounded down to provide conservative estimates (Figure 2-2). Mazria (2003) accentuates the severity of AEC energy consumption (Figure 2-3), which depicts a future projection of anticipated energy usage in the United States through the year 2020. Mazria (2003) concludes that it is the responsibility of architects to address this growing problem, citing conservatively that architects design 77% of all nonresidential buildings, 70% of all multifamily buildings, and 25% of all single-family homes. The United Nations Framework Convention on Climate Change promised to restore atmospheric greenhouse gas concentrations to 1990 levels. However, U.S. energy consumption increased by

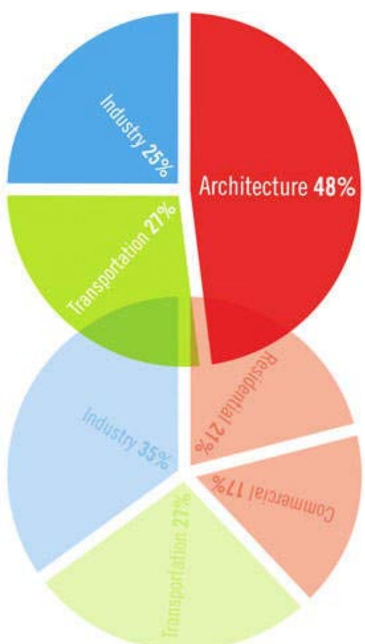

Figure 2-2. Modified U.S. energy consumption by sector

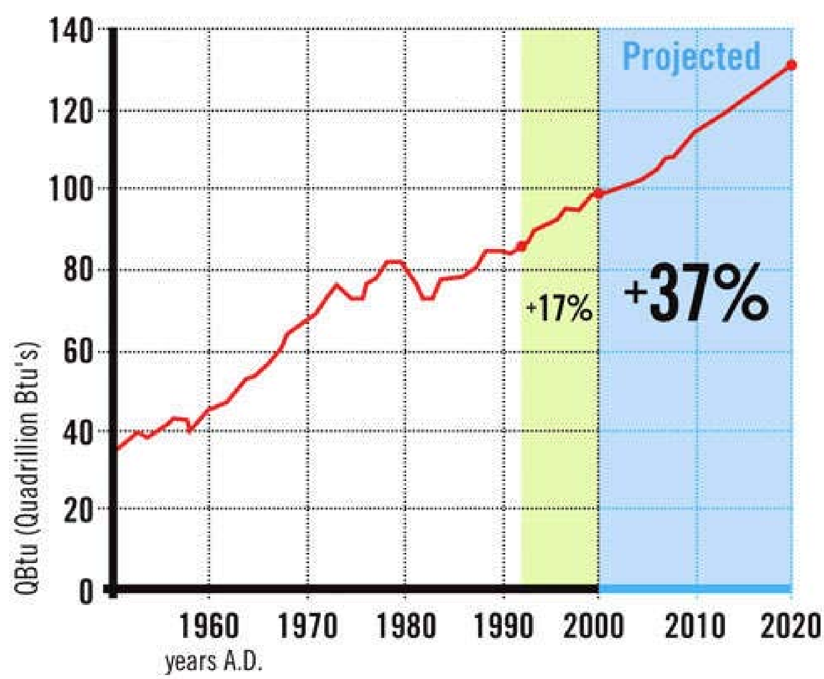

Figure 2-3. Total historic and projected U.S. energy consumption

17% through the 1990s and is expected to increase an additional 37% by 2020 (Mazria 2003). Since energy production and greenhouse gas emissions are related topics, the goal of reduced emissions and the trend of increased energy consumption appear to conflict, and in order to achieve the goal of a reduction in greenhouse gas emissions, changes to traditional methods of energy production and energy consumption are greatly necessary.

In addition to energy related sustainability issues concerning the built environment, the AEC industry consumes an exorbitant amount of raw materials, leading to greatly diminishing virgin materials stock on a global scale. From 1974 to 1994, the increased use of all raw materials for construction processes, except crude steel, far surpassed the growth in population. During this period, the global population increased by 40%, while also during this 20 year period, the global consumption of cement and plastics increased by 77% and 200%, respectively (Rekacewicz 2004). Buildings consume 40% of the raw stone, gravel, sand, and energy, 25% of the raw timber, and 16% of the water used globally every year (Lippiatt 1999). Each year, buildings in the U.S. consume 72% of total electricity, 39% of total primary energy, 14% of total potable water (15 trillion gallons annually), and 40% of raw materials (3 billion tons annually) (USGBC 2009). This extreme consumption results in the production of 38% of the total carbon dioxide emissions, and 136 million tons of construction and demolition (C&D) waste every year, in the United States alone. Annually in the United States, 210 million tons of municipal solid waste is disposed of, in addition to the 136 million tons of annual C&D waste (USGBC 2009). In the U.S., 39% of landfilled material by weight is the result of the AEC industry. Globally, the environmental impact of the AEC industry is almost unimaginable. Such aforementioned energy consumption, greenhouse gas emissions, virgin materials consumption, and waste statistics for the AEC industry cannot be deemed acceptable.

Referencing the recent and rapid increase in the number of construction projects globally, Smith (2007) stresses that the need for integrating sustainability into the AEC professions is essential to the future goals of the entire global AEC community. By 2030, approximately half of the total building stock in the U.S. will have been built after 2000 (Nelson 2004). This extraordinary increase in the U.S. building stock from 300 billion square feet in 2000 to an estimated 427 billion square feet by 2030 is a clear indication that sustainable intentions must be inherent to future design and construction projects, in order to ensure adequate energy and materials resources for future generations (Nelson 2004). From a global standpoint, the current and future growth in rapidly industrializing nations such as China will further increase the rate of energy and materials consumption and the generation of waste (Ortiz, Castells and Sonnemann 2007). Therefore, it is imperative that the AEC industry acknowledges these trends by continuing to address potential design and construction alternatives aimed at minimizing the environmental impact of this profession.

Sustainability Rating Systems

Sustainability rating systems are beneficial for establishing a framework for measuring the overall environmental impact of a building. These rating systems are referred to as third-party rating systems, meaning that a given project is not self-rated by any party involved in the project, thereby eliminating any conflicts of interest. Such rating systems assist the AEC community by providing a multitude of options helpful in rating projects based on a set of criteria. Utilizing these criteria, AEC professionals are better able to judge the environmental impacts of a particular project, establish a defined set of objectives and goals required for minimal acceptable performance, plan methodologies and establish rewards for achieving those goals, predict and observed trends, or predict problems areas before they occur (Pitts 2004). Rating systems might be used on any given project for a variety of reasons, including requests by the owner, requirement of local or regionally applicable legislation, or due to other reasons internal to the project team requirements for the project.

There are currently many frameworks that can be used to measure the extent of sustainability of building projects. Different rating systems use a variety of different performance indicators. The AEC team should determine which rating system is most applicable to a specific project based upon a variety of factors, often including: project specific details such as location, program, size, scope, owner and legal requirements; familiarity with the rating system by all contractually bound parties; and the ability and willingness of all parties to participate (Pitts 2004).

In the United States, the most common and universally accepted method for complete building analysis is LEED (Leadership in Energy and Environmental Design) (Werthan 2007). LEED is the only metric for sustainability thoroughly discussed here, but many such metrics exist, some of which measure the sustainable aspects of an entire building similar to LEED, while others focus more specifically on certain products and/or materials commonly used in buildings. Just as project owners might ask that LEED is used as a decision-making framework without actually pursuing LEED certification, other non-LEED systems can and should be employed by the AEC team to help ensure that sustainable intentions are realized. Tables 2-1 and 2-2 illustrate the variety of many recognized sustainability frameworks available to all parties of the project team including owners, designers, constructors, and engineers. It should be noted that these figures are not inclusive of every rating system currently available, but instead they help to illustrate the wide variety of possible metric systems for measuring sustainability intentions. Some frameworks analyze not only sustainable design and construction, but they also analyze building operations, maintenance, and life cycle assessment (LCA). Benefits of LCA can be

Table 2-1. Sustainability metric systems for buildings

Sustainability metric system	Sustainability related topics	Official online resources
(LEED) Leadership in Energy and Environmental Design	Building certification and LCA in LEED v3 (International)	http://usgcb.org/leed
(BREEAM) Building Research Establishment Environmental Assessment Method	Building certification and LCA (International)	http://www.breeam.org
Green Globes	Building certification and LCA (International)	http://www.thegbi.org
(CIBSE) Chartered Institution of Building Services Engineers	Building certification (International)	http://www.cibse.org
Energy Star	Building certification and energy performance (U.S.)	http://www.energystar.gov
Green Star	Building certification (Australia)	http://www.gbca.org.au
(HERS) Home Energy Rating Systems	Residential certification (U.S.)	http://www.energy.ca.gov/HERS/index.html
(SAP) Standard Assessment Procedure	Residential certification (U.K.)	http://projects.bre.co.uk/sap2005/index.html
(NABERS) National Australian Building Environmental Rating System	Existing building certification (Australia)	http://www.nabers.com.au

Table 2-2. Sustainability metric systems for building components

Sustainability metric system	Sustainability related topics	Official online resources
Green Guide to Specification	Building components and materials (International)	http://www.thegreenguide.org.uk
(C2C) Cradle-to-Cradle Certification	Building components and materials (International)	http://www.c2ccertified.com
(FSC) Forest Stewardship Council	Sustainable certified lumber (International)	http://www.fsc.org

significantly important to owners who are concerned with how a potential increase in up-front design and construction expenses can be validated by future benefits, economic as well as environmental.

Leadership in Energy and Environmental Design (LEED)

Established by the United States Green Building Council (USGBC) in 1999, the LEED Rating System was originally developed for commercial buildings (Fedrizzi 2009). LEED has since seen additions and revisions to its sustainability measurement protocol. The version used today is LEED 2.2, which has a variety of metrics for sustainability depending on project type. LEED is similar in many ways to BREEAM, CIBSE, Green Globes, and NABERS.

The current LEED rating system, LEED 2.2, includes: LEED for New Construction and Major Renovations (LEED-NC), LEED for Existing Buildings: Operations & Maintenance (LEED-EB), LEED for Commercial Interiors (LEED-CI), LEED for Core & Shell (LEED-CS), LEED for Schools (LEED-S), LEED for Healthcare (LEED-HC), LEED for Homes (LEED-H), and LEED for Neighborhood Development, which has been undergoing preliminary pilot testing for some time recently (USGBC 2008a). The categories within each LEED 2.2 Rating System are: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design Process. However, just as many non-LEED rating systems initiate periodic updates, the LEED 2.2 rating system will be soon be updated to LEED Version 3 (LEED v3), as the USGBC is currently in the process of updating its building certification criteria and methodology. After June 26, 2009, projects seeking LEED certification will be required to adhere to the LEED v3 protocol (USGBC 2008b).

LEED v3 will improve upon LEED 2.2 by: expanding the third-party certification program, providing updates to LEED Online, and introducing LCA into the LEED certification process (Fedrizzi 2009). Another significant change is that the wide array of LEED rating

Table 2-3. LEED v3 compared with LEED-NC 2.2 by category

LEED Category	LEED v3		LEED-NC 2.2		Percent Change
	Credits Available	Percent of Total Credits	Credits Available	Percent of Total Credits	
Sustainable Sites	26	23.64%	14	20.29%	3.35%
Water Efficiency	10	9.09%	5	7.25%	1.84%
Energy & Atmosphere	35	31.82%	17	24.64%	7.18%
Materials & Resources	14	12.73%	13	18.84%	-6.11%
Indoor Environmental Quality	15	13.64%	15	21.74%	-8.10%
Innovation & Design Process	6	5.45%	5	7.25%	-1.79%
Regional Bonus Credits	4	3.64%	0	0.00%	3.64%
Total Credits	110		69		

systems such as LEED-NC and LEED-EB will all be incorporated into three broad rating systems: Green Building Design & Construction, Green Interior Design & Construction, and Green Building Operations & Maintenance; this will help to normalize the point structure for possible credits (USGBC 2008c). Other modifications to LEED will include the redistribution of credits in order to place more emphasis on Energy & Atmosphere and Sustainable Sites, while reducing emphasis from Indoor Environmental Quality and Material & Resources (Table 2-3). Additionally, LEED v3 will add a new category of credits relating to regionally specific sustainability efforts to help encourage localized environmental consciousness, since many sustainable decisions might not be applicable to every possible geographic location. The USGBC provides a thorough breakdown of the changes to each category (Figure 2-4) (USGBC 2008d).

LEED v3 and Sustainability Legislation

Many municipalities currently have legislation, executive orders, and/or mandates which prescribe that certain building types must achieve a set level of sustainability in design and construction. Such jurisdictions include, but are not limited to: the states of Arkansas, Arizona,

LEED for New Construction and Major Renovation 2009 with comparison
Project Scorecard

Points Change
Threshold Change
Name Change
New Credit

Project Name:
Project Address:

Yes	?	No	Credit	Title	LEED 2009	Previous Version NCv2.2	Notes
				Sustainable Sites	26 Points	NCv2.2	Notes
Y			Prereq 1	Construction Activity Pollution Prevention	Required	Required	
			Credit 1	Site Selection	1	1	
			Credit 2	**Development Density & Community Connectivity**	5	1	
			Credit 3	Brownfield Redevelopment	1	1	
			Credit 4.1	**Alternative Transportation,** Public Transportation Access	6	1	
			Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	1	1	
			Credit 4.3	**Alternative Transportation,** Low-Emitting & Fuel-Efficient Vehicles	3	1	
			Credit 4.4	**Alternative Transportation,** Parking Capacity	2	1	
			Credit 5.1	Site Development, Protect or Restore Habitat	1	1	
			Credit 5.2	Site Development, Maximize Open Space	1	1	
			Credit 6.1	Stormwater Design, Quantity Control	1	1	
			Credit 6.2	Stormwater Design, Quality Control	1	1	
			Credit 7.1	Heat Island Effect, Non-Roof	1	1	
			Credit 7.2	Heat Island Effect, Roof	1	1	
			Credit 8	Light Pollution Reduction	1	1	
				Water Efficiency	10 Points	NCv2.2	Notes
			Prereq 1	**Water Use Reduction,** 20% Reduction	Required	X	changed from WEc3.1 to WEp1
			Credit 1.1	**Water Efficient Landscaping,** Reduce by 50%	2	1	
			Credit 1.2	**Water Efficient Landscaping,** No Potable Use or No Irrigation	2	1	
			Credit 2	**Innovative Wastewater Technologies**	2	1	
			Credit 3.1	**Water Use Reduction,** 30% Reduction	2	1	threshold change 20% to 30%
			Credit 3.2	**Water Use Reduction,** 40% Reduction	2	1	threshold change 30% to 40%
				Energy & Atmosphere	35 Points	NCv2.2	Notes
Y			Prereq 1	Fundamental Commissioning of the Building Energy Systems	Required	Required	
Y			Prereq 2	**Minimum Energy Performance:** 10% New Bldgs or 5% Existing Bldg Renovations	Required	Required	Threshold change 14% to 10%
Y			Prereq 3	Fundamental Refrigerant Management	Required	Required	
			Credit 1	**Optimize Energy Performance**	1 to 19	1 to 10	
				12% New Buildings or 8% Existing Building Renovations	1	1	
				16% New Buildings or 12% Existing Building Renovations	3	2	
				20% New Buildings or 16% Existing Building Renovations	5	3	
				24% New Buildings or 20% Existing Building Renovations	7	4	
				28% New Buildings or 24% Existing Building Renovations	9	5	
				32% New Buildings or 28% Existing Building Renovations	11	6	
				36% New Buildings or 32% Existing Building Renovations	13	7	
				40% New Buildings or 36% Existing Building Renovations	15	8	
				44% New Buildings or 40% Existing Building Renovations	17	9	
				48% New Buildings or 44% Existing Building Renovations	19	10	
			Credit 2	**On-Site Renewable Energy**	1 to 7	1 to 3	
				1% Renewable Energy	1	1	
				5% Renewable Energy	3	2	
				9% Renewable Energy	5	3	
				13% Renewable Energy	7		
			Credit 3	**Enhanced Commissioning**	2	1	
			Credit 4	**Enhanced Refrigerant Management**	2	1	
			Credit 5	**Measurement & Verification**	3	1	
			Credit 6	**Green Power**	2	1	

Figure 2-4. LEED v3 compared with LEED-NC 2.2 by credit

California, Connecticut, Colorado, Florida, Maryland, Massachusetts, Maine, Michigan, Nevada,New Jersey, New Mexico, New York, Pennsylvania, Rhode Island, Washington, and Wisconsin, as well as the cities of Atlanta, Austin, Boston, Boulder, Chicago, Dallas, Los

LEED for New Construction and Major Renovation 2009 with comparison
Project Scorecard

Points Change
Threshold Change
Name Change
New Credit

Project Name:
Project Address:

Yes	?	No		LEED 2009	Previous Version	
Yes	?	No	**Materials & Resources**	14 Points	NCv2.2	Notes
Y			Prereq 1 **Storage & Collection of Recyclables**	Required	Required	
			Credit 1.1 **Building Reuse,** Maintain 75% of Existing Walls, Floors & Roof	2	1	
			Credit 1.2 **Building Reuse,** Maintain 95% of Existing Walls, Floors & Roof	1	1	
			Credit 1.3 **Building Reuse,** Maintain 50% of Interior Non-Structural Elements	1	1	
			Credit 2.1 **Construction Waste Management,** Divert 50% from Disposal	1	1	
			Credit 2.2 **Construction Waste Management,** Divert 75% from Disposal	1	1	
			Credit 3.1 **Materials Reuse,** 5%	1	1	
			Credit 3.2 **Materials Reuse,** 10%	1	1	
			Credit 4.1 **Recycled Content,** 10% (post-consumer + ½ pre-consumer)	1	1	
			Credit 4.2 **Recycled Content,** 20% (post-consumer + ½ pre-consumer)	1	1	
			Credit 5.1 **Regional Materials,** 10% Extracted, Processed & Manufactured Regionally	1	1	
			Credit 5.2 **Regional Materials,** 20% Extracted, Processed & Manufactured Regionally	1	1	
			Credit 6 **Rapidly Renewable Materials**	1	1	
			Credit 7 **Certified Wood**	1	1	
Yes	?	No	**Indoor Environmental Quality**	15 Points	NCv2.2	Notes
Y			Prereq 1 **Minimum IAQ Performance**	Required	Required	
Y			Prereq 2 **Environmental Tobacco Smoke (ETS) Control**	Required	Required	
			Credit 1 **Outdoor Air Delivery Monitoring**	1	1	
			Credit 2 **Increased Ventilation**	1	1	
			Credit 3.1 **Construction IAQ Management Plan,** During Construction	1	1	
			Credit 3.2 **Construction IAQ Management Plan,** Before Occupancy	1	1	
			Credit 4.1 **Low-Emitting Materials,** Adhesives & Sealants	1	1	
			Credit 4.2 **Low-Emitting Materials,** Paints & Coatings	1	1	
			Credit 4.3 **Low-Emitting Materials,** ~~Carpet Systems,~~ Flooring Systems	1	1	
			Credit 4.4 **Low-Emitting Materials,** Composite Wood & Agrifiber Products	1	1	
			Credit 5 **Indoor Chemical & Pollutant Source Control**	1	1	
			Credit 6.1 **Controllability of Systems,** Lighting	1	1	
			Credit 6.2 **Controllability of Systems,** Thermal Comfort	1	1	
			Credit 7.1 **Thermal Comfort,** Design	1	1	
			Credit 7.2 **Thermal Comfort,** Verification	1	1	
			Credit 8.1 **Daylight & Views,** Daylight 75% of Spaces	1	1	
			Credit 8.2 **Daylight & Views,** Views for 90% of Spaces	1	1	
Yes	?	No	**Innovation & Design Process**	6 Points	NCv2.2	Notes
			Credit 1.1 **Innovation in Design:** Provide Specific Title	1	1	
			Credit 1.2 **Innovation in Design:** Provide Specific Title	1	1	
			Credit 1.3 **Innovation in Design:** Provide Specific Title	1	1	
			Credit 1.4 **Innovation in Design:** Provide Specific Title	1	1	
			Credit 1.5 **Innovation in Design:** Provide Specific Title	1	X	one additional ID point
			Credit 2 **LEED® Accredited Professional**	1	1	
Yes	?	No	**Regional Bonus Credits**	4 Points	NCv2.2	Notes
			Credit 1.1 **Region Specific Environmental Priority:** Region Defined	1	X	
			Credit 1.2 **Region Specific Environmental Priority:** Region Defined	1	X	
			Credit 1.3 **Region Specific Environmental Priority:** Region Defined	1	X	
			Credit 1.4 **Region Specific Environmental Priority:** Region Defined	1	X	
Yes	?	No	**Project Totals (Certification Estimates)**	110	Points	

Not Certified

Certified: 40-49 points **Silver:** 50-59 points **Gold:** 60-79 points **Platinum:** 80+ points

Figure 2-4. Continued

Angeles, Portland (Oregon), San Diego, San Francisco, San José, Seattle, and Washington D.C. The degree of sustainability, the building types requiring certification, and the rating systems recommended or required vary by municipality. This researcher has conducted independent research on this topic, which is reprinted in its entirety in Appendix H to provide detailed information for specific legislation as of 2007, in addition to providing resources for further research. Many municipalities requiring AEC sustainability either require a specified level of LEED certification (typically LEED Silver or equivalent) or they require that LEED is used as a framework without necessarily requiring certification. In many instances, existing legislation also have stipulations similar to: "adherence to all future versions of LEED promulgated by the USGBC shall be required" (Del Percio 2008).

As the USGBC is preparing to introduce LEED v3, Del Percio (2008) questions how changes to LEED will effect current legislation: Will the current laws be amended to reflect the new version of LEED? Will legislators become more hesitant to implement sustainable laws, since rating systems will continue to evolve? The USGBC LEED Steering Committee has commented has commented multiple times that it does not intend to treat LEED as a building code, however more and more localities are beginning to require some degree of sustainability (Del Percio 2008). In consideration of the extremely relative infancy of LEED v3, which in fact has yet to be completely introduced at the time of this writing, these and other questions will only be answered in due time.

Building Information Modeling (BIM)

Sustainability cannot remain a niche market within small pockets of the AEC community; instead, sustainability must become a vital aspect of the entire AEC industry. Striving to answer the question, "How is sustainability achieved?," it should be readily apparent that just like with any design related decision, there is no one single answer to this question. This research explores the potential of Building Information Modeling (BIM) software, which currently appears to be greatly beneficial in assisting AEC professionals throughout the processes of designing and constructing more sustainable buildings.

Building Information Modeling has no single widely-accepted definition (Campbell 2006). BIM can refer to either: the Building Information Modeling software, the process of creating the digital BIM model, or the actual digital BIM model itself. For the purposes of this research, BIM has all of these definitions, depending on the context in which the term BIM is used. In addition, this research also includes tertiary analysis software within the definition of BIM, such as specialized energy or lighting analysis software, for example. Sometimes, such analytical tools are built into BIM software packages. Other times, tertiary applications require importing the model data from external BIM software, especially in the event the tertiary analysis application cannot be used to build the digital model.

Building Information Modeling software utilize what are typically referred to parametric databases, in which all aspects of the building design and construction details are linked to one another to simplify building analysis. To elaborate, the building is digitally modeled in three dimensions, such that any modifications to the actual model are automatically updated in all supporting two-dimensional views or camera angles of the model, including not just the exterior elevations, but the floor plans, building sections, and any interior elevations as well. The parametric nature of data storage can possibly provide many potential benefits.

BIM is a technology integrated into various computer software applications as a way to potentially improve the processes of design and building documentation, construction, fabrication, and life cycle assessment of buildings. Building Information Modeling is the creation and use of coordinated, consistent, computable information about a building project in design—

information used for design decision making, production of high-quality construction documents, predicting building performance, cost estimating, construction planning, and, eventually, for managing and operating the facility (Krygiel and Nies 2008; Autodesk Inc. 2008). Bentley Systems describes BIM as new way to approach the design and documentation of building projects, elaborating several advantages of BIM over CAD (Bentley Systems Inc. 2008a):

- Building – consideration of the building's entire lifecycle (design/build/operations)
- Information – inclusion of all information about the building and its lifecycle
- Modeling - defining and simulating the building, its delivery, and operation using integrated tools

BIM models are not simply graphic tools; they are also databases for information that assist in the automatic generation of drawings and reports, design analysis, schedule simulation, facilities management, and more. These benefits assist the building team in making more informed decisions in collaboration among project team members while reducing or eliminating data redundancy, data re-entry, data loss, miscommunication, and translation errors (Bentley Systems Inc. 2008a). Eastman et al. characterizes BIM models as having the following characteristics (Eastman, Teicholz, Sacks and Liston 2008):

- Digitally represented building components with intelligent associations among graphic data, parametric rules, and object attributes necessary for project analysis and work processes including quantity takeoff, specifications, and energy analysis
- Consistent and non-redundant data such that changes to object data are reflected in all views of the object
- Coordinated data such that all views of the 3D model are associative

Campbell (2006) describes BIM as an "intelligent simulation of architecture." A digital representation of a building must have the following characteristics in order to characterize it a BIM model; these characteristics are critical for ease of future revisions and analyses:

- Digital
- Spatial (3D)
- Measurable (quantifiable, dimension-able, and query-able)
- Comprehensive (encapsulating and communicating design intent, building performance, constructability, and include sequential and financial aspects of means and methods)
- Accessible (to the entire AEC/owner team through an interoperable and intuitive interface)
- Durable (usable through all phases of a facility's life)

BIM is becoming an increasingly common catch-phrase among software developers when marketing their software. Eastman et al. (2008) stresses the importance of emphasizing information storage and analysis, the "I" of BIM, describing several characteristics of models which are NOT derived from BIM software:

- Models only containing graphic visual 3D data without object attributes
- Models with no support of behavior or parametric proportioning and dimensioning
- Models generated from combining multiple 2D CAD reference files
- Models allowing dimensional changes in one view which are not automatically updated in all other views

As BIM continues to gain more frequent usage among the AEC community, many professionals are beginning to utilize BIM for the design, construction, and operations of more sustainable buildings in a way which was not possible years ago using a more graphical 2D approach (Smith 2007). Within the context of sustainability, the following section compares traditional design methods with design methods using BIM.

Traditional Design Methodologies and BIM

The problem with traditional design methodologies is that the design aspect of the AEC community is traditionally comprised of architects, structural engineers, mechanical engineers, electrical engineers, and a host of other various professionals who work for owners and clients by typically prescribing buildings components as two-dimensional lines in paper format, or more recently, in AutoCAD or other digital software. Even after the transition from the traditional paper media to digital media, these drawings typically occurred in relative isolation from one another in comparison to the manner in which BIM relates the drawings; although tracing paper for physical media and drawing layers for digital media make it possible to view other 2-D drawings as an underlay, it is difficult if not impossible to place every other relevant finalized or in-process drawing, physical or digital, underneath the current drawing in progress. As a result, errors, omissions, inconsistencies, and/or clashes (overlapping building components) can and do occur quite frequently when any given drawing within the architectural documents is incorrect with respect to any other drawing (Eastman et al. 2008).

Building Information Modeling can potentially reduce such error among multiple drawings by uniting multiple aspects of the building design processes into a single database of information. With BIM software, the building is designed in 3-D, or potentially 4-D which considers time related issues of construction sequencing. The 3-D model can then be used to produce high quality 2-D construction drawings. Due the parametric modeling aspect of BIM, efficiencies are introduced which could expedite the design process (Eastman et al. 2008).

Consider a typical green building project before BIM was readily accessible. During preliminary design, rough drawings and sketch models are produced to explore architectural concepts such as building mass/void, exterior/interior views, materiality, lighting, color, etc. It is through a series of iterations which the process of building conceptualization progresses:

- Multiple conceptual physical models might be built in order to explore design possibilities and programmatic requirements of the building
- A solar analysis model might be constructed to study exterior shading of the building and its impact on the design

- A daylighting model might be used to analyze interior lighting conditions and to begin to design artificial lighting systems
- A separate 3-D digital model might then be produced to assist in fine-tuning of the design and to provide a presentation medium for the owner, investors, and other parties
- A digital 3-D energy model might be created to assess energy loads regarding solar insolation, heating/cooling, equipment heat gain, ventilation, and occupant loads

Ultimately, the architect will use a variety of tools which will be used to generate the final design, and finally the construction documents, which are typically generated as a series of lines printed in traditional 2-D CAD or similar software. Historically, it has been unlikely that these multiple phases in the design process occurred within the same platform. (Krygiel and Nies 2008). BIM has the potential to provide methods of consolidating the phases of sustainable architectural design, even at an extremely preliminary design phase. When the concept of BIM was originally introduced, it predicted the ability of a single building model to support all aspects of design, construction, and operations (Khemlani 2006a). It can very well be argued that this technology is not yet at this level of development, taking into account that BIM is still relatively new, but in consideration of recent and potential future improvements to software and hardware, the usefulness of BIM for sustainable design and sustainable construction is likely to increase (Livingston 2007a). While the capabilities, advantages, and disadvantages of BIM varies depending upon which software application(s) are utilized, it would be desirable that any software accurately marketed as BIM should be able to provide all of the benefits discussed in the following sections:

Benefits of BIM to Owners

BIM has the potential to streamline the planning and documentation processes of design and construction project delivery (Eastman et al. 2008). A Building Information Model is able to assist each individual party in coordinating the necessary AEC processes with every other party involved. The potential for coordination among multiple parties typically involved in construction projects is visualized in Figure 2-5 (Autodesk Inc. 2008). This collaboration of various professionals typically leads to an overall reduction of errors and/or omissions on the construction drawings, which in turn leads to more efficient cost estimating and construction sequencing planning. These benefits allow project planners to provide owners with more accurate estimates of project cost and construction duration, even very early in the design process. Obvious benefits to the owner include potentially reducing disputes over estimated costs versus actual costs, as well as reducing the potential for late completion (Eastman et al. 2008). In addition, architects using a three-dimensional model as a tool for discussion with the owner can ensure that the programmatic design requirements of the building are satisfied; the owner may not be as proficient as the architect at visualizing the building design in two dimensions. The 3-D model can assist the owner in becoming more involved in the conceptual design processes, thereby improving the likelihood that the owner will receive the building as envisioned. The collaboration between the designers and the owner can potentially reduce costly and time-consuming owner-directed change orders during the construction process.

In consideration of sustainability, BIM also has the potential to benefit the owner through lower operating costs. Because BIM

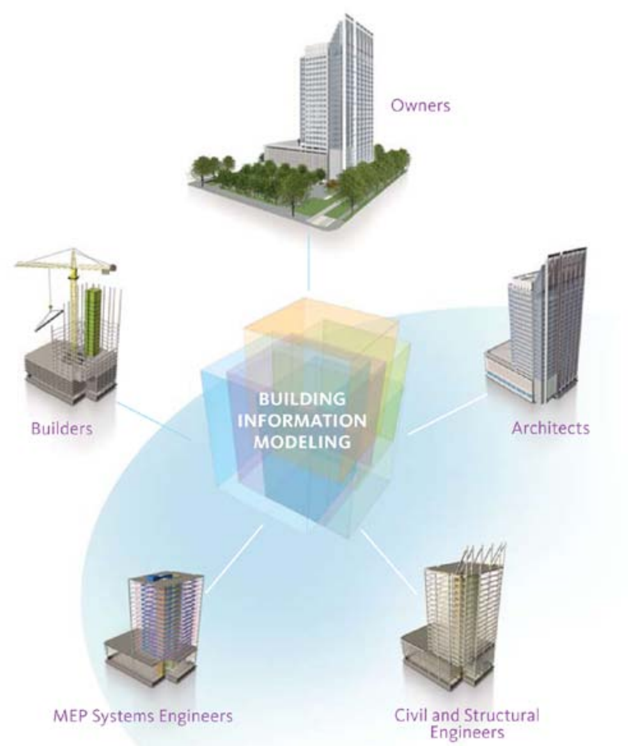

Figure 2-5. Potential of BIM for collaboration

stores its data in parametric databases, a Building Information Model can be utilized early in the design process to analyze expected energy usage in order to design strategies for energy usage reduction. Lighting, heating, cooling, and ventilation requirements for the building could be accurately modeled. (Eastman et al. 2008). Gleeson (2005) expresses his belief that the use of BIM by the architects and engineers can help make the building design more efficient, resulting in greatly reduced energy consumption and therefore greatly reduced operating expenses.

Benefits of BIM to Architects and Engineers

BIM has the capability to benefit architects in a variety of ways. During the early phases of conceptual design, experimenting with the building form in terms of mass and void in three dimensions instead of two dimensions can greatly help the decision-making processes of the design processes. BIM is also beneficial to architects by streamlining the process of building documentation. Because the design is created in three dimensions, the 2-D construction documents (CDs) can be derived from the 3-D model. Changes to the model are automatically applied to the drawings, eliminating the need to manually update each individual sheet and reducing the total time required for design documentation. Also, various schedules such as door, window, room, and materials schedules can be generated directly from the model, and these are also automatically updated as the model is modified. This automatic linkage between the Building Information Model and the CDs has the potential to reduce time-consuming and costly errors which might and often do occur when the information is extracted manually.

BIM also has the capability to improve collaboration between architects and engineers. Because the architectural design, the structural design, and the mechanical/electrical/plumbing (MEP) design are typically performed by separate professionals, many problems could arise. The most consequential problems relate to spatial constraints for the necessary equipment or for the installation of equipment. Utilizing a Building Information Model for the design of not just the architectural systems but also the MEP systems can maximize the efficiency of the design and construction processes. Conflicts between structural members, architectural components, and MEP systems can be detected early in the design process by a tool commonly referred to as clash detection, as opposed to identifying these conflicts manually during design or even during actual construction, when the time and cost necessary to resolve such issues are much greater (Eastman et al. 2008).

The ability of BIM to improve collaboration is greatly beneficial to sustainable design. Vaugan (cited in Tulacz and Traynor 2008) believes that a paradigm shift is necessary for sustainable design; the architects and engineers must work together as early in the design process as possible in order to make the greatest difference in optimizing MEP systems for improved sustainability regarding issues such as energy usage related to input-output analysis. Greater collaboration between architects and engineers, which is possible with BIM, can provide substantial energy savings, especially during the design of the building envelope which is a critical factor in energy analysis and energy consumption; the engineers are much more efficient with regard to sustainability when collaborating with the architect during preliminary design (Cooper cited in Tulacz and Traynor 2008).

Benefits of BIM to Contractors

Early collaboration between the owner, architect, and engineers is advantageous in resolving problematic issues before they arise; this is also the case with contractors. Involving the contractors during the design phase is beneficial in addressing constructability issues related to the project. The Building Information Model itself has the capacity to contain much more data than a non-parametric set of drawings. Assuming accuracy in the model, the quantities of materials to be delivered to the jobsite can be taken right from the model, thus eliminating the possibility of errors from manual quantity take-offs. The resulting quantities can have applicable costs applied to generate accurate cost estimates. Typically, the acts of preparing quantity take-offs and estimating occur very late in the design stages, since the design must be relatively complete to perform these tasks, but by utilizing BIM, these cost estimates can occur throughout the design process. As the design is modified, the estimates are continuously updated, allowing for better control to minimize these costs, a clear benefit to the owner. Attributes related to construction sequence planning can also be applied to objects within the model to assist project managers in sequencing of construction work in what is typically called 4D planning, by adding the element of time to the 3D model. This construction sequence can then be used to: control the delivery of materials to the site; compare the actual construction sequencing against the schedule; and monitor recordkeeping regarding requests for payment from the owner (Eastman et al. 2008).

Summary of BIM Processes

Building Information Modeling has great potential to provide dramatic improvements to productivity throughout the design, construction, maintenance, and occupation of buildings. It provides a single source for data relevant to the specific building project and facilitates the sharing of information among the numerous professions beneficial to design and construction processes. BIM facilitates AEC industry processes by the nature of how it stores information in a parametric database, which can contain as little or as much data pertinent to the building as necessary. All data originates from the 3-D model, so regardless of whether the project is in the preliminary design stage or at 99% design completion, a change to the BIM model will automatically update all 2-D drawings of the construction document set. Additionally, the updated model can be easily used to generate updated energy and lighting simulations, which typically requires re-exporting the modified 3-D model into external energy analysis software. In addition, as the model is updated, updates can be made automatically to the schedule of values (AIA Document G-703) to ensure accurate construction materials quantity takeoffs. Project planning regarding cost estimation and construction sequencing can be facilitated by the automatic generation of spreadsheets which are updated with accurate materials quantities as the BIM model is modified. Figure 2-6 graphically displays how the utilization of BIM can potentially reduce costs and save time while facilitating the processes of project planning from design conceptualization through construction and operation (Livingston 2008).

Advantages and Disadvantages of Selected BIM Software Applications

There currently exists a variety of different BIM software platforms, and the decision on which BIM application to use is influenced by a variety of factors. Primary factors which

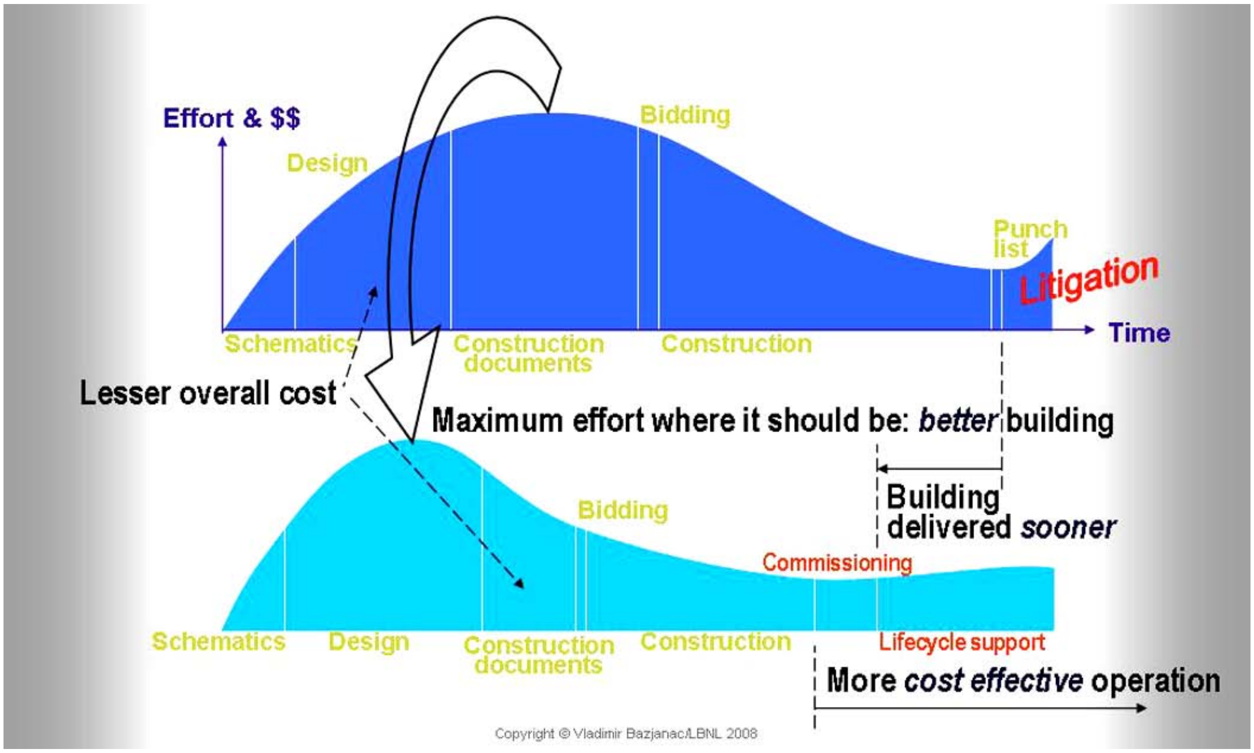

Figure 2-6. Efficiencies resulting from the use of BIM

typically influence the decision to utilize a particular BIM software application include (Eastman et al. 2008):

- The family of software applications available.
- The extent of interoperability between multiple BIM applications.
- The extent of the object or family libraries, such as doors, windows, walls, etc.
- The types of objects the software can model.
- The level of detail of the object attributes.
- The complexity of the software.
- The building classification system(s) supported.
- The ability to easily generate the construction drawings from the BIM model.
- The ease of use and the user interface.
- The software cost.
- The frequency and quality of software updates.
- The employee/contract-bound-party's familiarity with the software.
- The degree of training required to use the software.

The following sections detail various aspects of different BIM software applications, as compiled from a multitude of sources. This research provides a single concise source to assist in performing side-by-side comparisons. Note that although the following detailed BIM descriptions aim to be thorough, lists of features and benefits may or may not be all-inclusive. Attempts were made to generate these BIM descriptions from the most up-to-date versions of the software, at the time of the writing of this document.

Revit Architecture, Structure, and MEP (Autodesk Inc.)

Revit is possibly the most widely known BIM application and has been available from Autodesk since 2002. Revit is a series of programs including Revit Architecture, Revit Structure, and Revit MEP, which can be easily utilized by separate professionals working on the same project. By the definition of BIM, Revit applications utilize a central database to link all information pertaining to a specific project, so that all pertinent project data originate from and is saved to the same place.

Internally, Revit fosters communications among architects, engineers, contractors, and owners. The database for any given project can be shared among various professionals working on various aspects of the Building Information Model simultaneously. The database is typically saved to a main server, which can be accessed and modified by various team members working locally, and then the changes are saved to the central server. The software can be controlled such that various architectural, structural, MEP components of the building model can only be modified by the team members responsible for those components.

The software and its interface are relatively simple to learn; an understanding of basic AutoCAD somewhat improves the learning curve. However, there are some significant differences between Revit and AutoCAD. The actual 3D model is saved in a RVT file, but Revit utilizes ‘object families’ which are 2-D or 3-D parametric objects saved as RFA files. These families are similar to AutoCAD’s external references (XREFs), except that they are parametric in nature: ratios of dimensions can easily be manipulated and materiality information can be applied to the object’s properties to assist in assessing aesthetics as well as estimating cost. Families are loaded into the project as needed, reducing the size of the RVT file, but as more families are loaded to the project file, the file size inevitably increases. Changes to the family RFA files can quickly and easily be updated within the model, thereby ensuring that the construction drawings generated from the model accurately reflect changes to the family files.

Revit supports file imports from other software such as AutoCAD and SketchUp using DWG, DXF, DGN, SAT, and SKP file extensions. Camera views in Revit can be saved as common file formats such as BMP, JPG, TGA, TIF, or PDF files for still images. Additionally the 3-D model can be imported/exported to/from Autodesk 3DStudio using MAX files for improved detailed realism regarding rendering options. Revit files are useful for solar analysis, and Revit MEP is capable of energy analysis. Revit files can also be exported to the Green

Building Extensible Markup Language (GBXML files), which is also beneficial in predicting and minimizing energy consumption of the building (Eastman et al. 2008).

However, the in-memory system (in RAM, as opposed to in the file) that Revit uses can cause substantial computing slowdown for large files This drawback can be resolved by utilizing better and typically more expensive computers, or by breaking up the model into separate regions, then saving as individual files which can be re-combined after importing into other software. Another drawback is that the Revit platform has limited ability to parametrically model complex angles, and the ability to model complex curvatures is non-existent in the current version of Revit. Such geometry must generally be imported from other modeling software in order to accommodate such shortcomings (Eastman et al. 2008). However, this issue is addressed by Revit 2010. Despite such issues, Revit seems to currently have a competitive advantage within the current BIM market. This is due in part to that fact that Revit was developed in consideration of the BIM processes regarding information storage (Khemlani 2008a). Khemlani adds that Revit's ease of use for BIM processes make Revit appealing to companies transitioning from 2D CAD to BIM.

Advantages and disadvantages of Revit are summarized as follows (Livingston 2007b; Eastman et al. 2008; Khemlani 2008a):

- The Revit Suite of applications is the most widely known, widely used BIM platform, and compared to other software, Revit is relatively simple to learn.
- Parametric object families can be loaded into the project as needed, which minimizes file size and simplifies ease of software since modifications to object families can be easily updated within the BIM model.
- Multiple typical files types supported for exporting include: DWG, DXF, DGN, SAT, SKP, MAX, BMP, JPG, TGA, TIF, PDF, and GBXML.
- Revit MEP or external applications are capable of energy analysis for RVT files.
- The software has built-in features for rendering and animation.

- Revit is memory-based instead of file-based resulting in potential computing slowdown for large files, but this disadvantage can be compensated for by partitioning the project.
- Not appropriate for complex three-dimensional angled or curved geometry, an issue to be addressed by Autodesk in future versions of Revit; currently, complex geometry can be imported from other modeling software.

ArchiCAD 12 (Graphisoft)

As with any software which is appropriately marketed as BIM software, ArchiCAD also utilizes a central parametric database for the collection and storage of building information, so that changes to the model are automatically reflected in the 2-D drawings, greatly simplifying the construction documentation process. Similar to Revit's object families, ArchiCAD uses object libraries to make quick modifications to the design, and similarly uses what is referred to as a TeamWork concept to improve collaboration between multiple professionals working on the same project from the central database. Many of the interface menus and options are similar to Revit (Eastman et al. 2008). Rendering and animation capabilities are built in, or the model could be exported to other software for final visualization (Graphisoft R&D 2008). ArchiCAD works with Graphisoft's Constructor software, which imports the design BIM model generated in ArchiCAD and provides contractors the ability to upgrade the design model for use as an independent construction BIM model by allowing construction data to be added to the design model (Khemlani 2006a).

Advantages and disadvantages of ArchiCAD 12 are summarized as follows (Eastman et al. 2008; Graphisoft 2008; Khemlani 2008b):

- ArchiCAD is a relatively easy to learn BIM application.
- ArchiCAD is one of the few BIM products available for both Windows and Mac.
- Parametric object libraries, similar to Revit's object families, can be loaded into the project as needed, which minimizes file size and simplifies ease of software since modifications to object families can be easily updated within the BIM model.

- ArchiCAD's TeamWork concept assists collaboration amongst the parties involved in the project.
- The software has built-in features for rendering and animation.
- ArchiCAD is memory-based instead of file-based, similar to Revit, resulting in potential computing slowdown for large files, a disadvantage that can be compensated for by partitioning the project.
- The software lacks the ability to define spaces into zones, a necessity for energy modeling.
- The software lacks the ability to perform clash detection between multiple models; this can be compensated for by exporting the model into an external application such as NavisWorks or Vico.
- The software lacks the integration with structural and MEP BIM applications, an issue that Graphisoft has announced will be resolved soon.

Bentley Architecture, Structural, Electrical, and Mechanical (Bentley Systems)

Bentley Systems offers Bentley Architecture and Bentley Structural as its BIM software package. Bentley software is programmed with Microstation and TriForma, making it extremely versatile from a design standpoint. Similar to Revit, Bentley Systems software also uses what it calls families to build and categorize objects with as little or as much detailed type information added to the objects as needed. Unlike Revit or ArchiCAD, Bentley easily supports the modeling of extremely large projects, including projects with complex Bezier and NURBS curved surfaces. However, the modeling interface is not as fluid for quick 3D sketching as software like SketchUp, but geometry can be imported (Khemlani 2006b).

To facilitate collaboration, it utilizes what is referred to as Bentley ProjectWise to provide multiple parties access to the BIM database over a LAN (local area network) or a VPN (virtual private network) (Bentley Systems Inc. 2008b). A model created with Bentley Systems software can also be linked to project scheduling software, such as Primavera, in order to assist project members in coordinating construction activity sequencing with the architectural design. In addition to common file type supported by other software, the powerful RAM, STAAD, or

ProSteel file types can be used for thorough structural analysis using Bentley Structural (Khemlani 2006b).

Bentley software works with EnergyPlus, Trace700, and IES to perform sustainability analysis (Livingston 2007b). Also, Bentley has likely completed its compatibility with Green Building Studio and GBXML format, at the time of this writing. Additionally regarding sustainability, Roberts (cited in Livingston 2007b) states that Bentley Electrical and Bentley Mechanical provides links to manufacturers' catalogs, such that when light fixtures, fan units, chillers, etc. are inserted into the model, data such as power draw and cooling provided can be immediately incorporated into the energy analysis.

Unfortunately, the lack of clash detection reduces the integrity of the BIM model that this software is capable of producing; walls can overlap, doors and windows can overlap, even room areas can overlap without being readily detectable, making it critical that these potential inaccuracies are not overlooked by individuals digitally building the model. Additionally, Bentley Systems software is as complex as it is thorough, making it extremely complicated, very difficult to master, and time consuming to learn. Bentley System software also has smaller object libraries than other common BIM software (Eastman et al. 2008).

Advantages and disadvantages of Bentley System's BIM software are summarized as follows (Khemlani, 2006b; Livingston 2007b; Roberts cited in Livingston, 2007b; Eastman et al. 2008):

- Bentley software supports the design of large projects and the modeling of complex geometries.
- Multiple typical and atypical file export types include: DWG, DXF, DGN, PDF, STEP, IGES, STL, SKP, IFC, RAM, STAAD, and ProSteel.
- Bentley software is interoperable with Primavera Software for project scheduling.

- The software does not provide support for clash detection and has smaller object libraries compared to other BIM software.
- The software has a difficult learning curve, with less a than fluid modeling interface.

NavisWorks 2009 (Autodesk Inc)

Purchased by Autodesk in 2007, NavisWorks 2009 is available in four different software packages and is relatively simple to learn and utilize. NavisWorks is especially applicable to complicated projects with large 3D data sets, even manufacturing/process plants, airports, power plants, or commercial buildings. It is typically beneficial for large scale projects and not necessarily essential for smaller projects, such as single-family residential. NavisWorks is capable of combining models from various applications including Revit and ArchiCAD. Associations between groups of similar building components can be saved and the model can be searched for all components having specific properties. NavisWorks facilitates the design review processes among team members; building components can have comment tags applied, automatically creating a new 3D viewpoint which highlights the building component and the comment. The final NWC file uses a high compression technology claimed to result in up to 70% file size reduction, facilitating faster work on large projects which have been broken up into multiple 3D models, such as multiple architectural models, structural models, MEP models, etc. Earlier versions of NavisWorks support file extensions such as DWG, DXF, DGN, 3DS, and IGES; NavisWorks 2009 also supports 3D, DWF, STL, SKP, and IFC formats. NavisWorks also provides file exporters such that Revit, Bentley, and ArchiCAD files can be used in the NWC file format (Khemlani 2008c).

Advantages, and disadvantages of the four NavisWorks 2009 software packages are summarized as follows (Khemlani 2008c):

- NavisWorks Freedom, a free downloadable 3D viewer, retains saved viewpoints of the original file, and comment tags and clashes can be easily saved and retrieved as viewpoints.

- NavisWorks Freedom allows only for model viewing, comment review, and navigation, with regard to gravity and clash detection.

- NavisWorks Freedom cannot be redlined, limiting the capability of review processes.

- NavisWorks Review includes Roamer, which can be used to combine multiple 3D models (architectural, structural, MEP, HVAC, etc) from various platforms into one model, and can also be used to create animated walkthroughs by using viewpoints as keyframes, outputting to BMP, JPG, or AVI for video.

- NavisWorks Review also includes Publisher, used to create compressed and secure files for NavisWorks.

- NavisWorks Simulate includes the capabilities of NavisWorks Review, as well as Presenter, which allows textures, materials, lights, shadows for still and animated renderings including back/foreground atmospherics and other effects in addition support for output to TIF and TGA file formats.

- NavisWorks Simulate also includes TimeLiner, beneficial for linking specific 3D objects or object groups are to schedule activities to generate 4D construction simulation, providing a direct link to Primavera P3, Microsoft Project, and the common MPX file type from other programs including Primavera SureTrak.

- NavisWorks Manage includes the capabilities of NavisWorks Simulate, as well as Clash Detective, which assists in clash detection within models created by different 3D applications, although it only understands geometry and not building components, so defining the building component (wall, beam, column, duct, pipe, etc.) in the original models maximizes the usefulness of Clash Detective.

Innovaya (Innovaya LLC)

Innovaya software is possibly the first tool that brings the BIM model created during the design phase into construction the construction phase, providing a different perspective regarding the ongoing debate of "design models versus construction models," and "one model versus multiple models" (Khemlani 2006a). Innovaya was one of the first BIM applications which allows contractors to utilize the design model to perform quantity take-offs which facilitate cost estimations in Sage Timberline, without the need to re-build the model for construction related analyses. In contrast to the link between Graphisoft ArchiCAD and Graphisoft Constructor, Innovaya software does not require a separate BIM model to be created by the contractor. Innovaya LLC is planning future improvements to the software by developing other construction-related applications related to scheduling and constructability analyses in an effort to reduce the need to create a separate construction model or heavily modify the design model in order to make the model appropriate for construction and operations analyses (Khemlani 2006a). Similar to NavisWorks, Innovaya uses a high file compression ratio to more easily handle large projects which have been merged from multiple imported files, in the event the building was broken up into multiple models. However, the only files which can be imported into Innovaya's INV file format are Revit, AutoCAD Architecture, or AutoCAD MEP files (Khemlani 2006a). The potential interoperability of Innovaya software is illustrated in Figure 2-7.

Advantages and disadvantages of the five Innovaya software packages are as follows (Khemlani 2006a):

- Innovaya Visual BIM is beneficial for visualization, however other Innovaya products are necessary for greater usefulness of the BIM model.

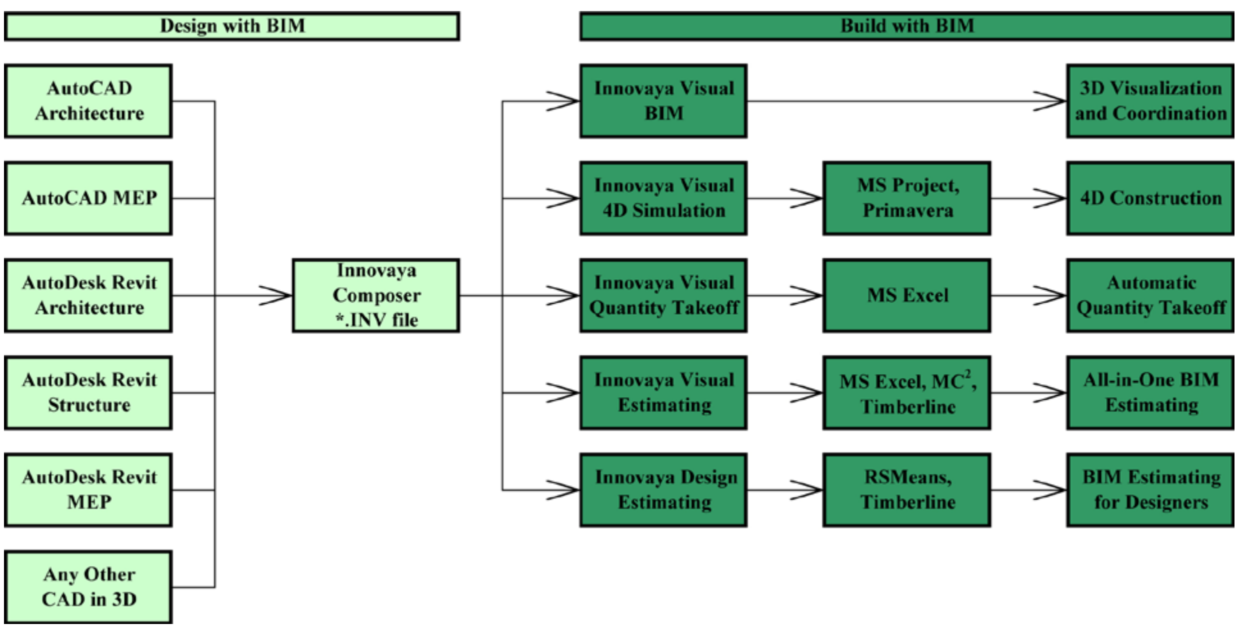

Figure 2-7. Interoperability functionality of Innovaya, as adapted from Innovaya LLC 2008

- Innovaya Visual Quantity Takeoff 9.4 is capable of visualization and quantification.
- Innovaya Visual Estimating 9.4 is capable of visualization, quantification, and price estimating, and has integrated the UniFormat and the MasterFormat building component classification systems which are beneficial for linking the model data to the specifications in order to generate high-quality quantity takeoffs and cost estimates.
- Innovaya Design Estimating 9.4 provides interoperability with RS Means Assembly Database and Sage Timberline Estimating.
- Innovaya Visual 4D Simulation 3.0 provides interoperability with Primavera software and Microsoft Project for 4D planning of construction sequencing.
- Innovaya has limited importing interoperability with other software.

Additionally, the two Innovaya add-ons to AutoCAD and Revit provide the following opportunities for interoperability (Khemlani 2006a):

- Innovaya Composer is available as an add-on for AutoCAD Architecture or AutoCAD MEP, capable of merging multiple projects into an INV file which automatically updates when changes are made to the original models.
- Innovaya Composer is also available as an add-on for Revit Architecture, Structure, and MEP with the same capabilities as the AutoCAD add-on, but it is also capable of tracking building assemblies through Revit's Assembly Code in an object's Family Type in order to link assemblies to other Innovaya software for estimating and scheduling without the need to map the object's geometric data.

IES <Virtual Environment> (Integrated Environmental Systems Ltd.)

Typically abbreviated IES <VE>, this BIM software package has extremely thorough tools capable of analyzing energy usage, carbon emissions, daylighting, artificial lighting, and solar shading. IES <VE> is available as the complete software package as or individual programs. Khemlani (2008d) presents the following attributes of IES <Virtual Environment>:

VE-Ware is downloadable freeware capable of assessing energy from heating, cooling, lighting, equipment, and carbon emissions from heating and cooling based on Energy Star (U.S.), Green Star (Australia), or CIBSE (U.K.), as well as comparing the building against the Architecture 2030 Challenge. Other more thorough and specialized programs within the full IES <VE>

software package include: VE-ModelBuilder, VE-Energy, VE-Lighting & Daylighting, VE-Egress, VE-Mechanical, VE-Value & Cost useful for initial and life-cycle cost planning, and VE-CFD (computational fluid dynamics) capable of predicting exterior air flow around the building and interior air flow within the building and useful for considering HVAC system planning with regard to exterior climate and internal heat sources (Figure 2-8).

VE-Toolkits provide additional functionality of IES software, and are ideal for assessing sustainability during preliminary design. The Sustainability Toolkit contains the aforementioned capabilities of VE-Ware as well as having the ability to perform ASHRAE and CIBSE load calculations, daylight assessments, and solar shading animations. The LEED Toolkit is beneficial in checking preliminary designs regarding potential LEED credits; and the Green Star Toolkit and BREEAM Toolkit will be available soon (Khemlani 2008d).

However, IES <VE> and IES Architectural Suites are currently only interoperable with Revit Architecture 2008/2009, Revit MEP 2008/2009 and Google SketchUp 6 / Google Pro 6. In order to resolve this limitation, IES is currently developing methods of interoperability with other software (IES Ltd. 2008).

While the aforementioned capabilities of IES <VE> are quite impressive, it is very complicated software with a steep learning curve. Addressing this issue, IES Ltd. launched IES Architectural Suites in November 2008. This BIM application focuses on sustainability during the preliminary design process. IES Architectural Suites software packages are somewhat easier to use than IES <VE>. The IES Architectural Suites concentrates on providing architects with simplified preliminary design-oriented sustainability tools (Khemlani 2008a).

Advantages and disadvantages of the various IES software packages are as follows (Khemlani, 2008a, Khemlani 2008d, IES Ltd., 2008):

- IES <VE> provides intelligent software integration throughout design, analysis, and re-design resulting from the use of various intertwined applications.

- The freeware, VE-Ware, is capable of assessing energy and carbon emissions from heating, cooling, lighting, and equipment.

- The freeware, VE-Ware, is capable of energy analysis based on Energy Star (U.S.), Green Star (Australia), CIBSE (U.K.), or the Architecture 2030 Challenge

- IES <VE> offers the Sustainability Toolkit and the LEED Toolkit for further analyses. Green Star and BREEAM ratings assessment Toolkits will be released soon.

- IES <VE> and IES Architectural Suites have minimal interoperability with other software, an issue to be resolved soon.

- IES <VE> has an extremely difficult learning curve; however, the newly released IES Architectural Suites are somewhat easier to learn and are extremely capable of project analyses even during preliminary design.

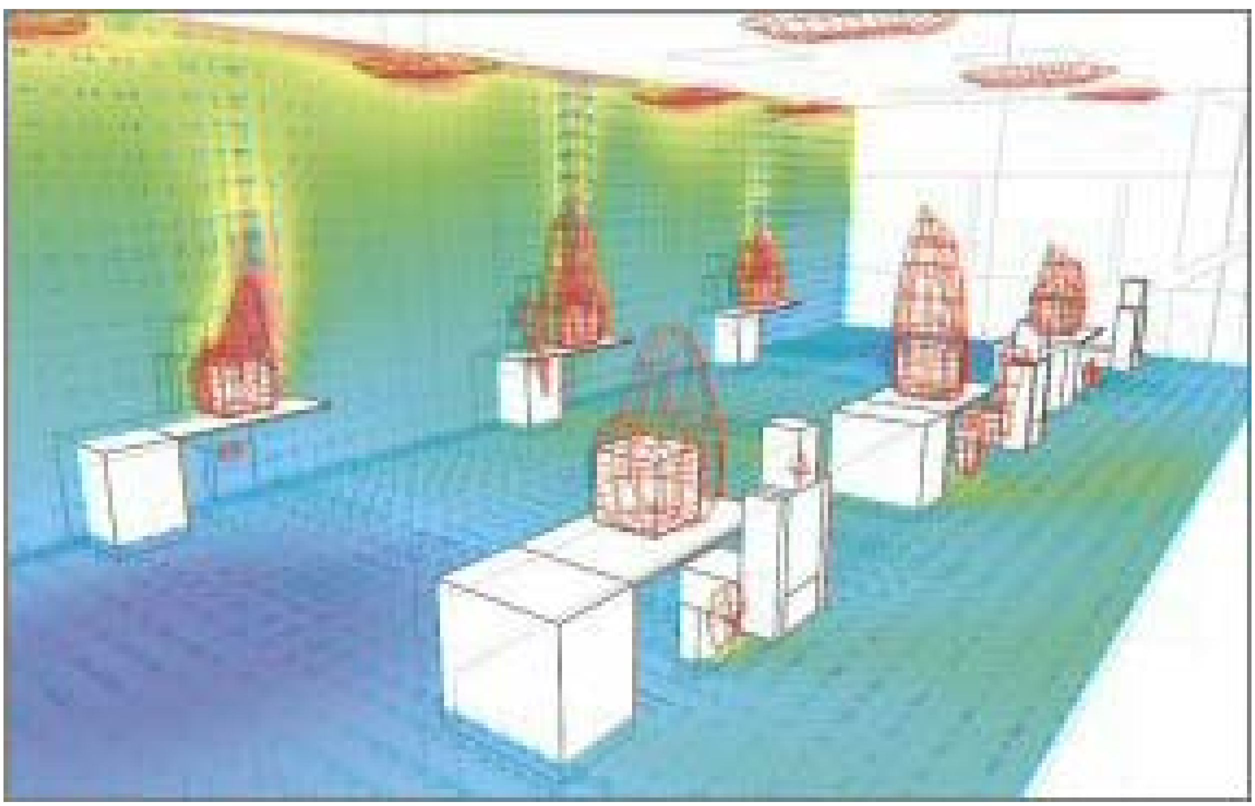

Figure 2-8. Computational fluid dynamics (CFD) in IES <VE>

DProfiler (Beck Technology)

DProfiler is a BIM tool useful for quickly creating conceptual design models using methods similar to SketchUp, making it easy to learn and use. DProfiler is unique in that the model is not derived from a floor plan, as there are no tools for placing walls, doors, or windows; instead, rooms of three different types are placed adjacent to one another to build the model, simulating a floor plan. However, floor plans can be imported from DWG or DXF formats to be used as a reference when creating the 3D model (Khemlani 2008e).

Even during preliminary design, DProfiler is capable of performing accurate cost estimations based on building type, project location, RSMeans, Sage Timberline Office estimating applications, or custom Excel files. DProfiler is also compatible with Uniformat and Masterformat (Khemlani 2008e). Khemlani (2008f) questions the paradox inherent in utilizing preliminary conceptual design models for detailed cost estimating. According to Beck Technology however, the users of DProfiler realize construction estimates within 5% of the actual cost, as opposed to a 20% margin of error resulting from other preliminary design phase estimating methodologies (Khemlani 2008f).

DProfiler can also be used to perform energy analyses on preliminary design models, a capability only recently introduced. It difficult to determine the accuracy DProfiler's inherent energy analysis tools during this early phase of software development (Khemlani 2008f). However, Beck Technology also provides an optional Energy Analysis module for integration with the energy simulation tool eQuest, which is installed as an add-on to DProfiler (Figure 2-9). Disadvantages of DProfiler include minimal interoperability on the importing side, which is limited to DWG and DXF, but the exporting capabilities are quite sufficient (Khemlani 2008f). DProfiler has no support for clash detection, so rooms can overlap or even extend outside the perimeter of the building mass without any error messages; it is unsure how this could impact the energy modeling, so it is imperative that the model is built accurately.

Ideally, architects would be the primary users of DProfiler, but the modeling interface lacks the fluidity of other software, making it less appropriate for the actual process of design conceptualization. Developers stand to gain the greatest potential benefits of DProfiler, using it to estimate project costs and perform energy analyses even before hiring architects and contractors, thus utilizing DProfiler as a tool to initiate discussion with other professionals (Eastman et al. 2008, Khemlani 2008f). Advantages and disadvantages of DProfiler are summarized as follows (Eastman et al. 2008, Khemlani 2008e, Khemlani 2008f):

Figure 2-9. DProfiler integration with eQuest for energy analysis

- DProfiler uses a simple and easy to learn interface, useful for quick generation of preliminary models; however the modeling tools are somewhat different from other software, slightly influencing the learning curve.

- DProfiler is compatible with the UniFormat and MasterFormat building component classification systems for integrated construction cost estimating on preliminary designs using RSMeans or Sage Timberline.

- DProfiler is beneficial for energy analysis and is also interoperable with eQuest for further energy analysis.

- DProfiler is most appropriate for developers desiring to assess project feasibility before hiring architects and contractors.

- DProfiler has no support for clash detection, so it must be ensured that the model is built accurately for reliable estimates and analyses.

- DProfiler has minimal file importing capabilities, supporting DWG and DXF only.

Digital Project (Gehry Technologies)

Digital Project is a powerful yet complicated BIM software. It can handle very large files, but it also requires intensive computing power. Digital Project includes many of the features typical of BIM software, including parametric modeling, database storage of the project, and clash detection sometimes absent in other software (Khemlani 2006c). Digital Project is capable of modeling complex geometry which is difficult, if not impossible to model in other software (Eastman et al. 2008). Similar to Innovaya and DProfiler, Digital Project also has the UniFormat and the MasterFormat building component classification systems integrated into the software. It also provides interoperability via Primavera Integration add-ons to assist project managers in the coordination of construction sequence planning (Gehry Technologies 2008), and it has interfaces with Ecotect for energy analysis (Eastman et al. 2008). Multiple typical and atypical export file types are supported by Digital Project: DWG, DXF, STEP, SAT, STL, IGES, CIS/2, 3DXML, SDNF; Release 3 also has IFC support. The major shortcomings of this software are its cost, its extreme complexity, and its steep learning curve. Its limited object libraries and drafting capabilities typically necessitate exporting sections to external drafting applications for the completion of assembly detailing (Eastman et al. 2008).

Advantages and disadvantages of Digital Project are summarized as follows (Eastman et al. 2008, Gehry Technologies 2008, Khemlani 2006c):

- Digital Project is very powerful and capable of modeling large, complex projects.
- Digital Project features clash detection capabilities missing in other applications such as Bentley or DProfiler.
- Digital Project is compatible with the UniFormat and MasterFormat building component classification systems for construction cost estimating.
- Digital Project is interoperable with Primavera for scheduling.
- Digital Project is interoperable with Ecotect for energy analysis.
- Digital Project is expensive, has a difficult learning curve, with limited object libraries.

Virtual Construction Suite 2008 (Vico Software Inc.)

The Virtual Construction Suite has been designed specifically as a BIM tool useful for the construction side of the AEC industry. The Virtual Construction Suite is actually six integrated platforms beneficial in construction modeling, estimating, scheduling, construction simulation, cost management, and change management: Vico Constructor includes a working version of ArchiCAD, but Vico Constructor takes ArchiCAD to the next level by including all structural and MEP objects essential for a complete and more thorough representation of the building (Laiserin 2008). The major difference between Vico Constructor and other BIM applications, is that the model is typically built just as the building will be constructed, allowing for a great level of detail while requiring extensive knowledge of construction techniques. Once the model is built, a quantity takeoff is easily and quickly generated for export into Vico Estimator for detailed cost estimations. Vico Estimator can easily prioritize construction line items by percent over budget versus percent of total project cost, simplifying the identification of cost control issues (Laiserin 2008). The model can be exported into Vico Control for the planning of construction sequencing to “allow for extensive ‘what-if’ analysis, and allows the construction team to explore many budgeting, scheduling, and procurement options, including those related to lean construction and fast-track construction” (Khemlani 2008e). Vico 5D Presenter can be used to combine the model with the estimate and the schedule to track to progress of the construction in real time. Vico Cost Manager can be used to compare the estimated costs and the project’s budget with the actual costs as the construction sequence progresses. Vico Change Manager can be used to simplify the process of managing change orders throughout the construction process, and considers the data enter into the other Vico applications. Each of these Vico applications, when used together, is currently the “most comprehensive, best integrated, and most highly evolved” construction oriented BIM application currently available” (Laiserin 2008).

In December 2008, it was announced that Vico is now integrating its software suite with Revit, such that a “Publish to Vico” option in Revit can be used to export the Revit model, presumably into Vico Constructor, which could then be used with any of the six Virtual Construction Suite platforms. This improvement to Vico’s interoperability “opens the doors for Vico to consider integrating with other BIM solutions” (Khemlani 2008d).

Advantages and disadvantages of the Virtual Construction Suite 2008 software package are as follows (Khemlani 2008d, Khemlani 2008e, Laiserin 2008):

- Vico Construction Suites are extremely thorough platforms for managing the construction-related aspects of a project. However, its interface and the methods of using the software entail a paradigm shift from traditional methodologies, but Vico Software Inc. provides extensive online tutorials and education programs to acclimate its users to the potential benefits.
- Vico Constructor is the interface for generating the 3D model, and is beginning to see improvements to interoperability with other software such as Revit.
- Vico Estimator is used for accurate model-based cost estimating.

- Vico Control is used to manage the 3D model with respect to the 4D schedule in real time.
- Vico 5D Presenter can display the 3D model, the 4D schedule, and the 5D cost management in a single view.
- Vico Cost Manager is used to track discrepancies between the estimated construction costs and the actual costs.
- Vico Change Manager is used to manage change orders to the project throughout the duration of construction.

Summary of Selected BIM Software Applications

The wide variety of differences among BIM software can often cause confusion over which software to utilize. The preceding discussion of BIM software is included to introduce the wide variety of capabilities of particular applications, and to assist in comparing the software. It is only through the exploration and research of such BIM applications that a company should select a specific application to be deemed most appropriate for the particular company's needs. Many BIM software manufacturers offer free downloadable trial versions of their software which should be explored when determining which BIM application is most appropriate.

Recent Improvements in AEC Sustainability

The general public's increasing awareness of the current environmental situation has been acknowledged by the construction industry, which has shown a continually increasing interest in sustainable construction during recent years.

Engineering News-Record (ENR) released its very first Top 100 Green Design Firms list in June 2008, which ranks U.S. design firms based on revenue from green projects. In 2007, 7.4% of the $8.68 billion total revenue for these 100 design companies was derived from projects which were either registered with or actively seeking certification by third-party sustainability rating systems such as LEED. In the general building market, sustainable projects for these top

100 companies generated $1.56 billion, 18.0% of the total revenue. Figure 2-10 illustrates the breakdown of green revenue for these 100 design firms (Tulacz and Traynor 2008).

In September 2008, ENR released its second ever Top 100 Green Contractors list, which ranks contractors based on revenue from green projects. In 2007, 20.1% of the $22.77 billion in total revenue for these companies was derived from projects which were either registered or certified by third-party sustainability rating systems such as LEED. This is an increase from 2006, when 15.3% of the total revenue for the Top 50 Green Contractors was derived from sustainable projects; the very first Top Green Contractors list only presented data for the top 50 companies. Figure 2-11 illustrates the breakdown of green revenue for the top 100 green contractors in 2007 (Tulacz 2008). In November 2008, Autodesk and the American Institute of Architects (AIA) revealed the results of the 2008 Autodesk/AIA Green Index, an annual sustainable building survey (TenLinks Inc. 2008). Some of the most significant findings of the survey are:

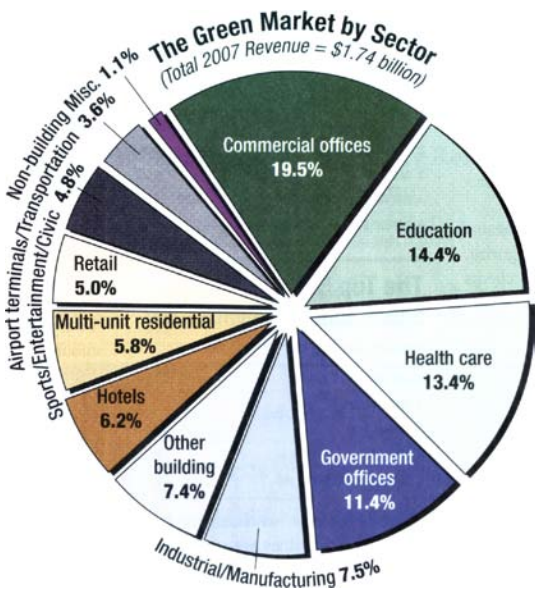

Figure 2-10. ENR 2008 top 100 green design firm's revenue from green projects in 2007

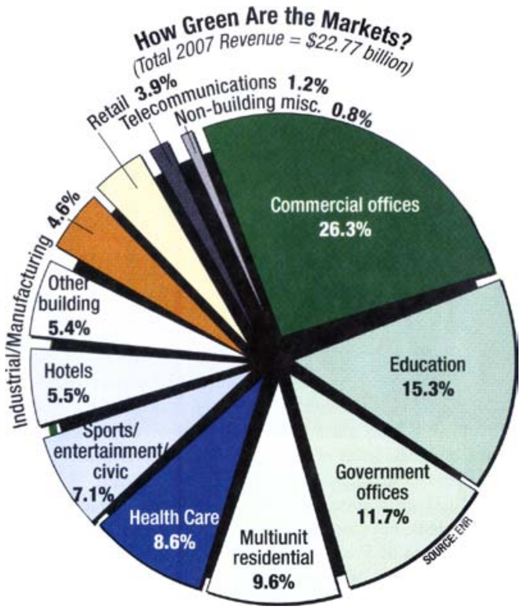

Figure 2-11. ENR 2008 top 100 green contractor's revenue from green projects in 2007

- Forty two percent (42%) of architects indicated that their clients are asking for sustainable building elements on over half of their projects

- Forty seven percent (47%) of clients are implementing sustainable building elements on their projects, up from 32% in 2007

- Thirty nine percent (39%) of architects are now using renewable, on-site energy sources, such as solar, wind, geothermal, low-impact hydro, biomass, or bio-gas on over half of new buildings, up from 6% in 2007

- Thirty four percent (34%) of architects are now designing with some type of green roof on over half of new buildings, up from 7% in 2007

- Fifty seven percent (57%) of architects indicated that their company is implementing standardized practices in order to inform their clients of sustainable design, up from 49% in 2007

- Forty one percent (41%) of architects use some type of software to assist them in evaluating the environmental impacts and lifecycle costs of the buildings they design

- Sixty six percent (66%) of architects indicate that client demand is the major factor on their practice of sustainable building; architects believe that the major reasons that their clients are requiring sustainable buildings are:

    - Reduced operating costs (60%)

    - Marketing (52%)

    - Market demand (21%, up from 10% in 2007)

- Architects indicated an increase in their use of design software to help evaluate:

    - HVAC operating costs (39%, up from 31% in 2007)

    - Energy consumption, energy modeling and baseline analysis (33%, up from 29% in 2007)

    - Alternative building materials (35%, up from 20% in 2007)

- Among of architects in the United States, 89% believe that architects should practice sustainable design whenever feasible, followed by 88% in the United Kingdom, 73% in Italy and 59% in Japan

- In the United States, sustainable building are primarily driven by client demand (66%); in the United Kingdom and Japan, the major drivers for sustainability are regulatory requirements (75% and 64% respectively); and in Italy, the major drivers for sustainability are rising energy costs (70%)

BIM for AEC Sustainability

Despite many obstacles and/or disadvantages to BIM, this type of software appears to be gaining acceptance due to its inherent advantages (Smith 2007). Although BIM is still not yet widely adopted, BIM has the potential to assist the AEC community in making extraordinary sustainability related improvements to the built environment (Gleeson 2005). Gleeson states that with BIM, architects now have the potential to more easily integrate higher degrees of sustainability into their preliminary design decisions, and not simply relegate it as the responsibility of mechanical engineers. BIM can and should be utilized to create and analyze the digital prototype of the building, so that once the building is constructed, the AEC team can be certain that the building will achieve its anticipated sustainable goals (Bhatt cited in Smith 2007).

Specialist in design, sustainability, and architectural technology, Heather Livingston conducted a 2007 interview with Renee Cheng, AIA, head of the School of Architecture at the University of Minnesota, to elaborate on the ongoing discussion on the use of BIM for sustainable design. The comments most relevant to this research are summarized as follows (Cheng cited in Livingston 2007a):

- The recent increase in BIM usage as well as sustainability efforts is a fortunate "augmentation of the two trajectories, where they both have had quite a bit of momentum in the past couple of years and we're starting to see them intersect." Sustainability efforts are mostly based on quantifiable data, whether immediate or long-term, and BIM has the capacity to handle volumes of data. The alignment between BIM and sustainable design is likely to increase into the foreseeable future.

- There is a big difference between what BIM could do, and what BIM is currently capable of doing, which is probably one of the most frustrating gaps with the potential of BIM for sustainable design.

- In theory, BIM and sustainability are a natural fit due to the capacity of BIM to inventory data beneficial for measuring lifecycle costs or performing energy analysis, but in practice, a lot of problems with BIM have been arising related to interoperability, regulation, and compliance issues, in addition to software which has been slow to respond to user's needs. The big three BIM software manufacturers, Autodesk, Bentley, and Graphisoft, need to improve interoperability with tertiary supporting software, such as energy analysis software like Ecotect. Graphisoft appears to handle such interoperability issues the best, but further improvements are certainly desirable. For example, if Revit could resolve interoperability with Ecotect by eliminating the need to rebuild models or manually transfer data between programs, then the software would become much more conducive to sustainable design.

- Ideally, both situations should exist, where tertiary programs such as energy analysis software could either be embedded and/or interoperable with the modeling software, depending on the needs of the user. Therein lies the inherent problem because unfortunately, BIM is still in such relative infancy that the 'mega-program' is not feasible and the 'micro-programs' are not currently communicating with each other very well.
- In five (5) years, the software will hopefully be able to function with greater interoperability, and it should facilitate improved and more detailed analysis on topics such as minimizing waste, performing energy calculations, and assessing lifecycle cost.
- In ten (10) years, the AEC community will hopefully witness sustainability compliance beyond the minimum, in addition to increased detail within the sustainability measurement systems such that many more factors will be assessed.

The Future of BIM for AEC Sustainability

Many professionals have voiced their expectations of improvements to the level of detail, interoperability, and integration of BIM over the coming years. Roberts (cited in Livingston 2007b) states that as BIM becomes the standard AEC practice, sustainability will become integrated into the design process instead of being treated as an afterthought; this is when BIM can truly provide significant benefits. Smith (2007) notes that future challenges of using BIM to achieve sustainability within the AEC industry include the ability of the software adequately represent the building and its components, considering that materiality has an extreme impact on energy consumption. Future BIM models must fully represent all elements of the building, and as manufacturers begin to market sustainable building products, the technical and sustainable data must become available for use in the energy analysis (Smith 2007). The use of BIM to achieve sustainability has the potential to dramatically change the AEC profession by assisting in the design and construction of higher quality buildings (Gleeson 2005).

As legislation for more and more jurisdictions is mandating some degree of sustainable design and construction, the use of BIM to achieve sustainability will soon become essential (Bhatt cited in Livingston 2007b). The difficulty with sustainable legislation is that variations exist in the laws from county to county, or jurisdiction to jurisdiction, or even among individual agencies within the same city; therefore the technology must be able to accommodate such variations (Smith 2007). However, BIM technology is not yet the penultimate solution to attaining a higher level of sustainability, but it is instead one of many tools available to assist the entire AEC community continuously in assessing the environmental benefits and consequences of their actions and decisions.

Summary

As the AEC professions, and truly humanity as a whole, continues to gain a greater understanding of the environmental impacts of the actions and decisions we make, we must strive to learn from the mistakes of the past in an effort to provide a path towards a more sustainable future. Imbuing the AEC professions with greater degrees of sustainability will definitely not be the Rosetta Stone for the environmental quagmire resulting from the industrialization of society, but after analyzing the environmental atrocities committed by the AEC professions on a daily basis including virgin materials consumption, energy consumption, and waste generation, increased AEC sustainability will certainly help improve the current environmental situation. Many experts agree the BIM is a perfect fit for increased AEC sustainability, but to what extent is the current BIM technology capable being used to facilitate improvements to AEC sustainability?

Upon the conclusion the literature review, it became immediately clear that it was imperative to compose and distribute a voluntary survey to be completed by various AEC professionals from companies of differing sizes and specializations. The survey gained insight into their perceptions of sustainability, and their perceptions of BIM, but most importantly, their specific uses of BIM for sustainability. In addition, the survey results are compared to the current literature. The details of the survey are introduced in Chapter 3.

CHAPTER 3
RESEARCH METHODOLOGY

This research was conducted in order to explore the potential for the use of Building Information Modeling to achieve improved sustainability within the various AEC professions. Additionally, this research analyzes the extent to which the use of BIM has modified and/or improved the workflow processes of various companies within the AEC industry. As such, this research uses a survey to attain insight from various AEC professionals as to what extent BIM is utilized by these professionals in order to complete projects with higher degrees of sustainability.

A list of potential survey participants was established to include a wide variety of companies, in order to involve every possible sector of the AEC community, such as design, engineering, general contractors, subcontractors, design-build firms, and construction management firms, etc. This researcher intended to include companies who work on projects of every possible type of project, such as commercial, industrial, residential, transportation, heavy civil, etc. Potential survey respondents were all listed in the following recent 2008 Engineering News-Record (ENR) lists: the Top 100 Green Design Firms (ENR 2008a), the Top 100 Green Contractors (ENR 2008b), the Top 100 Design-Build Firms (ENR 2008c), the Top 100 Construction Management-at-Risk Firms (ENR 2008d), and the Top 100 Construction-for-Fee Firms (ENR 2008e).

A total of 500 company names were acquired from the five ENR lists previously introduced. However, due to many companies appearing on multiple lists, 343 individuals from their respective companies were contacted in order to determine their willingness to participate in the survey. The minimum preferred sample size was calculated to be 47 responses, based upon a 95% confidence level, and a permissible error of 0.05, therefore the ideal minimum response rate should be at least 13.7% of the total 343 possible survey respondents.

The survey can be found in Appendix F in its entirety. The survey included six categories of questions, specifically: 1) company information, 2) personal information, 3) sustainability related questions, 4) BIM related questions, 5) questions which relate BIM to sustainability, and 6) a final question asking respondents if they would like to receive the final product of this research. The following sections elaborate on how each individual survey question addresses the five research objectives initially presented in Chapter 1.

Category 1: Company Information

This category of questions were focused on acquiring basic company information such as the type of company: general contractor, specialty contractor, architecture firm, engineering firm, and/or other; the method of project delivery: design-build or construction management; the types of projects the company becomes involved in: residential, commercial, industrial, heavy civil, transportation, and/or other; the number of company employees; the number of LEED-Accredited Professionals (LEED-AP's) employed; and how long the company has been in business. These questions only had true potential usefulness when analyzed in combination with other responses; these questions indirectly address all five research objectives.

Q1.1) Company Name: Responses to this question, among two others (particularly Q2.1 and Q2.2), will remain anonymous indefinitely, due to the confidentiality requirements of research prescribed by the UF Institutional Review Board (IRB). Submitted IRB documentation is found in Appendices B and C. It should be noted every confidential question was included in the survey to impart a humanistic and interpersonal aspect to the survey, since face-to-face interviews and/or telephone surveys were not practical for all 343 potential companies indentified for possible participation. Since the responses to Q1.1 will never be reported anywhere, the sole purpose of this question was to eliminate the occurrence of unnecessary duplicate requests to potential survey respondents who had already previously replied.

Q1.2) Company Type: Individual responses to this question presented their most significant relevance when compared against other survey responses. The analysis of these combinations of survey responses addressed the relationship between: company type and sustainability, company type and its use of BIM, as well as company type and its use of BIM to achieve sustainability (Q1.2 + Q3.X, Q4.X, and Q5.X, respectively).

Q1.3) Number of Employees: Similar to question 1.2, this question provided research relevance when analyzing the size of surveyed companies in relation to other survey responses. The analyses of these combinations of survey responses addressed the relationship between: company size and sustainability, company size and its use of BIM, as well as company size and its use of BIM to achieve sustainability (Q1.3 + Q3.X, Q4.X, and Q5.X, respectively).

Q1.4) Number of LEED-Accredited Employees: The relevance of Q1.4 was ultimately not to determine the *number* of LEED-AP's employed by each company, but the *percentage* of LEED-AP's within each company. Similar to question 1.2, this question provided research relevance when analyzing the percentage of LEED-APs employed in relation to other survey responses (Q1.4 + Q3.X, Q4.X, and Q5.X).

Q1.5) How long has the company been in business?: Similar to Q1.2 and Q1.3, this question provided research relevance when assessing the size of surveyed companies in relation to other survey responses (Q1.5 + Q3.X, Q4.X, and Q5.X).

Category 2: Personal Information

This category of questions was largely focused on gaining insight into the survey respondent's expertise in the profession. Since the responses to these questions will not be reported due to confidentiality requirements of the UF IRB, they were mostly optional questions. It should be noted that these confidential questions were included to impart a humanistic and interpersonal aspect to the survey, since face-to-face interviews or telephone surveys were not practical for all 343 potential companies.

Q2.1) Name *(Optional)*: The personal names of individual respondents will remain confidential, due to ethical reasons, as well as the UF IRB requirements previously discussed. This question was included solely to facilitate one-on-one communications with individual survey respondents at the conclusion of this research regarding category 6 and whether the respondent asked to receive a copy of this completed research.

Q2.2) Title/Position *(Optional)*: Responses to this question will also remain confidential. This question was included for correspondence purposes and also to determine if the respondents' specialization within the company was pertinent to research exploring the subjects of sustainability and BIM.

Q2.3) How long have you been in this industry?: As with question 2.2, this confidential responses to this question were aimed at gauging the survey respondent's level of expertise in the AEC industry.

Q2.4) How long have you been with this company?: Similar to question 2.2, this question was intent on gauging the respondent's familiarity of the company he or she is representing, particularly the familiarity of company-specific knowledge pertaining to sustainability and BIM typically revealed in subsequent categories.

Category 3: Sustainability

This category of questions were focused on gaining insight into the sustainability aspects of projects the company undertakes, such as the frequency of sustainable projects and the motivation for achieving sustainability. These questions were independent of BIM usage.

Q3.1) What percentage of project completed by this company has received LEED or other green building certification?: The intent of this question was to determine the extent of sustainability of the surveyed company's projects, regardless of the reasons why sustainability is pursued.

Q3.2) What percentage of sustainable projects was LEED or otherwise certified because it was requested by the owner?: The intent of this question was to determine the extent to which sustainable certification is required by the owner, one of the major reasons why a project might be required to be certified, as discussed in Chapter 2.

Q3.3) What percentage of sustainable projects was LEED or otherwise certified because certification was required to be certified by either federal, state, or local legislation?: The intent of this question was to determine the extent to which sustainable certification is pursued by project managers due to legal requirements to achieve improved sustainability. The combination of Q3.2 and Q3.3 addressed the question: "Is the pursuit sustainability predominantly a result of request from the owner, or is it instead more often the result of the requirement of conformance to the law?"

Category 4: Building Information Modeling (BIM)

This category of questions were focused on gaining insight into the BIM applications the company does or does not use and why the company does or does not use them, in addition to determining perceived advantages and disadvantages of using BIM. This category addressed research objective 3: determine the perceived and actual advantages and disadvantages to utilizing BIM.

Q4.1) Does your company utilize BIM software, and if so, which software applications?: An introductory question regarding BIM usage among survey respondents, this question was simply aimed at determining specifically which software platforms are utilized by various companies. Using the aforementioned ENR lists to identify potential survey respondents, the researcher intended to identify companies representing a variety of the AEC professions, in order to determine how various sectors of the AEC community are or are not utilizing BIM for sustainability. Ideally, every survey respondent would have some familiarity with the use of BIM for sustainability, thus maximizing their abilities to divulge more detailed responses to the category 5 questions which examined the perceptions of using BIM to achieve greater sustainability and the impacts of BIM on the AEC professions. Conversely, it was also important to receive responses from companies which do not utilize BIM in order to analyze reasons as to why BIM is not used.

Q4.2) How long has your company used BIM?: A straightforward question regarding the duration of BIM utilization, responses to this question were beneficial in combination with responses to other questions, similar to the questions from category 1: Company Information

Q4.3) If [your company does not utilize BIM], why not?: Question 4.3 through the remainder of the survey consisted of seven open-ended questions. As elaborated in the Survey Informed Consent Documentation (Appendix E), survey respondents were encouraged to divulge as much or as little information as desired or necessary, particularly for such open-ended questions, and many did so in paragraph format. In order to analyze the responses to open-ended questions, the researcher established a framework or rubric in order to categorize the type of information included in each response, discussed in greater detail in Chapter 4. The major goal of Q4.3 was simply to determine reasons for not utilizing BIM software applications, regardless of the specific software platform.

Q4.4) What do you feel are the greatest advantages to utilizing BIM?: The second of seven open-ended questions, Q4.4 identified specific advantages of BIM, as perceived from companies which use BIM as well as companies which do not. Ideally this question would generate a wide variety of responses to indicate the benefits of BIM to every phase of AEC project delivery for design, construction, and operations. A rubric was established for Q4.4 to categorize each advantage as applicable to any one or multiple phases of a building's lifespan.

Q4.5) What do you feel are the greatest disadvantages or obstacles to utilizing BIM?: Obstacles were implied to refer to any negative attributes of a particular BIM software platform which might deter companies from pursuing utilization of a particular BIM software platform. Disadvantages were implied to refer to any negative attributes of any particular BIM software application which does not improve or even detracts from particular work flow processes. In many instances, a disadvantage could also be an obstacle, just as an obstacle could also be a disadvantage, but this is definitely not always the case; not every potential obstacle is a disadvantage and likewise not every potential disadvantage is an obstacle. This question explored perceptions across various sectors of the AEC industry as to what obstacles might deter the use of BIM and what difficulties might arise as a result of utilizing BIM.

Category 5: Sustainability and BIM

This category of questions was focused on linking the two previous categories in determining perceived and actual advantages and disadvantages to utilizing BIM for improved sustainability. The questions within this category measured AEC perceptions regarding the use of LEED for sustainability, as well as AEC perceptions regarding the use of BIM for sustainability. Bringing to conclusion categories 3 and 4, category 5 addressed research objectives 4 and 5 by asking AEC professionals if and how LEED and/or BIM is being used to provide sustainable projects, as well as if and how BIM is changing the traditional methods of project delivery.

Q5.1) Do you perceive that utilizing LEED (or other certification) has improved your company's ability to provide your clients with sustainable projects, and if so, how?: This question determined the extent to which sustainable benefits are actually realized as a result of using sustainable rating systems to help achieve sustainability, not the potential for increased sustainability if rating systems were to be used.

Q5.2) Do you perceive that utilizing BIM has improved your company's ability to provide your clients with sustainable projects, and if so, how?: This question determined the extent to which sustainable benefits are actually realized as a result of using BIM, not the potential sustainable benefits which could become realized if companies were to use BIM. Combined, Q5.1 and Q5.2 determined whether BIM applications or sustainability rating systems are more conducive to providing benefits for increased sustainability.

Q5.3) Do you feel that BIM is changing the traditional methods of project delivery with regard to sustainable project delivery, and if so, how?: The intention of this question was simply to explore if BIM is changing or improving the methods by which the AEC industry conducts business, not necessarily changes to how the particular respondent’s company conducts business.

Q5.4) Do you think that improvements could be made to the BIM applications your company uses in order to better facilitate the delivery of sustainable projects, and if so, what improvements would you like to see?: The intention of this question was to determine how BIM software manufacturers could possibly improve the software to increase the functionality of BIM for sustainability.

Category 6: Optional

Q6.1) Would you like to receive a digital copy of this research, once completed, to help inform you of the potential for utilizing BIM to provide your clients with green and sustainable projects?: This sole question in category 6 was offered to survey respondents in order to provide bi-directional communication between this research and the specific members of the AEC community participating in the survey. Just as survey respondents graciously and typically enthusiastically offered their time and knowledge to the benefit of this research, the researcher has returned their favor of participation by providing an exchange of information to potentially enhance the BIM-related sustainability efforts of those respondents and the companies which employ them.

Summary

The survey portion of this research proved to greatly compliment the review of a variety of literature discussing the use of BIM for improved AEC sustainability. Chapter 4, which follows, examines the responses to the survey, and then categorizes the responses to the open-ended questions for further analysis. Ultimately, the survey analysis will be compared with the literature in a series of conclusions presented in Chapter 5.

CHAPTER 4
RESULTS AND ANALYSIS

The minimum preferred sample size of this study was determined to be 47 out of 343 possible responses. A total of 29 individuals from various AEC companies agreed to participate, completing the survey and submitting their responses electronically, and a survey response rate of 8.5% was established. Due to the survey sample size of 29 being less than the minimal preferred sample size of 47 respondents, and due to the open-ended and subjective nature of the most significant survey questions, the survey results were evaluated utilizing descriptive statistics. As a consequence of the sample size being less than statistically preferable, the results of this survey cannot be deemed to be representative of the entire AEC industry. However, the following results can still be beneficial to companies and individuals interested in sustainability, BIM, and the use of BIM for improved sustainability.

The most beneficial survey responses were those responses to the various open-ended questions, in which respondents were encouraged to divulge as much or as little information as desired or necessary; many responded with great detail in paragraph format. Such questions were asked in survey categories 4 and 5, which explore BIM and the use of BIM for sustainability, respectively. In order to analyze the nature of such open-ended responses, the researcher established rubrics for those questions in order to categorize the type of information in each response to these open-ended questions. The nature and intent of the rubrics for each question are explained as they are presented in subsequent sections.

The analyses of the responses to each survey question are presented in the following sections. The verbatim survey responses are reprinted in their entirety in Appendix G, providing first-hand insight into the nature of the responses. Additionally, the original responses ensure the validity of the rubrics established to categorize each response.

Survey Analysis

The following analysis of the completed surveys excludes the responses to confidential questions. In particular, the responses to Q1.1) Company Name and Q2.X) Personal Information have been excluded from the following discussion of the research results and analysis. In order to protect the anonymity of companies involved, the 29 company names have been replaced by letters, for example: Company A, B . . . BB, and CC. Among the responses reprinted verbatim within this document, any references to a company name or the specific geographic location of a company have been withheld to further protect anonymity.

Company Name: Q1.1

Responses to this question will remain indefinitely confidential in order to preserve the anonymity of the companies who assisted this research.

Company Type: Q1.2

This question subtly asked two questions at once: "What types of services does this company perform?", and "What types of projects does this company pursue?" The most prevalent services of surveyed companies are: general contracting, 59% (17 respondents); construction management, 45% (13 respondents); design-build 41% (12 respondents); architecture, 34% (10 respondents); and engineering, 17% (5 respondents) (Figure 4-1). The types of projects on which these companies work are predominantly: commercial 55% (16 respondents); industrial, 21% (6 respondents); residential 10% (3 respondents); and transportation 7% (2 respondents) (Figure 4-2). Other less frequent responses are also presented in Figures 4-1 and 4-2. While the original responses to this question (Appendix G, Figures G-1 and G-2) are only marginally useful alone, when used in conjunction with other survey responses, these figures facilitated more detailed analyses pertaining to other questions, for example: "Is BIM use more prevalent among architecture firms versus engineering firms?", or

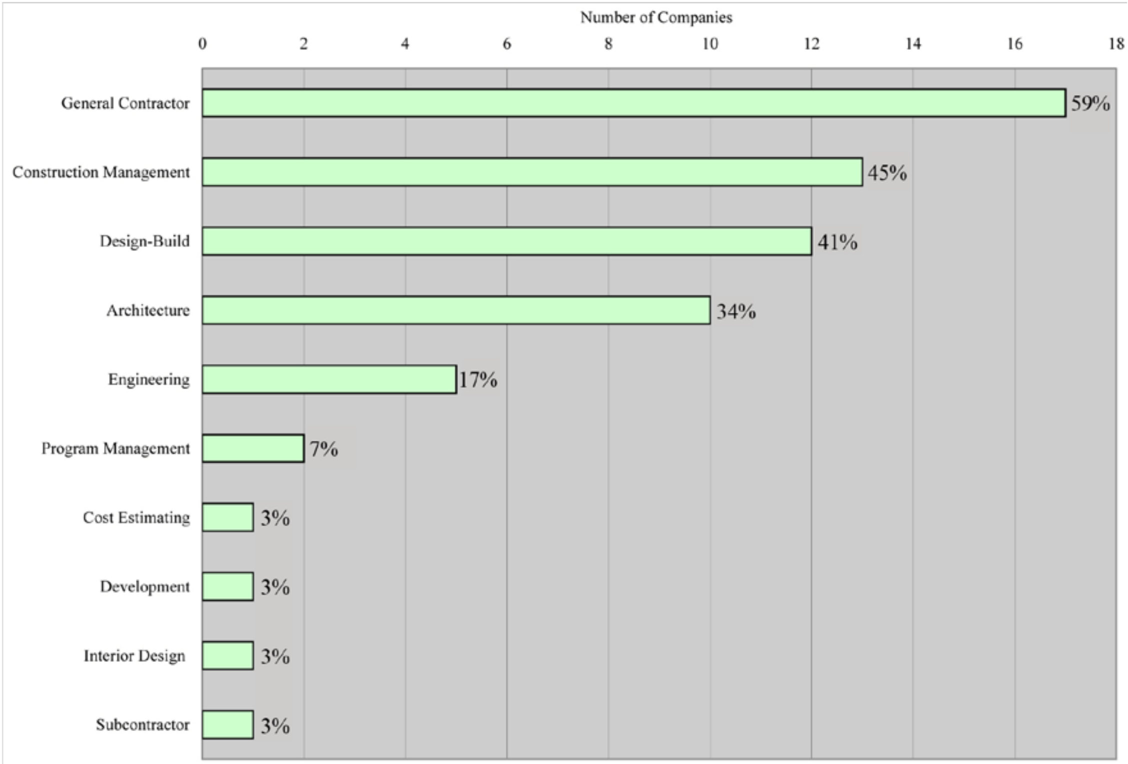

Figure 4-1. Types of company services: Q1.2

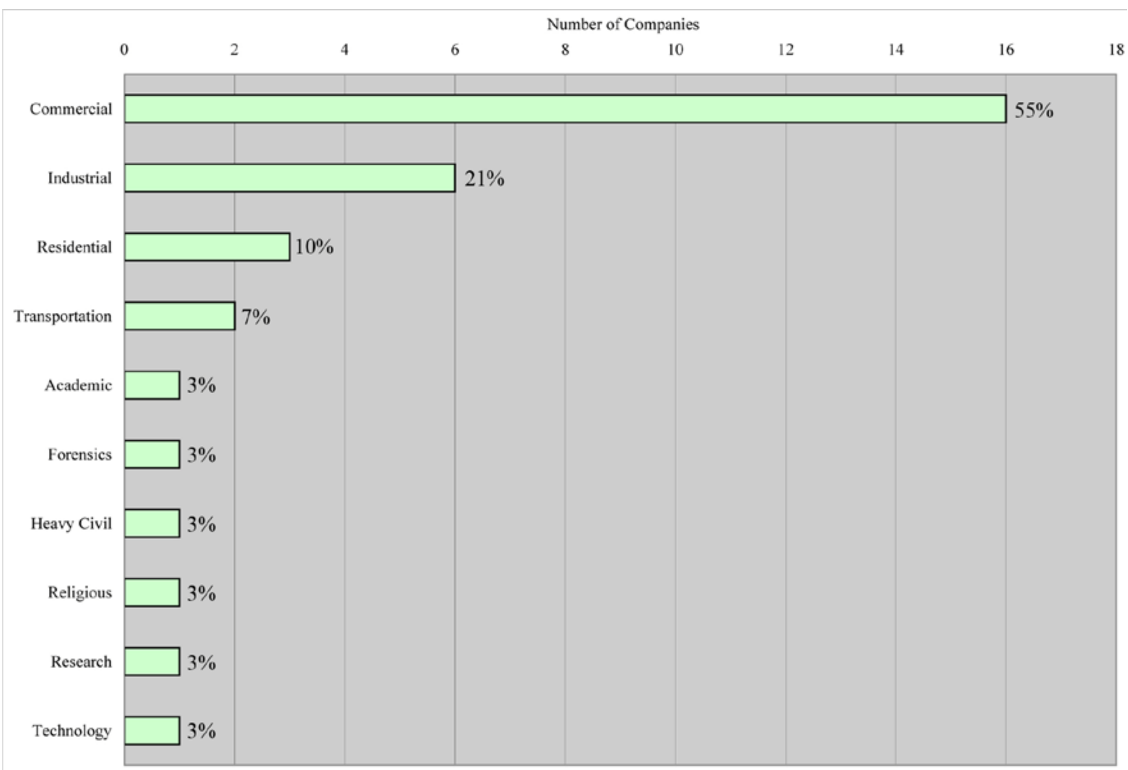

Figure 4-2. Types of projects: Q1.2

“Is the use of BIM for sustainability more prevalent among contractors versus design-build firms?” Such analyses are presented in subsequent sections pertinent to BIM (category 4), and the use of BIM for sustainability (category 5), in an effort to address the objectives of this research introduced in Chapter 1.

Number of Employees: Q1.3

Similar to Q1.2, responses to this question are analyzed in combination with other questions, and such simultaneous analyses of multiple questions are addressed in subsequent sections. This research developed a rubric which defines: small companies (≤100 employees), medium-sized companies (100-500 employees), and large companies (≥500 employees). These ranges were selected to attain the most normalized distribution among responses, as opposed to selecting the ranges based upon preconceptions of the AEC industry by this researcher’s personal perceptions of what is meant by small, medium, or large AEC companies. Among the respondents, 8 (28%) are employed by small companies, 10 (34%) are employed by medium sized companies, and 9 (31%) are employed by large companies (Figure 4-3). General categorizations of the size of surveyed companies shown in Figure 4-3 are presented for general assessment of company characteristics to be compared with other characteristics in upcoming sections. While Figure 4-3 is useful for general analysis, it is ultimately the original responses to Q1.3 (Appendix G, Figure G-3) which facilitated detailed analyses relating company size with

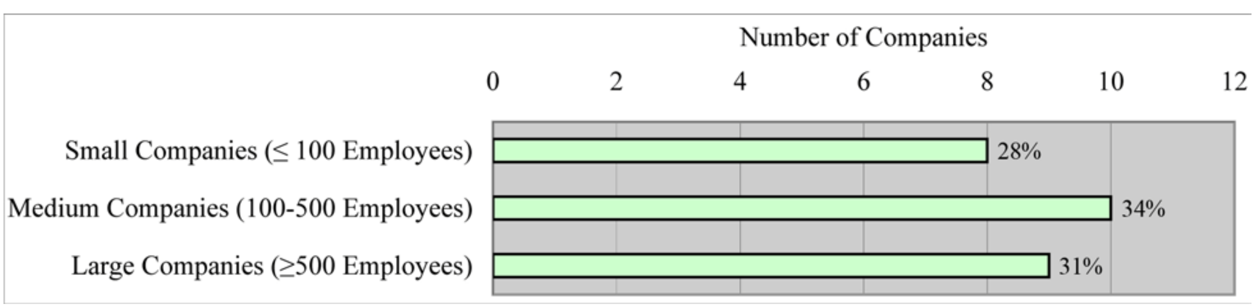

Figure 4-3. Company size: Q1.3

BIM usage (survey category 4), and the use of BIM for sustainability (survey category 5). The smallest company has 60 employees, the largest company has 2,000+ employees, and the mean was 300 employees, illustrating the relatively normal distribution of the rubric established by this research. Data presented in Figure 4-3 is useful for general analysis, whereas Figure G-3 is useful for thorough analyses which follow.

Number of LEED-Accredited Employees: Q1.4

The relevance of this question was not to determine the number of LEED-AP's employed by each company, but the percentage of LEED-AP's within each company, simplifying the comparison among companies. Similar to other questions in category 1, the responses to this question have lesser significance in isolation of the other questions, and greater significance when compared against other question responses. The rubric was developed to categorize the percentages of LEED-AP's as low (≤5%), medium (5%-25%), and high (≥25%), in order to approximate the most normalized distribution among these three categories. Among the respondents, 7 (24%) are employed by companies with low LEED-APs, 13 (45%) are employed by companies with medium LEED-APs, and 8 (28%) are employed by companies with high LEED-APs (Figure 4-4). This data is beneficial for general assessment of the companies responding to the survey, and the significance of this data is presented once all other company characteristics are introduced.

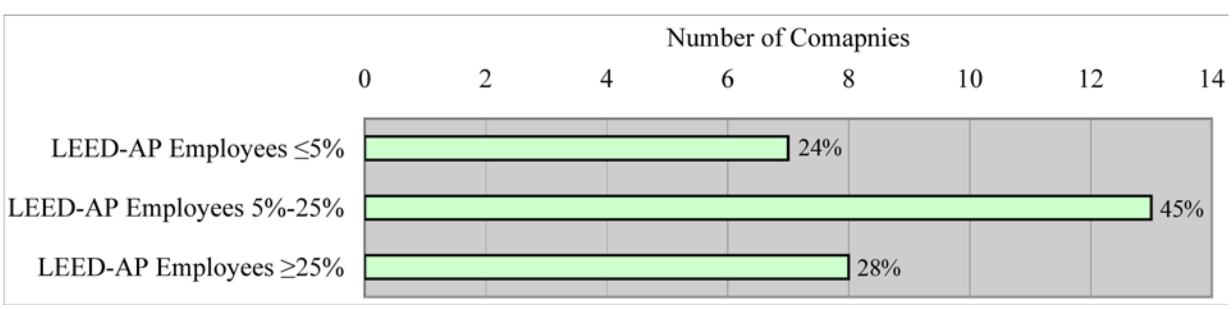

Figure 4-4. Percentage of LEED-AP's employed: Q1.4

The original verbatim responses to Q1.4 (Appendix G, Figure G-4) facilitated detailed company-specific analyses relating percentage of LEED-APs with BIM usage (category 4 questions), and the use of BIM for sustainability (category 5 questions). As with previous questions, data presented in Figure 4-4 is useful for general analysis, whereas Figure G-4 is useful for company-specific analyses. Subsequent sections use the original responses in Appendix G for greater thoroughness of survey response analysis.

Duration of Company Operations: Q1.5

Similar to the three previous questions, the companies were categorized into three general groups: new companies (≤25 years old), medium-aged companies (26-75 years old), and well-established companies (≥76 years old). Again, this rubric was not confined by any preconceived definition by the researcher of what defines new, medium-aged, and well-established companies, but instead the companies were grouped as such in order to normalize the distribution among these three categories. Among the respondents, 7 (24%) are employed by new companies, 12 (21%) are employed by medium-aged companies, and 9 (31%) are employed by older companies (Figure 4-5). This categorization was helpful in determining if there is any general relationship among company age, BIM usage (category 4 questions), and the use of BIM for sustainability (category 5 questions). Similar to other category 1 questions, the original responses to Q1.5 (Appendix G, Figure G-5) were used for more detailed analyses in subsequent sections.

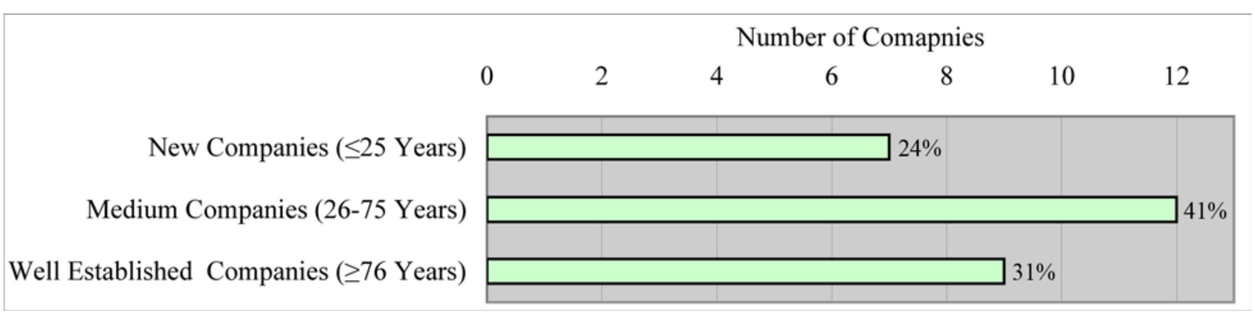

Figure 4-5. Duration of company operations: Q1.5

Personal Information: Q2.X

Similar to Q1.1, responses to these questions will remain indefinitely confidential in order to preserve the anonymity of the companies and the individuals who assisted this research.

Sustainability: Q3.X

Due to poor phrasing of the questions and the resulting misunderstanding by survey respondents of the intentions of these questions, a wide variety of responses were generated, responses which could not be adequately compared to one another. The original intentions of the questions in category 3 (see Chapter 3) were to explore the sustainability efforts of surveyed companies, independent of BIM usage. However, the responses to these questions proved to be the least beneficial to this research, such that a thorough analysis of the responses is not necessary. See Chapter 5: Conclusions and Recommendations for several suggestions to improve these questions, to help make the intent of these questions more clear to respondents such that more useful information could be obtained by future research.

Utilization of Specific BIM Software: Q4.1

Among the companies surveyed, 79% (23 respondents) reported that they utilize at least one BIM software application (Figure 4-6). The utilization of particular BIM applications by survey respondents is illustrated in Figure 4-7, revealing that the most frequently used BIM software is Autodesk's Revit. Many companies using Revit, 48% (14 respondents) did not indicate a specific Revit platform, whereas the utilization of specific Revit applications such as: Revit Architecture, 10% (3 respondents); Revit MEP, 10% (3 respondents); and Revit Structure, 3% (1 respondent) were indicated less frequently than the general response of "Revit". In total, 19 of the 29 companies (66%) use at least one type of Revit application. Figure G-6 presents all original responses to this question since Figure 4-7 does not indicate company usage of multiple applications. (Since many survey respondents relied with multiple responses, the fact that 66% of surveyed companies use Revit cannot be implied from Figure 4-7, as the percentages shown there do not sum to 100%.) The predominant usage of Revit was somewhat anticipated regarding the market position of Autodesk's Revit as the most widely known and accepted BIM software. As a result of such widespread usage of Revit among survey respondents, this research indentifies no direct relationship between the use of Revit and specific company characteristics including: company type (Q1.2), size (Q1.3), percentage of LEED-APs (Q1.4), or the company's duration of operations (Q1.5). Revit is used by a wide variety of surveyed companies, for example: large and small; new and well-established; design, engineering and construction companies. It is impossible to state that only companies with certain characteristics use Revit applications.

The second most prevalent BIM application among survey respondents is Autodesk's NavisWorks. NavisWorks provides greater capacities than Revit to link the design activities with the construction activities (see Chapter 2). Among the 31% (9 companies) using NavisWorks, 8 companies perform general contracting services, and 5 companies perform general contracting,

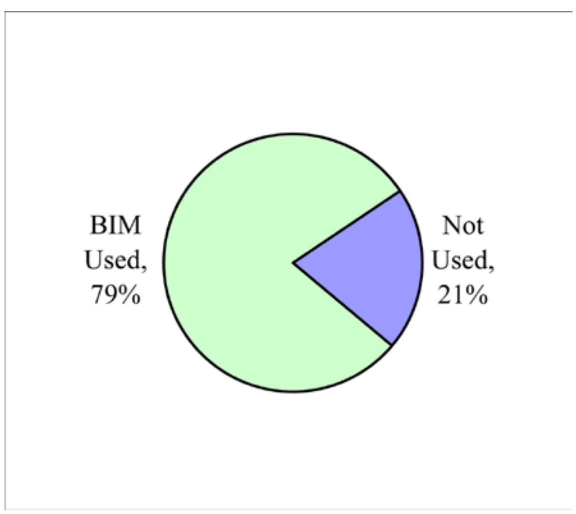

Figure 4-6. General utilization of BIM: Q4.1

construction management, and design-build services. The utilization of NavisWorks by companies performing such services indicates the software's usefulness for both design and construction planning, especially among the design-build companies (Appendix G, Figure G-5).

AutoCAD was cited as a BIM used by 14% (4 respondents), and while AutoCAD is not traditionally considered BIM software, models generated in the DWG format can be exported to many tertiary applications for greater project analysis; all 4 of the companies mentioning the use

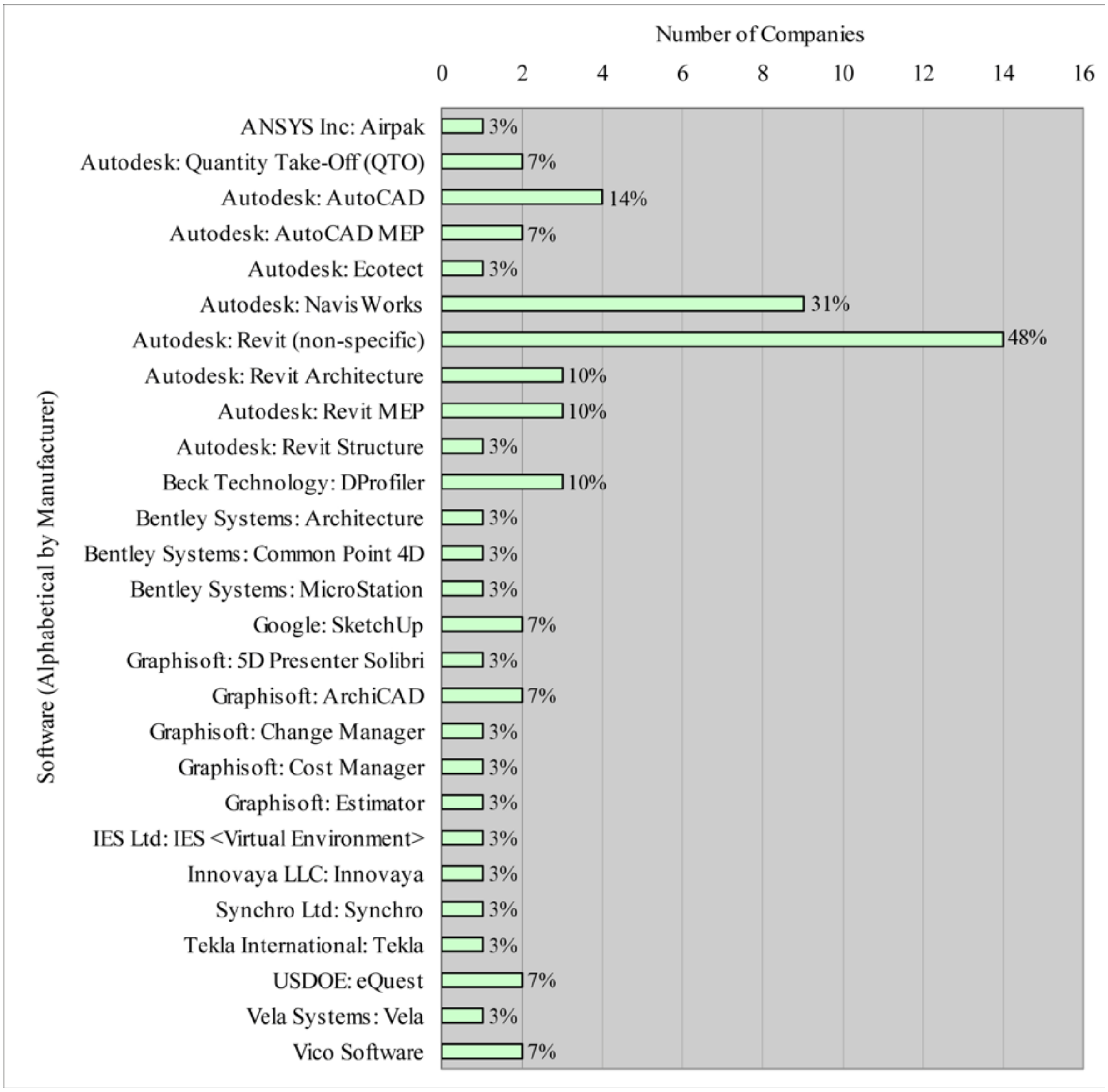

Figure 4-7. General utilization of particular BIM applications: Q4.1

of AutoCAD as BIM software use tertiary applications. Therefore, AutoCAD is included in the discussion and the figures pertaining to this survey question. However, only one (1) of the four (4) companies citing the use of AutoCAD as BIM actually indicated increases in sustainability as a result of using BIM, based upon the comparison of responses to Q4.1 and Q5.2. (see Figure G-5 and Table G-4) Less frequently used BIM applications include: Bentley software, 10% (3 respondents); and Graphisoft's ArchiCAD, 7% (2 respondents). Recalling various literature cited in Chapter 2, Autodesk, Bentley, and Graphisoft are three big players in the field of BIM, and a more even distribution of the usage of their software was anticipated.

Another result of this question is the total number of BIM applications used by each company (Figure 4-8): 21% do not use BIM, 42% use one BIM application, and 38% use two or more. Figures 4-8, G-3, G-4, and G-5 provide the basis for the following analysis:

- The 6 companies (21%) not using BIM are small to medium sized companies having less than 8% of employees LEED-accredited. With the exception of one, they are all relatively new companies.
- The 12 companies (42%) using exactly one BIM application are typically slightly larger companies with higher percentages of LEED-APs. These companies have been operating for relatively longer periods of time. Revit is used as the sole BIM application by 8 (28%) of these companies, which did not specifically note the use of Revit MEP. Note that Revit MEP or other external software is necessary for energy modeling with Revit.
- The 11 companies (38%) using two or more BIM applications are also typically larger companies with higher percentages of LEED-APs. Many of these companies have been in business for the longest periods of time.

Some BIM platforms are ideal for modeling the building, but cannot perform detailed energy analyses, while other BIM platforms are excellent for energy analysis but cannot be used to generate a 3D model at all (see Chapter 2). The sustainability related benefits of BIM to companies which use only one BIM application are possibly limited, since there does not currently exist a single BIM application capable of providing every benefit; currently, for better or worse, AEC professionals must typically work within multiple platforms to realize the maximum potential benefits of BIM. Companies using more than one BIM application are typically larger companies, with more LEED-APs, and a more established history, with the exception of a few which are smaller, newer companies also having high percentages of LEED-APs. Companies using more BIM applications typically provide a wider array of services, especially general contracting, construction management, architectural, and/or design-build. The company-specific utilization of BIM software (Appendix G, Figure G-6) is used to determine specific relationships between this question and subsequent questions.

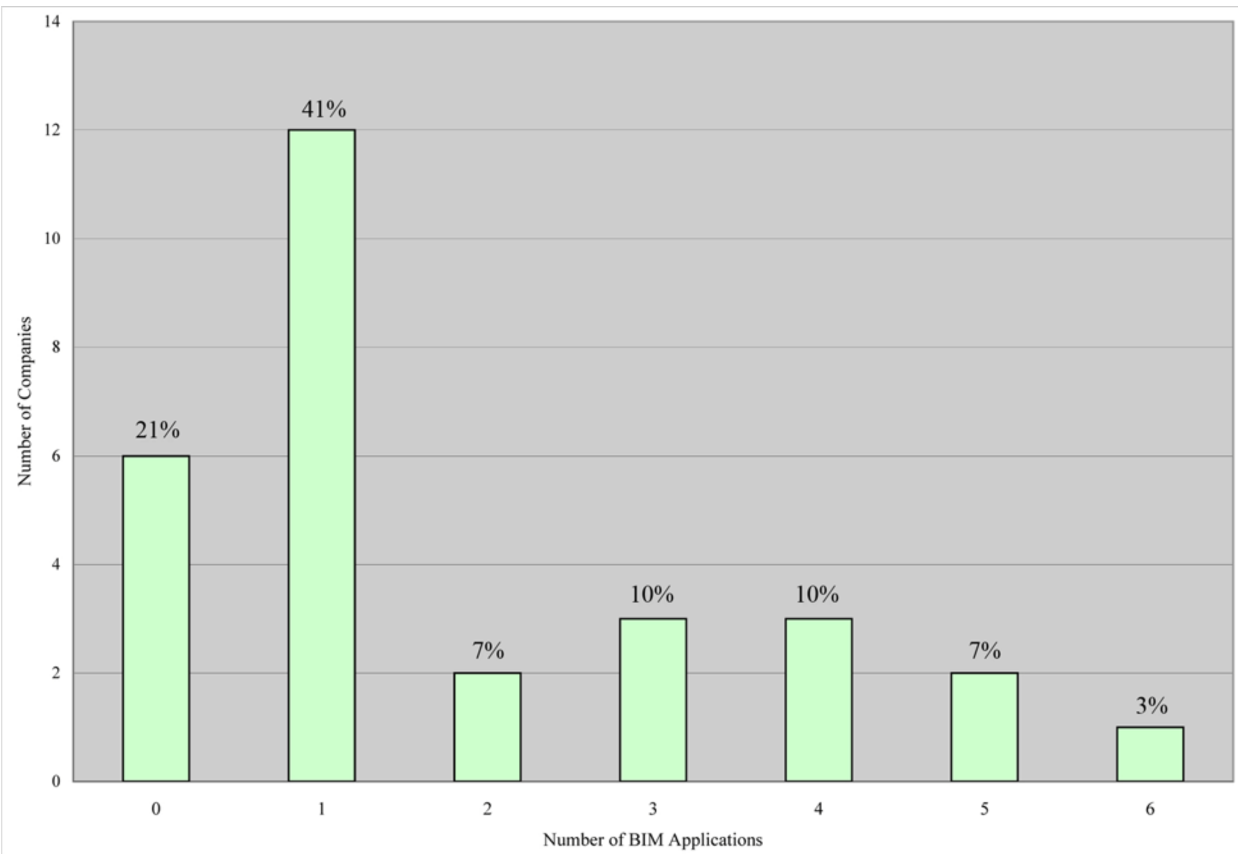

Figure 4-8. Number of BIM applications utilized: Q4.1

Duration of BIM Utilization: Q4.2

The duration of BIM usage among the 23 of 29 survey respondents who use BIM is not lengthy: 83% (19 of 23 respondents) of companies using BIM reported BIM utilization of 4 years or less; 22% (5 of 23 respondents) of companies using BIM have used it for 1 year or less;

and 21% (6 of 29 respondents) do not use BIM at all (Figure 4-9). Such relatively low duration of BIM usage was somewhat anticipated, simply due to the consideration of how recently the software manufacturers have adopted the terminology “BIM” despite the history of such technology, in addition to how historically slow the AEC industry responds to change. In fact, only Company P reported using BIM for more than 6 years, reporting 10+ years. Generally, companies using BIM for the longest periods of time are most often larger sized companies, with lengthy histories of company operations, and higher percentages of LEED-APs (Appendix G, Figure G-7). Additionally, survey respondents with extreme familiarity of BIM provided highly detailed responses to the open-ended questions relating BIM to sustainability. See Appendix G for thorough verbatim survey responses.

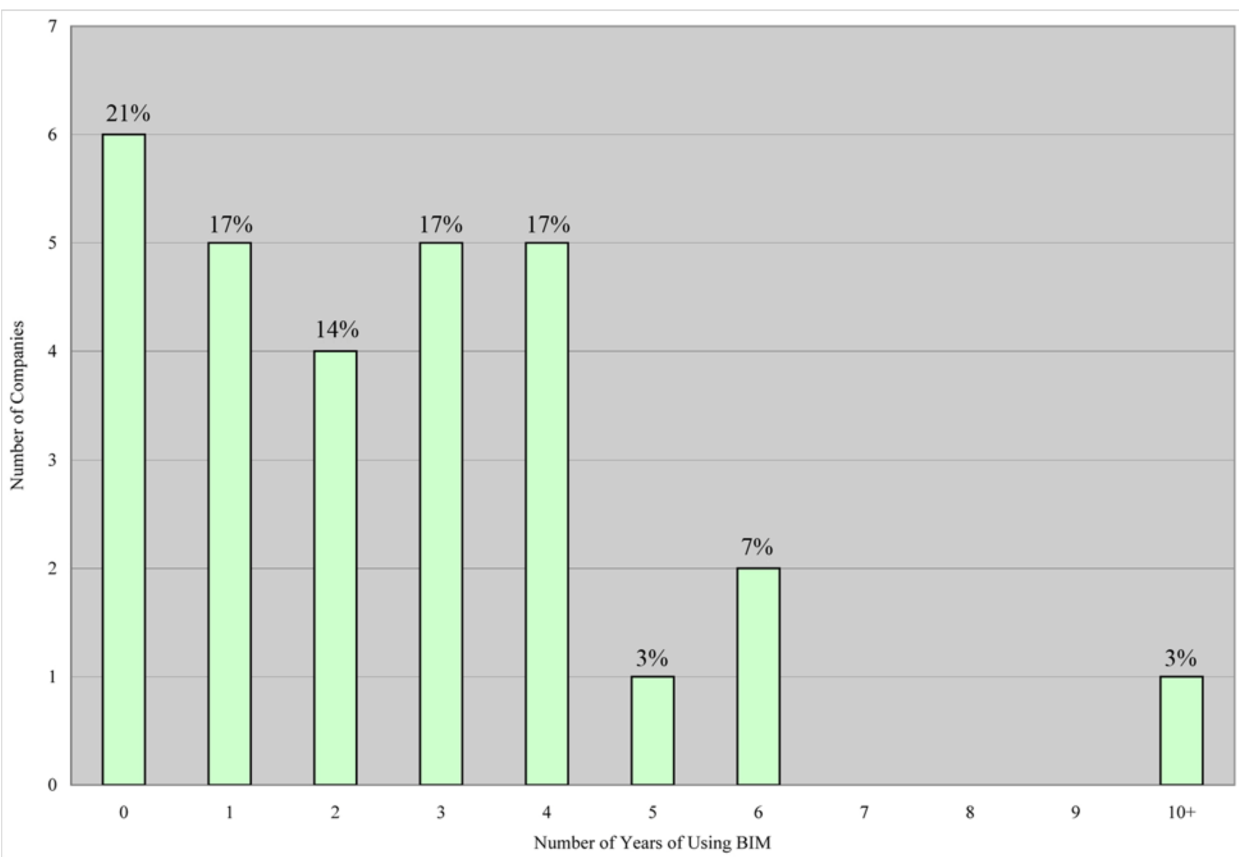

Figure 4-9. General duration of BIM usage: Q4.2

Reasons for not Utilizing BIM: Q4.3

Among the 29 surveyed companies responding to the survey, 79% of surveyed companies (23 respondents) are currently using BIM whereas 21% (6 respondents) are not currently using BIM. Responses to this question were used by the researcher to generate four (4) categories of responses (Figure 4-10). Most notably, among the companies not currently using BIM, 14% (4 respondents) indicated that their company is currently researching BIM and exploring its usage. Additionally, 3% (1 respondent) perceives that BIM is not necessary for the type of work its company performs; and 3% (1 respondent) indicates that BIM is not used because local business associates do not use BIM, therefore BIM is unnecessary when collaborating with these other companies. The original verbatim responses to Q4.3 by survey participants are presented in Appendix G (Table G-1), to ensure the validity of the rubric created by the researcher for this question (Figure 4-10).

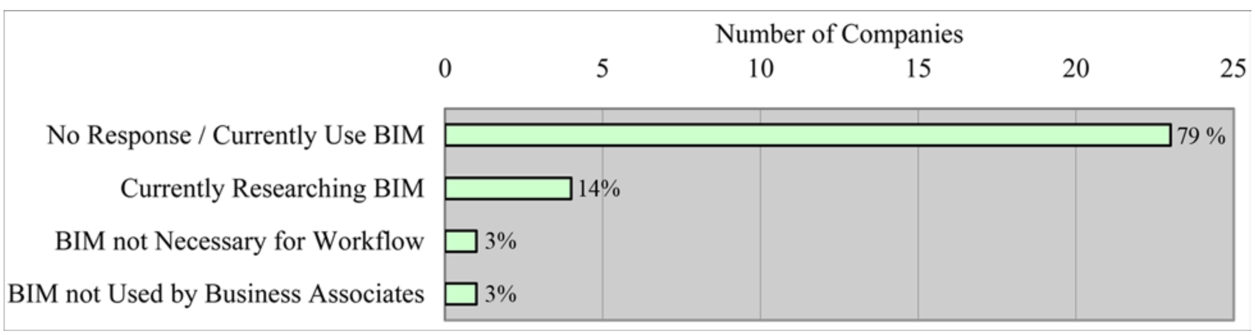

Figure 4-10. General reasons for not utilizing BIM: Q4.3

Perceived Advantages of Utilizing BIM: Q4.4

As indicated in Figure 4-8, 79% of companies (23 respondents) use at least one specific BIM application, and such widespread BIM usage by respondents established the foundation for a wide variety of detailed advantages of BIM. Every company described at least one advantage of using BIM, even companies not currently using BIM. Due to multiple responses from many companies, the 29 companies generated a total of 108 responses regarding the advantages of

BIM, according to the rubric categorizing the responses to this survey question (Figure 4-11). The rubric developed to categorize the responses considered particular advantages of BIM as applicable to one of the three major phases of a building's lifecycle: design, construction, and operations. The end-of-lifecycle activities such as deconstruction, recyclability, and/or materials reuse are not specifically addressed by respondents, thus these topics are not addressed here (see recommendations in Chapter 5). Advantages of BIM pertaining to design-oriented BIM benefits are perceived or realized more frequently than BIM-related advantages pertaining to construction or operations. Design advantages represented 42% of responses (45 of 108 responses); construction advantages represented 20% of responses (22 of 108); and operations advantages represented 11% of responses (12 of 108). General advantages of BIM pertaining to both the design and construction phases of a project represented 27% of responses (29 of 108). The detailed analysis of specific advantages of BIM is displayed in Figure 4-12. The greatest specific advantage of BIM indicated by 69% (20 respondents) is its ability to improve the coordination among various project team members within the same company as well as across multiple companies. The most prominent significance of this result is that: if 69% of these companies feel project team member coordination is important, and if these companies are using

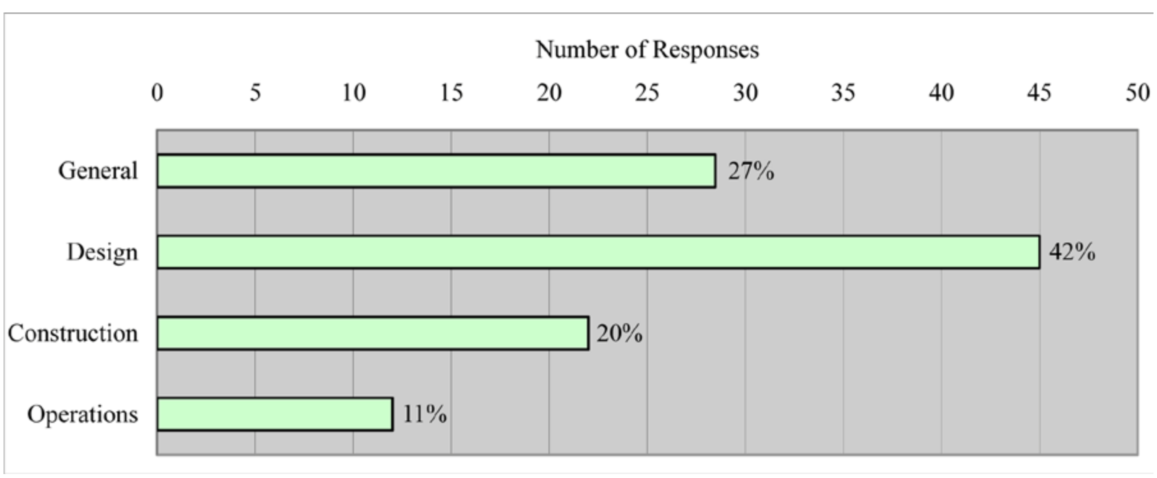

Figure 4-11. General advantages of BIM by project phase: Q4.4

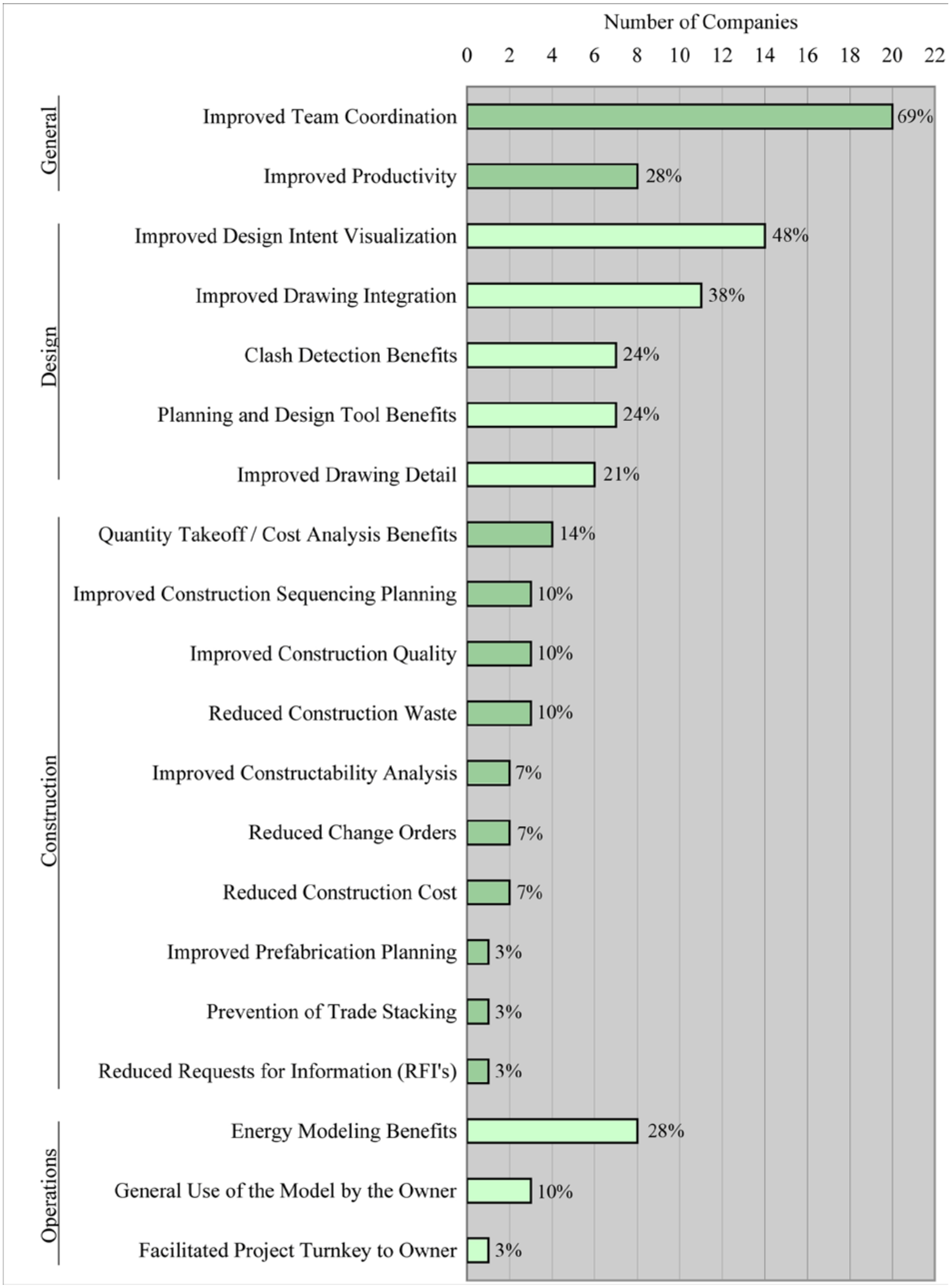

Figure 4-12. Specific advantages of BIM by project phase: Q4.4

BIM to improve coordination, they should be capable of producing highly sustainable projects, as opposed to situations where such collaboration is difficult or non-existent. Coordination is an extremely important aspect of being able to prepare documentation for LEED or other green certification which is helpful in improving the extent of sustainability throughout design and construction.

Improvements to productivity are indicated by 28% (8 respondents) are also general advantages of BIM, and for some companies, this response is applicable to the design phase, for other companies it is applicable to the construction phase, and for others it is applicable to the entire project lifecycle (Figure 4-12 and Table G-2). A wide variety of literature indicates that potential synergies could result from using BIM (see Chapter 2). Other advantages of BIM frequently cited all pertain to the design phase of a project, including: improvements to design visualization, 48% (14 respondents); improvements to drawing quality, 38% (11 respondents); detecting and preventing object clashes, 24% (7 respondents); and the use of BIM to facilitate pre-design planning, 24% (7 respondents). The potential advantages of BIM specific to improved sustainability include: energy modeling benefits, 28% (8 respondents); and a reduction of construction waste, 10% (3 respondents).

The rubric developed by the researcher (Appendix G, Figure G-8) displays the company-specific advantages of BIM software. As in previous figures, the ‘X’ in Figure G-8 indicates a definitive response, whereas some new symbols are introduced: the ‘!’ indicates that the response is most likely applicable to the rubric, the ‘?’ indicates that the response is implied to be applicable to the rubric, and an entry such as ‘Q5-3’ indicates that the respondent identified this response in question 5.3. Such symbols are used throughout the remainder of these figures in Appendix G.

The original survey responses are reprinted in their entirety (Appendix G, Table G-2) to ensure validity of the rubric created by the researcher and to assist future analyses. The highlighted company names in Table G-2 indicate certain responses with high levels of detail and are noteworthy responses worth singling out. All equally noteworthy survey responses in such tables throughout the remainder of Appendix G are similarly highlighted. In many instances, the companies providing the most detailed responses have typically been using BIM for the longest amount of time (see Figure G-7 and Table G-2).

Many of the aforementioned advantages of BIM can most often create synergies within the processes of project development which can allowing the AEC project teams to devote more time and effort to the design and construction of buildings with greater degrees of sustainability. The specific details of how the surveyed companies actually use BIM to achieve improved sustainability are presented in the discussion of category 5 questions in subsequent sections.

Perceived Disadvantages or Obstacles to Utilizing BIM: Q4.5

A subtle distinction between disadvantages and obstacles was implied here. As with other open-ended survey questions, many respondents replied in paragraph format, necessitating the creation of a rubric to categorize the nature of the response to simplify the analysis. Many respondents replied with multiple advantages and/or obstacles to BIM, such that 29 individuals reported a total of 60 responses to this question, resulting in 18 distinct categories of replies (Figure 4-13).

One of the most frequently noted disadvantage and/or obstacle of BIM is the cost of utilizing and/or implementing BIM, as cited by 28% (8 respondents). Among these eight (8) respondents, four (4) mentioned the not only software cost, but they also noted additional expenses related to hardware upgrades and the cost to hire and/or train employees to utilize the software.

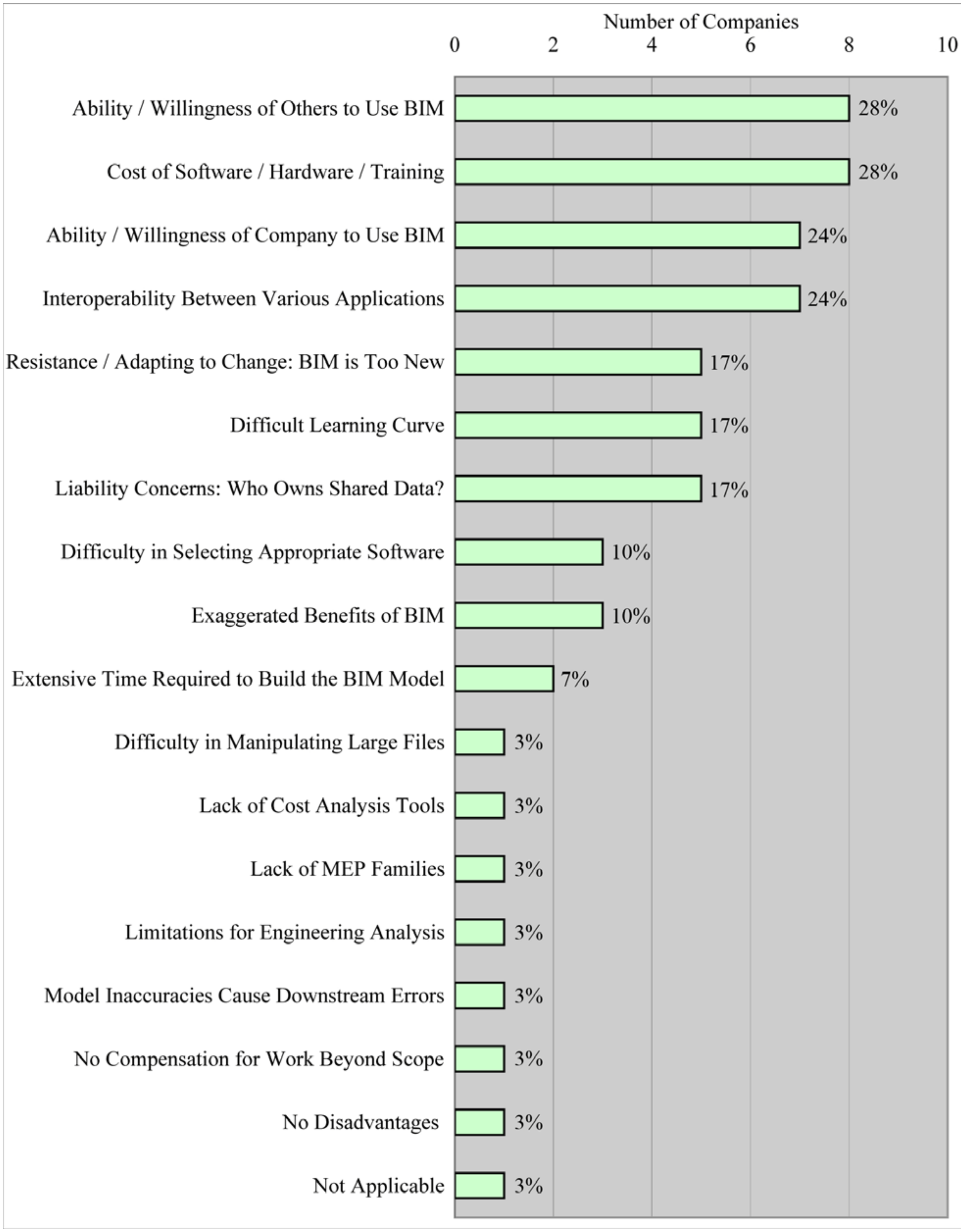

Figure 4-13. General disadvantages and/or obstacles to BIM: Q4.5

The difficulty in persuading the entire project team to use BIM is cited as an obstacle to BIM and/or a disadvantage of BIM mentioned by 28% (8 respondents). Considering that the project team is typically comprised of employees from multiple companies, and recalling that collaboration is a great advantage of BIM, greater benefits can be realized if more project team members are either using the same software, or if the variety of software applications used by multiple entities are actually capable of smoothly transferring data to and from one another.

As a result of actual or perceived disadvantages and/or obstacles, BIM is not used by every AEC company surveyed, and convincing other project team members to incur the necessary costs to make the transition to BIM is not always a simple argument. The difficulty of convincing your own company's executives to make the transition to BIM is noted by 24% (7 respondents). Interestingly, six (6) of these seven (7) companies currently use BIM, having first-hand experience of the difficulties arising when transitioning to BIM software (Appendix G, Figures G-6 and G-9).

Another disadvantage and/or obstacle to BIM commonly cited in AEC literature is its lack of smooth interoperability amongst various applications, mentioned by 24% (7 companies). Among these seven (7) companies, five (5) companies currently utilize more than one (1) BIM application, indicating their first-hand experience in dealing with interoperability limitations. This is an extremely significant issue, since not a single BIM application can provide every potential desired benefit. Therefore, it is commonly necessary to transfer files from one program into another in order to realize the maximum potential advantages related to BIM usage, especially regarding sustainability-related advantages pertaining to analytical tools.

Additionally, the topic of liability is repeatedly cited in the literature as being detrimental to the proliferation of BIM within the AEC community, as reported by 17% (5 respondents).

Traditionally, the architect is responsible for the accuracy of the information contained within the drawings, but as more individuals from various professions within the AEC community are working in collaboration on the BIM model, how is liability assessed and who is responsible if drawings generated from a BIM model contains errors? In particular, one respondent noted that many contracts will either discourage or not allow sharing of BIM data, and as mentioned previously, data sharing and collaboration are greatly beneficial to imparting sustainable attributes to a building project.

Other disadvantages and/or obstacles include: the fact that many BIM applications have a difficult learning curve, 17% (5 respondents); and that resistance to change and adapting to change also deter BIM proliferation, 17% (5 respondents). To assist in detailed analysis summarized in subsequent sections, the original responses to Q4.5 are presented in Appendix G (Table G-3).

Realized Benefits of Rating Systems to Improve Project Sustainability: Q5.1

A common benefit of utilizing LEED or other certification systems is that they provide a framework for measuring the extent of a project's sustainability, as cited by 62% (18 respondents). Other benefits of rating systems include the use of rating systems to: assist in the proliferation of sustainability throughout the AEC community, 38% (11 respondents); assist in improving sustainable project planning and development, 24% (7 respondents); increase awareness regarding environmental responsibility, 17% (5 respondents); and utilizing the rating systems to improve the sustainability of projects which do not actually intend to obtain certification, 10% (3 respondents). Sustainability rating systems such as LEED can potentially provide other benefits, as illustrated by Figure 4-14. The rubric developed to analyze this question is itemized by company in Appendix G (Figure G-11) for further analysis. The verbatim responses to Q5.1 are presented in Table G-4 to ensure the validity of the rubric. Table G-4 also provides a basis for comparison between Q5.1 and Q5.2, which is presented in the following section.

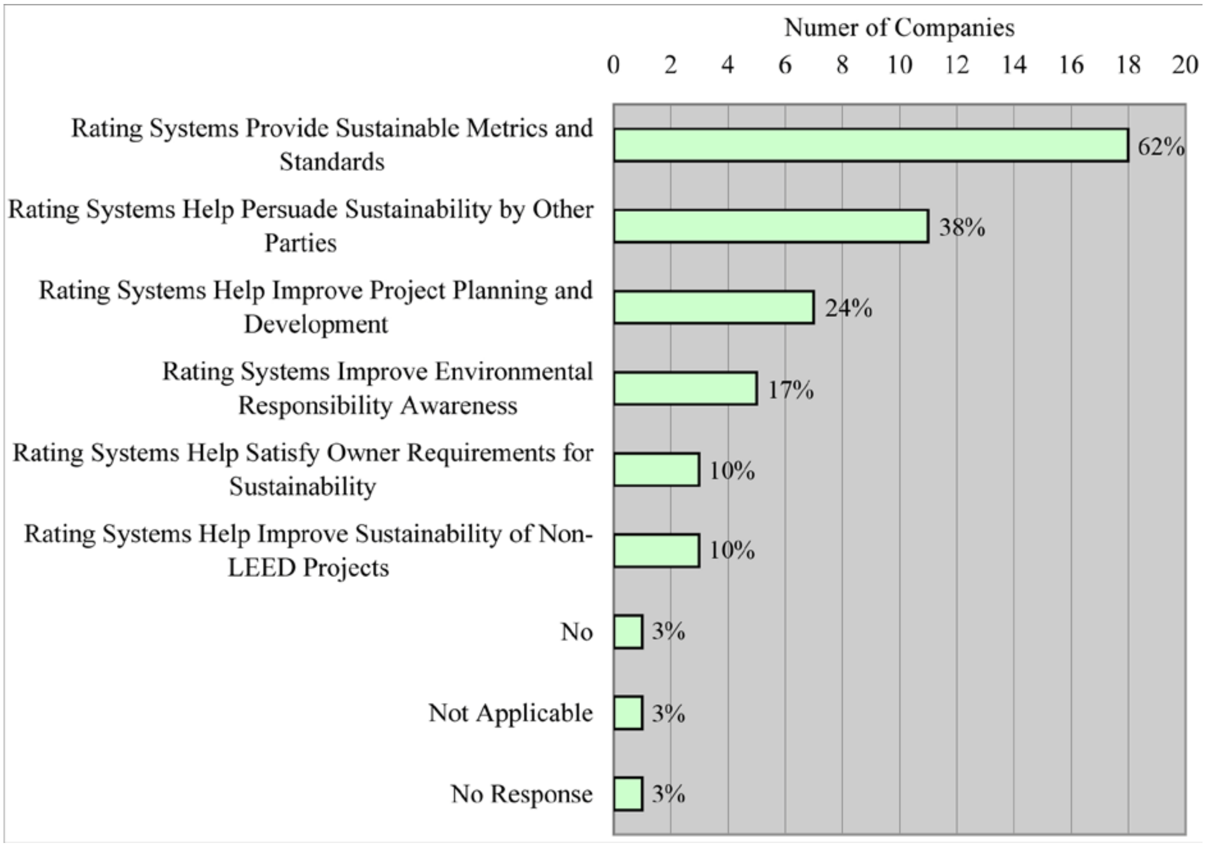

Figure 4-14. General realized benefits of certification rating systems for sustainability: Q5.1

Realized Benefits of BIM to Improve Project Sustainability: Q5.2

A slight majority of companies surveyed, 52% (15 respondents), state that BIM has not improved project sustainability, but these respondents indicate that the potential of BIM to improve project sustainability will become more significant in the near future as the software capabilities increase. (Figure 4-15). Among the 17% (5 respondents) of companies which have not realized any sustainable benefits from BIM, three (3) companies do not currently use BIM and are currently exploring its potential benefits, and the remaining two (2) companies use BIM, but do not perceive any usefulness of BIM for sustainability purposes (Figures 4-15 and G-11).

Specific uses of BIM for improving sustainability (Figures 4-15 and 4-16) are indicated by 31% (9 respondents). Among these nine (9) companies currently realizing improved analysis beneficial for sustainability resulting from the use of BIM, six (6) went into greater detail regarding the benefits realized, including using BIM for: energy analysis, 10% (3 respondents);

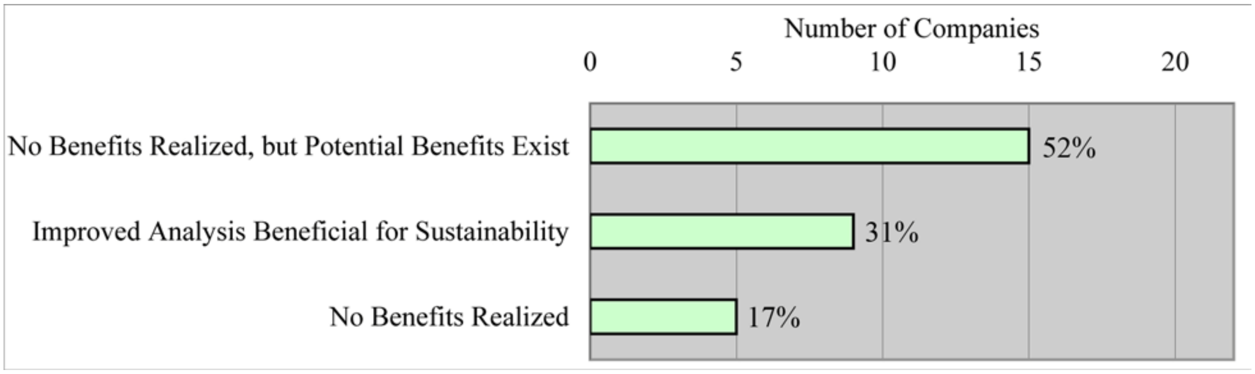

Figure 4-15. General realized benefits of BIM to improve project sustainability: Q5.2

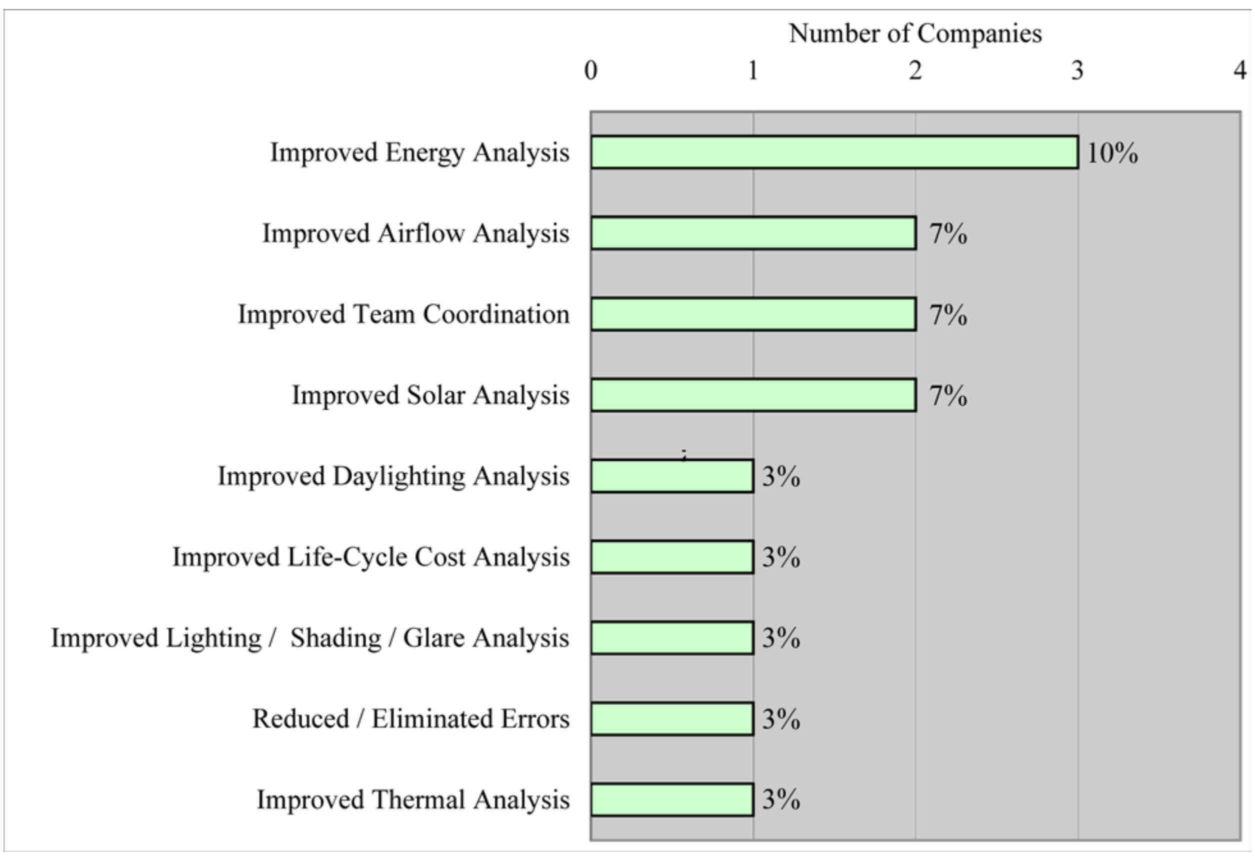

Figure 4-16. Specific realized benefits of BIM to improve project sustainability: Q5.2

airflow analysis, 7% (2 respondents); and solar analysis, 7% (2 respondents). While many of the uses for BIM to assess project sustainability (Figure 4-16) are greatly beneficial, it is interesting to note the relatively low percentages of the use of BIM to ascertain sustainable aspects of projects among the entire survey sample. The rubric developed to analyze this question, which links BIM to sustainability, is itemized by company in Appendix G (Figure G-11) for further analysis. The verbatim survey responses to Q5.2 are presented in Appendix G (Table G-5) for detailed analysis.

In comparing responses to Q5.1 and Q5.2, the researcher queries: "Does BIM or sustainability rating systems provide greater benefits for improved sustainability?" The survey respondents replied with a total of 47 responses regarding uses of LEED or other rating systems for improved project sustainability (Q5.1 and Appendix G, Figure G-10), However, a total of 23 responses indicated increased project sustainability resulting from usage of BIM software (Q5.2 and Appendix G, Figure G-11). While BIM is beneficial to certain companies identified by this research, LEED appears to have a greater impact on the overall ability to provide improved sustainability. In many instances, companies realizing sustainable benefits resulting from the use of BIM are larger companies, performing a wide variety of services with higher percentages of LEED-APs, but this is not always necessarily the case (Appendix G, Figures G-7 and G-11). There is no direct relationship between questions in category 1 and Q5.2 which indicates that companies with specific characteristics are more likely to use BIM for sustainability than other companies (see Appendix G).

Improvements to Traditional Methods of Sustainable Project Delivery Resulting from BIM: Q5.3

Whereas the sustainable benefits actually realized as a result of using BIM are not universal (Q5.2, Figures 4-15 and 4-16), the perceptions that BIM is changing the AEC profession's ability to deliver projects with improved sustainability are more commonplace (Figure 4-17). Specific ways in which BIM can potentially improve the ability of companies to deliver sustainable projects are as follows: The ability of BIM to improve the efficiency for designing and delivering sustainable projects was noted by 34% of responses (10 respondents). Improvements to coordination among project team members working on sustainable projects were indicated by 28% of responses (8 respondents). The indication of the use of BIM for energy

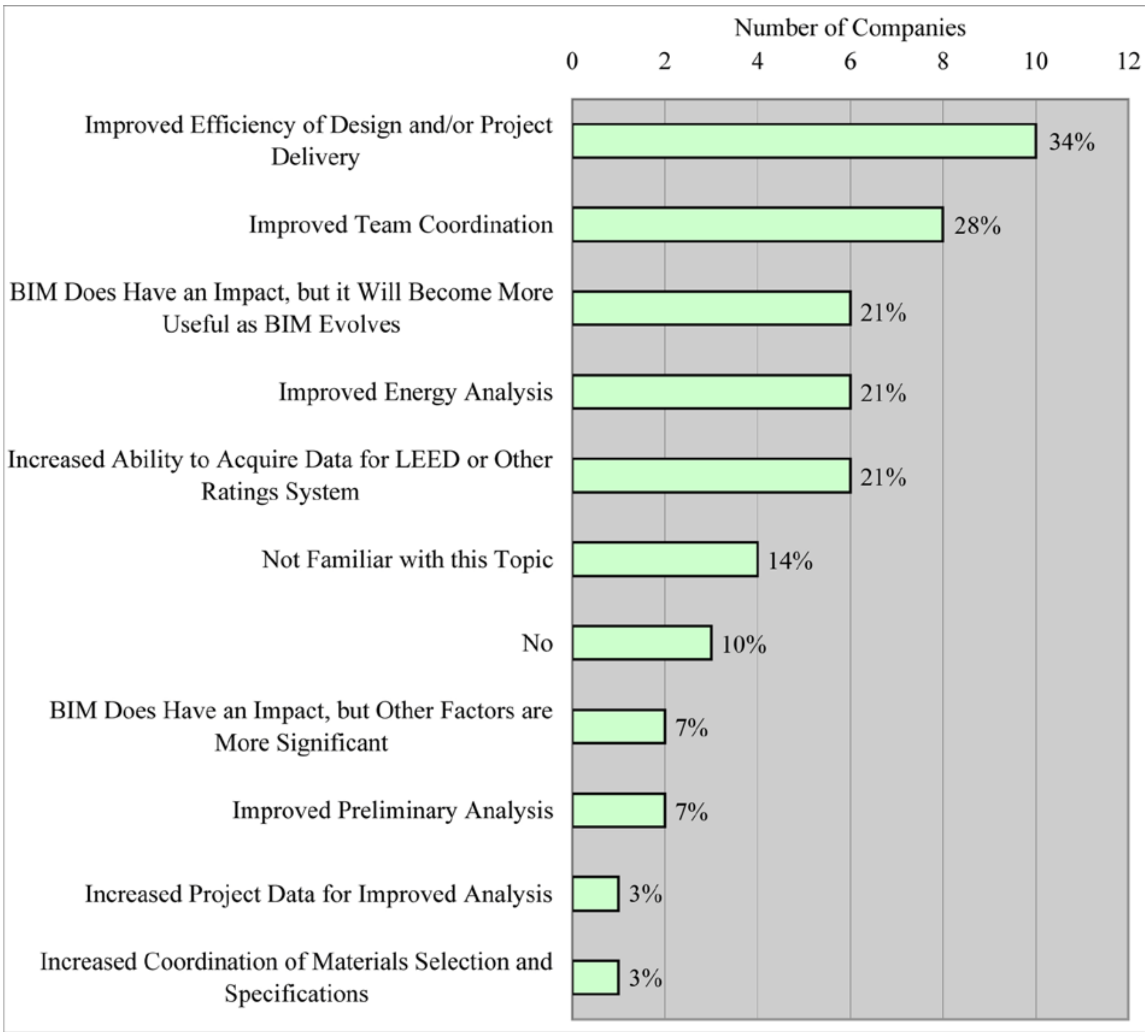

Figure 4-17. General potential of BIM for improving the methods of delivering sustainable projects: Q5.3

analysis to potentially improve project delivery, opined by six (6) companies (21%), is interesting considering that eight (8) companies (28%) believe energy analysis is one of the general benefits of BIM (Q4.4 and Figure 4-12), yet four (4) companies (14%) have actually realized the benefit of using energy analysis to improve project sustainability (Q5.2 and Figures 4-15 and 4-16). Another perceived use of BIM for sustainability is BIM's ability to store and process data, especially data pertinent for achieving LEED or other certification (21%).

Among the surveyed companies, 21% (6 respondents) believe that BIM evolves, it could possibly become a major driver for promoting sustainability, and 7% (2 respondents) believe that factors other than BIM are more substantially impacting the ability to deliver sustainable projects. Additionally, 14% (4 respondents) were unfamiliar with the subject of using BIM to facilitate the delivery of sustainable projects and 10% (3 respondents) feel that BIM is not applicable to sustainable project delivery.

The rubric developed by this research to analyze this question is itemized by company in Appendix G (Figure G-12) and the verbatim survey responses to Q5.3 are also presented in Appendix G (Table G-6). Detailed analysis of the results conclude that perceptions of BIM's impact on the industry are not directly linked to specific company characteristics, and the reasons for using BIM are as varied as the AEC community itself (see Appendix G).

Recommended Improvements to BIM for Increased Sustainability Analysis: Q5.4

Despite the sustainability-related advantages of BIM, improvements to BIM software currently available must continue in order to fully realize the potential synergies between BIM and sustainability (see Chapter 2). (Figure 4-18) The most commonly suggested improvement to BIM for sustainability is the addition and/or improvement of sustainability tools and tips within the software, as indicated by 28% of responses (8 respondents). Additionally, 24% (7 respondents) requested improved abilities of BIM to analyze projects for compliance with sustainable rating systems such as LEED. Improvements to interoperability were also suggested by 24% (7 respondents). Other recommended improvements to BIM for sustainability include: increased capabilities of BIM to provide more internal benefits for sustainability, as opposed to

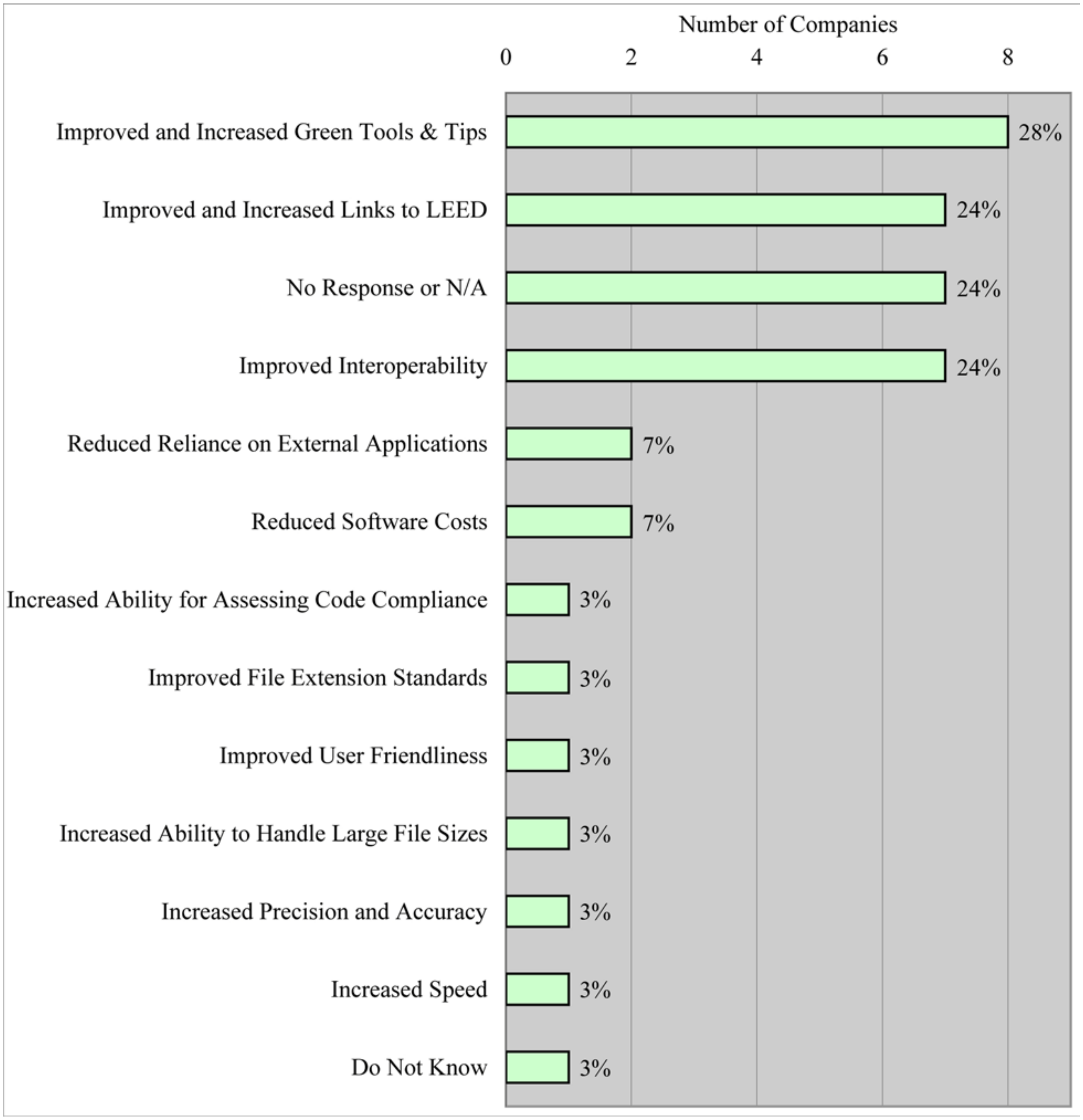

Figure 4-18. General recommendations to improve to BIM for sustainability analysis: Q5.4

relying on external software, 7% (2 respondents); and improvements to the abilities of BIM to check the design against building code requirements, 3% (1 respondent). Among the seven (7) respondents replying N/A or giving no response, five (5) do not currently utilize BIM (Tables G-1 and G-7). All original survey responses to Q5.4 are presented in Figure G-19 for further analysis.

The rubric developed by this researcher to analyze this question itemized by company (Figure G-13) indicates that every company perceives potential improvements to BIM for increase sustainability analysis, regardless of specific company characteristics. The verbatim recommended improvements to BIM (Table G-7) provide further insight into specific company's utilization of BIM within their specific niche within the AEC community; generally, the recommended improvements could be beneficial to both the design and construction aspects of the industry.

Survey Respondent's Requests for Copies of this Document: Q6.1

A large majority of individuals from surveyed companies (28 of 29, 97%) indicated they want to learn more on the topic of BIM for sustainability. These 28 respondents asked to receive a digital copy of this document, with the intention that this research could assist companies in gaining a greater understanding of the utilization of BIM for sustainability. In addition, the researcher hopes this document can assist these companies implementing the use of BIM for improved sustainability analyses. Again, the researcher would like to thank these companies for their contribution to this research.

Summary

The following information has been compiled from the previous sections to consolidate the results of this research.

Characteristics of Companies Using BIM

Reasons for utilizing or not utilizing BIM are as varied as the different BIM applications, as well as the entire AEC community itself. Companies using BIM the longest are typically larger companies with longer durations of company operations and higher percentages of LEED-APs. Among the 29 companies participating in this research:

- Seventy nine percent (79%) of surveyed companies using at least one BIM application:
    - Forty two percent (42%) of surveyed companies use exactly one BIM application, and are typically slightly larger companies, slightly older companies, and have slightly increased percentages of LEED-APs employed.
    - Thirty eight percent (38%) of surveyed companies use two or more BIM applications, and are also typically larger companies with the longest durations of company operations, and having the highest percentage of LEED-APs employed.
    - Eighty three percent (83%) of surveyed companies using BIM have used BIM for four (4) years or less.
    - Twenty two percent (22%) of the surveyed companies using BIM have used BIM for one (1) year or less.
    - Sixty six percent (66%) of surveyed companies use Revit.
    - Thirty one percent (31%) of surveyed companies use NavisWorks.
    - Twenty one percent (21%) of surveyed companies use Bentley software.
    - Other software is utilized significantly less frequently.
- Twenty one percent (21%) of surveyed companies do not use BIM, and are typically smaller, newer companies having less than 8% of employees LEED-Accredited.
- Fourteen percent (14%) do not use BIM, but are currently researching BIM.
- Three percent (3%) do not use BIM due to perceptions that BIM is not necessary for the type of work performed.
- Three percent (3%) do not use BIM because it is not practical, since business associates do not use BIM.

Perceived Advantages of BIM

Perceptions of the advantages to utilizing BIM were provided by every company participating in this research, regardless of whether or not the company actually uses BIM or has actually realized any of these potential benefits:

- Forty two percent (42%) of perceived advantages of BIM were specific to design:
    - Forty eight percent (48%) of surveyed companies perceived improvements to design visualization.
    - Thirty eight percent (38%) of surveyed companies perceived improvements to the integrity of the architectural drawings with respect to consistency and/or accuracy.
    - Twenty four percent (24%) of surveyed companies perceived improvements to project planning and overall design.
    - Twenty four percent (24%) of surveyed companies perceived benefits related to clash detection capabilities.
    - Twenty one percent (21%) of surveyed companies perceived increased detail of the drawings.
- Twenty seven percent (27%) of perceived advantages of BIM were general in nature, specific both design and construction:
    - Sixty nine percent (69%) of surveyed companies perceived improvements to team coordination.
    - Twenty eight percent (28%) of surveyed companies perceived improvements to productivity.
- Twenty percent (20%) of perceived advantages of BIM were specific to construction:
    - Fourteen percent (14%) of surveyed companies perceived the usefulness of quantity takeoff and cost analysis tools.
    - Ten percent (10%) of surveyed companies perceived improved planning of construction sequencing.
    - Ten percent (10%) of surveyed companies perceived improvements to construction quality.
    - Ten percent (10%) of surveyed companies perceived a reduction of construction waste.

- Seven percent (7%) of surveyed companies perceived improved constructability analysis.
- Seven percent (7%) of surveyed companies perceived a reduction of change orders.
- Seven percent (7%) of surveyed companies perceived a reduction of construction cost.
- Three percent (3%) of surveyed companies perceived improvements to the planning of prefabricated building components.
- Three percent (3%) of surveyed companies perceived a reduction in trade stacking.
- Three percent (3%) of surveyed companies perceived reduced RFI's.

- Eleven percent (11%) of perceived advantages of BIM were specific to operations:
    - Twenty eight percent (28%) of surveyed companies perceived the ability to perform energy analysis.
    - Ten percent (10%) of surveyed companies perceived general uses for the BIM model during operations.

Perceived Disadvantages of BIM and Obstacles to BIM

Again, every company participating in this research indicated perceived disadvantages and/or obstacles to BIM:

- Twenty eight percent (28%) of surveyed companies perceived that other company's inability or unwillingness to use BIM prevents them from realizing the full potential benefits of BIM.
- Twenty eight percent (28%) of surveyed companies perceived that the cost of BIM is prohibitive; fourteen percent (14%) of companies mention not only software cost, but also hardware costs, employee training costs, and the costs of hiring new employees skilled in BIM.
- Twenty four percent (24%) of surveyed companies perceived disadvantages related to interoperability limitations.
- Seventeen percent (17%) of surveyed companies perceived obstacles pertaining to the relative infancy of BIM, stating that the software is too new to make the transition to BIM.
- Seventeen percent (17%) of surveyed companies perceived disadvantages and/or obstacles pertaining to the difficulty of the learning curve of BIM software.

- Seventeen percent (17%) of surveyed companies perceived disadvantages related to liability issues pertaining to exactly who owns the BIM model and who is ultimately responsible for its accuracy when the data is shared among multiple companies.
- Ten percent (10%) of surveyed companies perceived obstacles relating to how to decide which BIM application to use, in consideration that no single application is capable of providing every desirable benefit.
- Seven percent (7%) of surveyed companies perceived disadvantages relating to the time required to build the BIM model.
- Three percent (3%) of surveyed companies perceived difficulties of BIM software's ability to manipulate large files; specifically, Revit, NavisWorks, eQuest, and DProfiler are noted.
- Three percent (3%) of surveyed companies perceived a minimal capability to perform cost analysis.
- Three percent (3%) of surveyed companies perceived a minimal extent of MEP families in Revit.
- Three percent (3%) of surveyed companies noted that inaccuracies built into the model perpetuate errors for other parties using the model.
- Three percent (3%) of surveyed companies perceived limitations for engineering analysis.
- Three percent (3%) of surveyed companies noted that the additional work required when using BIM does not necessarily guarantee additional compensation.

The Use of LEED or Other Certification Rating Systems for Sustainability

Every company participating in this research indicated specific improvements to the sustainability of projects as a result of using LEED or other rating system, with the exception of three (3) companies:

- Sixty two percent (62%) of surveyed companies perceived that rating systems help provide the metrics and standards necessary for measuring the extent of project sustainability.
- Thirty eight percent (38%) of surveyed companies perceived that rating systems help persuade other parties to pursue sustainability.
- Twenty four percent (24%) of surveyed companies perceived that rating systems assist in making improvements to the development and planning stages of projects.
- Seventeen percent (17%) of surveyed companies perceived that rating systems improve awareness of environmental responsibility.

- Ten percent (10%) of surveyed companies perceived that rating systems assist them achieving the sustainable requirements of project owners.

- Ten percent (10%) of surveyed companies perceived that rating systems assist them in improving the sustainability of projects, without the necessarily pursuing any sustainability certification processes.

Benefits of BIM Actually Realized by Companies to Deliver Sustainable Projects

Whereas nearly every company identified advantages of LEED for improved sustainability, the use of BIM to achieve improvements to sustainability are not nearly as commonplace:

- Fifty two percent (52%) of surveyed companies have not realized any benefits from using BIM to improve sustainability, while noting that there is potential for using BIM to achieve greater degrees of sustainability, especially as improvements are made to the software.

- Seventeen percent (17%) of surveyed companies have not realized any improvements to sustainability on their projects as a result of BIM; 60% of these companies do not currently utilize BIM whereas 40% of these companies do currently utilize BIM.

- Thirty one percent (31%) of surveyed companies have used project analysis tools within BIM to improve overall project sustainability; among these companies, specific benefits actually realized include:

    - Ten percent (10%) of surveyed companies have used BIM for energy analysis to improve overall project sustainability.

    - Seven percent (7%) of surveyed companies have used BIM to assist in team member coordination beneficial to improve overall project sustainability.

    - Seven percent (7%) of surveyed companies have used BIM for airflow analysis tools and/or solar analysis tools to improve overall project sustainability.

    - Three percent (3%) of surveyed companies have used BIM for daylighting analysis, life-cycle cost analysis, lighting/shading/glare analysis, and/or thermal analysis to improve overall project sustainability.

Perceptions of BIM for Improving the Delivery of Projects with Greater Degrees of Sustainability

Although LEED is used more frequently than BIM to attain improved sustainability, many companies perceive that BIM is beginning to have an impact on how the AEC industry delivers sustainable projects:

- Thirty four percent (34%) of surveyed companies perceive that BIM increases the overall efficiency beneficial for the delivery of sustainable projects.

- Twenty eight percent (28%) of surveyed companies perceive that BIM improves collaboration among project team members beneficial to realizing more sustainable projects.

- Twenty one percent (21%) of surveyed companies believe that as BIM technology evolves, it will become more conducive to facilitating the delivery of sustainable projects.

- Twenty one percent (21%) of surveyed companies believe that the energy analysis benefits of BIM facilitate the delivery of sustainable projects.

- Twenty one percent (21%) of surveyed companies believe that BIM provides the increased ability to acquire data necessary to attain LEED or other certification for sustainable projects.

- Fourteen percent (14%) of surveyed companies are not familiar with the topic of using BIM to deliver projects with higher degrees of sustainability.

- Ten percent (10%) of surveyed companies do not believe that BIM is changing the ability to provide sustainable projects.

- Seven percent (7%) of surveyed companies believe that factors other than BIM are more significantly changing the traditional methods of delivering sustainable projects.

Recommended Improvements to BIM to Facilitate the Delivery of Sustainable Projects

Although BIM for sustainability is not universally accepted, many AEC professionals will agree that improvements to BIM could definitely facilitate its use for improvements to the sustainability of projects:

- Twenty eight percent (28%) of surveyed companies recommend that more tools and tips should be built into the BIM software to facilitate sustainability analysis.

- Twenty four percent (24%) of surveyed companies recommend more direct links to LEED within BIM to more easily assess a project's ability to acquire LEED credits; currently the LEED Toolkit for IES <VE> is the only direct link between LEED and BIM.

- Twenty four percent (24%) of surveyed companies recommended improving the interoperability of various BIM applications to improve their ability to deliver projects with higher degrees of sustainability.

- Twenty four percent (24%) of surveyed companies did not recommend improvements to BIM or responded not applicable; five (5) of these seven (7) companies do not currently use BIM, whereas two (2) of these companies do use BIM but do not suggest any improvements to BIM for improved sustainability analysis.

- Seven percent (7%) of surveyed companies recommended improved capabilities of BIM software to provide more internal benefits for sustainability instead of relying on external software.

- Three percent (3%) of surveyed companies recommended the ability to check the BIM model against building codes in order to more easily facilitate their ability to deliver projects with higher degrees of sustainability.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Awareness of environmental responsibility has increased over recent decades while simultaneously, extraordinary improvements to technology have occurred, more specifically, BIM technology in particular. The potential usefulness of BIM to design, construct, and operate buildings in a more sustainable manner is certainly promising. The following sections discuss the research conclusions derived from both the literature review and the analysis of the survey responses (see Chapter 2 and Chapter 4).

Research Conclusions

Many within the profession currently use BIM as a general design and analysis tool, not necessarily for sustainability purposes. The benefits of BIM pertaining to productive data storage and data computation are greatly advantageous throughout the design and construction processes. Benefits including increased coordination and collaboration among project team members, improved design visualization, improved project productivity, and constructability feasibility analysis are commonly touted reasons for utilizing BIM. Other benefits including reduced construction and operating costs as well as improvements to project management are cited as well. The current and future potential advantages of BIM are beginning to have an influence on the AEC industry.

The use of BIM to attain higher degrees of sustainability is certainly becoming more commonplace than ever before. However, BIM is used for design and construction management purposes more often that it is used for sustainability analysis. Factors other than BIM such as rating systems like LEED still currently have greater influences on improved sustainability of the design, construction, and operations of buildings.

As technology tends to improve at an exponential rate, the future uses of BIM to realize greater levels of sustainability is likely to increase as the technology is improved and as more AEC professionals begin to integrate BIM software as a part of their standard workflow procedures. The utilization of BIM to assess project sustainability is certainly possible, but continued improvements to BIM are necessary for improved and more thorough sustainability analysis.

The current functionality of BIM can assist AEC professionals in assessing a project's ability to secure sustainability certification, but it is not currently the penultimate solution. While some BIM applications are more conducive than others in collecting data for sustainability rating systems, measurements outside the capabilities of BIM such as collecting field data must also occur throughout the certification process to ascertain evidence that the environmental footprint they imprint during design and construction is actually minimized as predicted. However, BIM holds the potential for the general assessment of a building's environmental footprint, possibly more so today than ever before. As the society clamors for increased environmental responsibility, many AEC professionals are likely to continue to demand an increase in BIM software's ability to assist in sustainability certification assessment of buildings.

The use of BIM does appear to be increasing amongst AEC companies. However, many problematic issues arise resulting from the use of BIM, especially regarding the interoperability of different software applications and the abilities of multiple applications to communicate with each other effectively while transferring data back and forth. Many BIM applications must export data to external analysis software for sustainability assessment. Although BIM has evolved and interoperability improvements have been made, the software has still not been perfected, especially pertaining to the use of BIM for sustainability analysis, wherein the use of multiple software applications is typically necessary.

Assessment of the Research Objectives

The goals of this research were to address specific objectives pertaining to sustainability, BIM, and the use of BIM for sustainability. These research objectives are reprinted here to assist in assessing if and how this research addresses them:

1. Determine the extent to which sustainability is affecting the AEC industry.
2. Determine the extent to which BIM is being utilized by the AEC community.
3. Determine the perceived and actual advantages and disadvantages to utilizing BIM.
4. Determine various AEC company's perceptions of BIM regarding utilizing BIM in order to achieve sustainability, and the reasoning behind such perceptions.
5. Determine whether or not BIM is changing the traditional methods of project delivery with regard to sustainability, and if so, how and why.

Research Objective 1

The goal of achieving improvements to sustainability within the AEC industry is certainly becoming more commonplace. The "greening" of cities across the United States, and indeed across the globe, is beginning to occur faster than the first environmentalists could have ever hoped for. More AEC companies are beginning to implement procedures and methodologies to facilitate the awareness of the need to improve overall sustainability, as indicated by various literature and the analysis of the survey conducted as part of this research. AEC sustainability-related terminology such as LEED is slowly but surely becoming a part of everyday language and not simply relegated as specialized colloquial jargon. While this research cannot definitively indicate the rate at which sustainability is proliferating within the AEC industry, this research can definitely conclude that an era of increased sustainability awareness is certainly upon us.

Research Objective 2

The use of BIM is certainly becoming more commonplace. As a result of improvements to technology, BIM has evolved from its ancestor, the traditional CAD format, as a tool capable of imbuing greater levels of information into the design and construction documents. Similar to CAD, BIM is a means to an end which will likely become as commonplace as the currently antiquated blueprint once was many years ago. This research is not capable of determining the rate at which BIM utilization is proliferating within the AEC industry, but it can conclude that the use of BIM is increasing, and many decades will likely pass before BIM becomes as outdated as the ammoniated blueprint; in fact BIM is likely to evolve in perpetuity, never to become a relic of the past, as its capabilities evolve and its users expect greater software functionality from improved technology.

Research Objective 3

Specific advantages and disadvantages of BIM are discussed in detail in Chapters 2 and 4, and need not be recalled in detail here. Suffice to say that the current BIM technology is capable of providing extraordinary benefits beyond the comprehension of a young Vitruvius. Despite such advantages previously cited, many flaws are inherent to BIM, and despite attempts by software manufacturers to resolve such issues, many disadvantages currently remain unresolved, much to the chagrin of many AEC professionals who utilize BIM. However, many agree that despite potential disadvantages, the advantages of BIM have provided substantial benefits to the project teams which utilize BIM.

Research Objective 4

The specific use of BIM to ascertain project sustainability is certainly not as commonplace as the general use of BIM for its other advantages, as clearly indicated by various literature as well as by the survey conducted as part of this research. Those professionals utilizing BIM for sustainability analysis praise its advantages while simultaneously cursing its disadvantages. BIM is definitely not perfect, but the AEC industry has come a long way since the days of graphite on trace paper. As more AEC professionals make the transition to BIM, many are beginning to utilize the capabilities of BIM to assist them in maximizing sustainability related benefits realized on project using BIM specifically for improving sustainability.

Research Objective 5

The AEC industry is always changing, albeit comparatively slower than other industries, and while BIM is not necessarily leading the way, BIM is beginning to have an impact on the means and methods by which AEC companies provide their clients with sustainable projects. Professionals disagree over the extent to which BIM is having an impact on sustainable project delivery. Some do not feel BIM has any impact on sustainability, whereas others revere it as a necessity for their ability to deliver sustainable projects. As previously noted, the definition of BIM varies depending upon who is providing their own perception of what specifically constitutes BIM. As the software continues to evolve to become more conducive for sustainability analysis, it is likely that the terms BIM and sustainability will become synonymous. However, such synchronicity is not expected to occur for many years or even decades.

Retrospective Improvements to this Research

In order to receive more descriptive survey data, Q1.2: Company Type, could have made a better distinction between:

- AEC Sector (architectural design, interior design, engineering, general contractor, specialty contractor, etc.)
- Project Type (commercial, industrial, residential, transportation, etc.)
- Client Type (government, private, public, non-profit entity)

- Project Delivery Method (Design-Build, CM at Risk, CM for Fee, etc.)

A more immediately clear distinction in this question could improve the usefulness of this question when using the responses to analyze responses to other questions.

In order to receive more pertinent survey data, Q3.1: “What percentage of projects completed by this company has received LEED or other green building certification?” should have read: “How many projects has this company completed which have been LEED or otherwise certified?” The original question was poorly worded and resulted in diluted response data, especially for older companies who have completed numerous projects. Among newly formed companied, the percentage of LEED projects might be high; among older companies, the percentage of LEED projects will be much lower, considering the relative infancy of LEED compared to companies which have 80, 90, 100 year histories, for example.

In order to receive more pertinent survey data, Q3.2: “What percentage of sustainable projects was LEED or otherwise certified because it was requested by the owner?” should have read: “How many LEED or otherwise certified projects achieved certification due to owner’s requirements, but not legal requirements?” Several respondents were unable to make a clear distinction between the intent of Q3.2 and Q3.3, and due to the confusion regarding the nature of this question, a wide variety of responses were generated. The responses to the original question did not prove to be beneficial when comparing responses from different companies. One respondent in particular noted that if a specified degree of sustainability is required by law, it is implied that the owner will require sustainability in order to comply with the law, so logic dictates that the only correct answer to the original question is 100%. This slight change to Q3.2 would convey the intention of the question much better, thereby facilitating more useful responses.

In order to receive more pertinent survey data, Q4.1: “Does your company utilize BIM software, and if so, which software applications?” should have read: “If you utilize BIM, why do you utilize the specific BIM applications currently utilized as opposed to other applications?” This will address not only which BIM applications are used, but also the reasoning behind their usage. Check boxes should be used instead of requesting a type-written response, so that respondents can peruse a list of various applications, and select those which are most applicable. Additionally, do not simply use one check box for Revit, for example, but instead use separate check boxes for Revit Architecture, Revit Structure, and Revit MEP to ensure that every application actually used by respondents is adequately accounted for.

A higher response rate could be realized by indentifying more potential respondents. This research identified 343 potential respondents and required that at least 47 respond, thus approximately 1:7 responses were necessary. Realistically, this ratio should be closer to 1:12 or 1:15, and a larger sample size would greatly facilitate more responses. Additionally, the Survey Participation Request Letter (Appendix D) should have been written such that potential respondents are immediately made aware of who is conducting the survey, that this is UF research as opposed to an independent study. This could have potentially resulted in a higher survey response rate.

Recommendations for Future Research

Repeat the survey multiple times over the time span of several years to determine the rate at which the AEC industry is integrating sustainability and BIM. Intuitively, the use of BIM for sustainability will increase over time, but just how rapidly is the AEC industry accepting BIM as a possible solution for increased sustainability? Additional topics to consider include specifically analyzing the uses of BIM for sustainability tactics such as recyclability, deconstructability, materials reuse, or passive design, and include specificity within the actual survey form to determine if such sustainable tactics are actually realized as a result of using BIM or if they are achieved by other methods.

Recommendations for the AEC Community

If sustainability rating systems are to be used in an effort to improve project sustainability, the AEC community should be certain to use the rating system most applicable to the project, always bearing in mind the sustainable goals of the project and using the rating systems as a guideline, not as the sole indicator of sustainability. Also, for example, simply because two buildings are both rated LEED Silver does not imply that they are equally as sustainable; attaining certain LEED credits can improve the overall sustainability of the project much more significantly than attaining others. Instead of simply attaining credits which only marginally improve overall sustainability in order to cross the threshold from LEED Silver to LEED Gold, for example, professionals must always remain cognizant of the actual sustainable impacts resulting from achieving particular credits.

If BIM is to be utilized for improving project sustainability, AEC professionals must be certain to fully understand the capabilities of the particular software being used. The capabilities of the software should determine which application(s) are most appropriate to suit the particular needs of the companies using the software. However, in many instances, other companies working in collaboration on the same project might use different software. Therefore, it is essential to understand the extent of currently available interoperability amongst the software used by business partners, to maximize the potential benefits of the software.

A common saying in the BIM community is “garbage in, garbage out”, implying that if the BIM model is inaccurate, incorrect, or inapplicable in any way, the resulting analysis is not likely to adequately represent real-world conditions. Professionals must never forget that BIM models are representations of reality which might not completely reflect every possible real-world condition. Conversely, BIM models attempt to most adequately represent reality to the fullest extent possible, determined by the capabilities of the specific BIM application. The model and the resulting analysis of the model will more closely approximate reality as more and more detailed information is applied to the model.

Recommendations for BIM Software Manufacturers

Many experts have expressed their belief that there is potential for BIM to be utilized in sustainability analysis, and while improvements to BIM over the years have increased the software's ability to provide such benefits, there is always room for improvement. It is unfortunate that so few BIM applications can analyze aspects of projects in respect to actually achieving certification. For example, some LEED credits can be tracked in Revit, but many credits cannot be tracked by any current software. The ability of BIM software to analyze a project's ability to attain certification must be improved. Additionally, BIM should not just provide the ability to analyze the potential for LEED certification, but it should also be compatible with Green Globes, BREEAM, etc.

Although improvements to interoperability between applications have occurred over the years, increased improvements are demanded by many within the AEC community. As hardware and software technologies improve, some professionals believe that there should simply be one single BIM application capable of performing every possible function, effectively negating the interoperability issue. On the other hand, other professionals believe that different applications should be specialized to suit their specific needs, effectively reducing the complexity and the cost of the software. Ideally, there should be both 'mega-programs' and 'micro-programs', all capable of smooth interoperability among each other to maximize transfer of data and minimize the need to modify the original model within ancillary software. These applications must be capable of communicating among each other in a more fluid manner. Currently, interoperability issues typically necessitate re-working the model in different programs, which is simply inefficient, non-productive, and unacceptable.

APPENDIX A
RESEARCH PROPOSAL

Committee: __X__New, _____Changed, _____ Same
Degree Sought: _____MBC, __X__MSBC
Funded Research Project: _____Yes, __X__ No

January 16, 2009

To: Dr. R. Raymond Issa
From: Christopher M. Hostetler
Subject: Proposal for Graduate Committee

Proposed Committee:

Chair: Dr. Svetlana Olbina x___________
Co-Chair: Dr. Robert Ries x___________
Member: Dr. Charles Kibert x___________

Proposed Subject:
Building Information Modeling (BIM) and sustainability within the architecture / engineering / construction (AEC) community.

Research Objectives:
The primary goal of this research is to determine the extent to which Building Information Modeling (BIM) is utilized by the architecture/engineering/construction (AEC) community in order to improve its ability to deliver green or sustainable projects to their clients.

The secondary goal of this research is to provide recommendations to the AEC community on how to utilize BIM to deliver sustainable projects to their clients.

The objectives which this research intends to address are as follows:

1) Determine the extent to which sustainability is affecting the AEC industry.

2) Determine the extent to which BIM is being utilized by the AEC community.

3) Determine the perceived and actual advantages and disadvantages to utilizing BIM.

4) Determine various AEC company's perceptions of BIM regarding utilizing BIM in order to achieve sustainability, and the reasoning behind such perceptions.

5) Determine whether or not BIM is changing the traditional methods of project delivery with regard to sustainability, and if so, how and why.

Research Methodology:
This research will use surveys to collect information from various sectors of the AEC industry in an attempt to identify relationships between BIM and sustainable project delivery. The data will be collected and analyzed. Following data analysis, recommendations will be provided for the AEC community and for future researchers.

Expected Completion:
August 2009

1/20/2009

Dr. R. Raymond Issa, Director of the Graduate Program Date

APPENDIX B
IRB SURVEY PROPOSAL SUBMISSION

<table>
<tr><th colspan="2">UFIRB 02 – Social & Behavioral Research
Protocol Submission</th></tr>
<tr><td colspan="2">Title of Protocol: Building Information Modeling and its Impacts on Sustainable Building Project Delivery</td></tr>
<tr><td>Principal Investigator: Christopher M. Hostetler</td><td>UFID #: [redacted]</td></tr>
<tr><td>Degree / Title:
Masters Degree, Thesis

Department:
School of Building Construction</td><td>Mailing Address:
[redacted]

Email Address & Telephone Number:
[redacted]</td></tr>
<tr><td>Co-Investigator(s):
N/A</td><td>UFID#:
N/A</td></tr>
<tr><td>Supervisor:
Dr. Svetlana Olbina</td><td>UFID#[redacted]</td></tr>
<tr><td>Degree / Title:
Assistant Professor

Department:
School of Building Construction</td><td>Mailing Address:
[redacted]

Email Address & Telephone Number:
[redacted]</td></tr>
<tr><td colspan="2">Date of Proposed Research:
09/20/2008 – 07/30/2009</td></tr>
<tr><td colspan="2">Source of Funding:
No external sources of funding.</td></tr>
<tr><td colspan="2">Scientific Purpose of the Study:
The primary objective of this research is to determine the extent to which Building Information Modeling (BIM) is utilized by the architecture/engineering/construction (AEC) community in order to improve its ability to deliver green or sustainable projects to their clients.</td></tr>
</table>

The secondary objective of this research is to provide recommendations to the AEC community on how to utilize BIM to deliver sustainable projects to their clients.

Describe Potential Benefits and Anticipated Risks:

Potential benefits will depend on whether or not survey respondents wish to receive a copy of the research when completed, with the intention of using this research to make more informed decisions regarding sustainable building practices. All survey responses will be held in complete confidentiality, so there are no anticipated risks to participating in this survey.

Describe How Participant(s) Will Be Recruited, the Number and AGE of the Participants, and Proposed Compensation:

I will contact various members of the AEC community who have participated in previous University of Florida career fairs, and other AEC community members who have been listed as Engineering News-Record top companies. The total number of answered surveys must be at least 47. Assuming a response rate of 1:6, a minimum of 282 surveys will be mailed electronically. Participants will be working age adults and will be contacted by telephone to assess their interest in becoming involved in this research.

The sole compensation will be optional and non-monetary. It will consist of a digital copy of the completed research to assist AEC companies surveyed on how to utilize BIM to improve the sustainability of the projects they undertake.

Describe the Informed Consent Process. Include a Copy of the Informed Consent Document:

Once potential survey participants have been identified, I will send the survey and consent forms electronically.

Principal Investigator(s) Signature: Christopher Hostetler	**Supervisor Signature:** Dr. Svetlana Olbina
Department Chair/Center Director Signature: Dr. R. Raymond Issa	**Date:** 01/20/2009

APPENDIX C
IRB SURVEY APPROVAL

UF | Institutional Review Board
UNIVERSITY *of* FLORIDA

PO Box 112250
Gainesville, FL 32611-2250
352-392-0433 (Phone)
352-392-9234 (Fax)
irb2@ufl.edu

January 28, 2009

TO: Christopher M. Hostetler
[redacted]

FROM: Ira S. Fischler, PhD; Chair ISF/dl
University of Florida
Institutional Review Board 02

SUBJECT: **Exemption of Protocol #2009-U-0060**
Building Information Modeling and its Impacts on Sustainable Building Project Delivery

SPONSOR: None

The Board has determined that your protocol is exempt from review. This exemption is issued because this protocol does not involve the use of human participants in research in accordance with 45 CFR 46. Human participants are defined by the Federal Regulations as living individual(s) about whom an investigator conducting research obtains (1) data through intervention or interaction with the individual; or (2) identifiable private information.

Should the nature of your study change or if you need to revise this protocol in any manner, please contact this office before implementing the changes.

IF:dl

APPENDIX D
SURVEY REQUEST LETTER

Dear AEC Professional:

Will you please help us with a very important research project?

We are conducting a survey in order to determine a correlation between the use of Building Information Modeling (BIM), and the ability of the architectural / engineering / construction (AEC) community to deliver sustainable projects to their clients.

A major goal of this research is to provide a resource to AEC professionals to assist them in utilizing BIM in order to make more sustainable decisions. Your responses to the attached questionnaire will be extremely helpful to this body of research. The survey should only take about 15-25 minutes depending on the level of detail in your responses, and will be of no risk to you or your company, as all responses will be anonymous.

If the topics of BIM and sustainability are not your specialty, would you please forward this message to someone in your company who specializes in these topics, and who would be willing and able to participate.

Please download the attached pdf file, complete the form, and click the “Email Completed Survey” button at the end. Your prompt reply will be greatly appreciated and I thank you very much for your help. We hope to hear back from you soon.

Sincerely,

Christopher M. Hostetler

Principal Researcher
University of Florida Graduate Student

APPENDIX E
SURVEY INFORMED CONSENT DOCUMENTATION

Protocol Title:
Building Information Modeling and its Impacts on Sustainable Building Project Delivery

Please read this Informed Consent Document carefully before you decide to participate in this study.

Purpose of this research study:
The primary objective of this research is to determine the extent to which Building Information Modeling (BIM) is utilized by the architecture/engineering/construction (AEC) community in order to improve its ability to deliver green or sustainable projects to their clients.

The secondary objective of this research is to provide recommendations to the AEC community on how to utilize BIM to deliver sustainable projects to their clients.

What you will be asked to do in this study:
Answer a short survey regarding Building Information Modeling and sustainability.

Time required:
The survey will take about 15-25 minutes, depending on the level of detail of your responses.

Benefits:
Your involvement in this survey could potentially benefit you and/or your company. If you would like to receive a digital copy of this research, in order to help inform you of the potential for utilizing BIM to provide your clients with sustainable projects, please indicate as such on the survey form.

Risks:
There are no risks involved with participating in this survey. Your completed survey can contain as little or as much information as you wish to divulge.

Confidentiality:
Your responses will be held in complete confidentiality. It is completely optional to include your personal information in the survey.

Voluntary participation:
Participation in this survey is completely voluntary, and there is no penalty for not participating.

Right to withdraw from this study:
You have to right to withdraw from this study at any time with no risk.

Whom to contact with questions about this study:
Chris Hostetler, Principal Investigator, School of Building Construction
Phone: [redacted]
Email: [redacted]

Dr. Svetlana Olbina, University of Florida School of Building Construction
Phone: [redacted]
Email: [redacted]

Whom to contact about your rights as a research participant in this study:
IRB02 Office, POBox 112250, University of Florida, Gainesville, FL 32611-2250
Phone: 352-392-0433
Email: irb2@ufl.edu

Agreement:
I have read the Informed Consent Documentation above. I have received a copy of the research proposal, and I voluntarily agree to participate in this research.

Participant: ____ Date:_______

Principal Investigator: ____________________________________ Date:_______

APPENDIX F
SURVEY QUESTIONNAIRE

1) <u>Company Information</u>

1.1) Company Name: ☐

1.2) Company Type (Please select all that apply to In-House work)

- ☐ General Contractor
- ☐ Specialty Contractor ______ (Please Specify)
- ☐ Architecture
- ☐ Engineering
- ☐ Design-Build
- ☐ Construction Management
- ☐ Industrial
- ☐ Transportation
- ☐ Commercial
- ☐ Heavy Civil
- ☐ Residential
- ☐ Other ______ (Please Specify)

1.3) Number of Employees:

1.4) Number of LEED-Accredited Employees:

1.5) How long has the company been in business?

2) <u>Personal Information</u>

2.1) Name *(Optional)*:

2.2) Title/Position *(Optional)*:

2.3) How long have you been in this industry?

2.4) How long have you been with this company?

3) <u>Sustainability</u>

3.1) What percentage of projects completed by this company has received LEED or other green building certification?

3.2) What percentage of sustainable projects was LEED or otherwise certified because it was requested by the owner?

3.3) What percentage of sustainable projects was LEED or otherwise certified because certification was required certified by either federal, state, or local legislation?

4) <u>Building Information Modeling (BIM)</u>

4.1) Does your company utilize BIM software, and if so, which software applications?

4.2) If so, how long has your company used BIM?

4.3) If not, why not?

4.4) What do you feel are the greatest advantages to utilizing BIM?

4.5) What do you feel are the greatest disadvantages or obstacles to utilizing BIM?

5) <u>Sustainability and BIM</u>

5.1) Do you perceive that utilizing LEED (or other certification) has improved your company's ability to provide your clients with **sustainable projects**, and if so, how?

5.2) Do you perceive that utilizing BIM has improved your company's ability to provide your clients with **sustainable projects**, and if so, how?

5.3) Do you feel that BIM is changing the traditional methods of project delivery with regard to **sustainable project** delivery, and if so, how?

5.4) Do you think that improvements could be made to the BIM applications your company uses in order to better facilitate the delivery of **sustainable projects**, and if so, what improvements would you like to see?

6) <u>Optional</u>

6.1) Would you like to receive a digital copy of this research, once completed, to help inform you of the potential for utilizing BIM to provide your clients with green and sustainable projects? If so, please confirm by providing your contact information below:

(Please provide your E-Mail Address. This E-Mail Address will ONLY be used for this purpose.)

Click to E-Mail Completed Survey

Thank you for your participation!!!

APPENDIX G
SURVEY RESPONSES

	Question 1.2: What types of services does this company perform?										
	General Contractor	Construction Management	Design-Build	Architecture	Engineering	Program Management	Cost Estimating	Development	Interior Design	Subcontractor	Total Response
# of Responses	17	13	12	10	5	2	1	1	1	1	63
% of Companies	59%	45%	41%	34%	17%	7%	3%	3%	3%	3%	217%
A	X										1
B			X	X	X						3
C					X						1
D					X						1
E	X	X	X								3
F	X	X	X								3
G	X	X									2
H	X	X	X								3
I				X							1
J	X									X	2
K			X	X							2
L		X		X							2
M	X	X	X								3
N				X							1
O	X	X	X								3
P	X	X	X	X				X			5
Q				X							1
R	X	X	X								3
S		X				X	X				3
T				X							1
U	X		X								2
V	X	X									2
W	X		X								2
X				X	X				X		3
Y	X	X				X					3
Z	X										1
AA	X	X	X								3
BB				X	X						2
CC	X										1

Figure G-1. Types of company services by surveyed companies: Q1.2

	Question 1.2: What types of projects does this company pursue?										
	Commercial	Industrial	Residential	Transportation	Academic	Forensics	Heavy Civil	Religious	Research	Technology	Total Response
# of Responses	16	6	3	2	1	1	1	1	1	1	33
% of Companies	55%	21%	10%	7%	3%	3%	3%	3%	3%	3%	114%
A											0
B	X										1
C											0
D											0
E	X	X									2
F	X	X									2
G	X										1
H	X	X		X			X				4
I											0
J	X										1
K	X				X						2
L	X										1
M	X	X									2
N											0
O											0
P	X		X					X		X	4
Q											0
R	X	X		X							3
S	X		X			X					3
T											0
U	X										1
V											0
W	X	X									2
X											0
Y											0
Z											0
AA	X										1
BB	X		X						X		3
CC											0

Figure G-2. Types of projects by surveyed companies: Q1.2

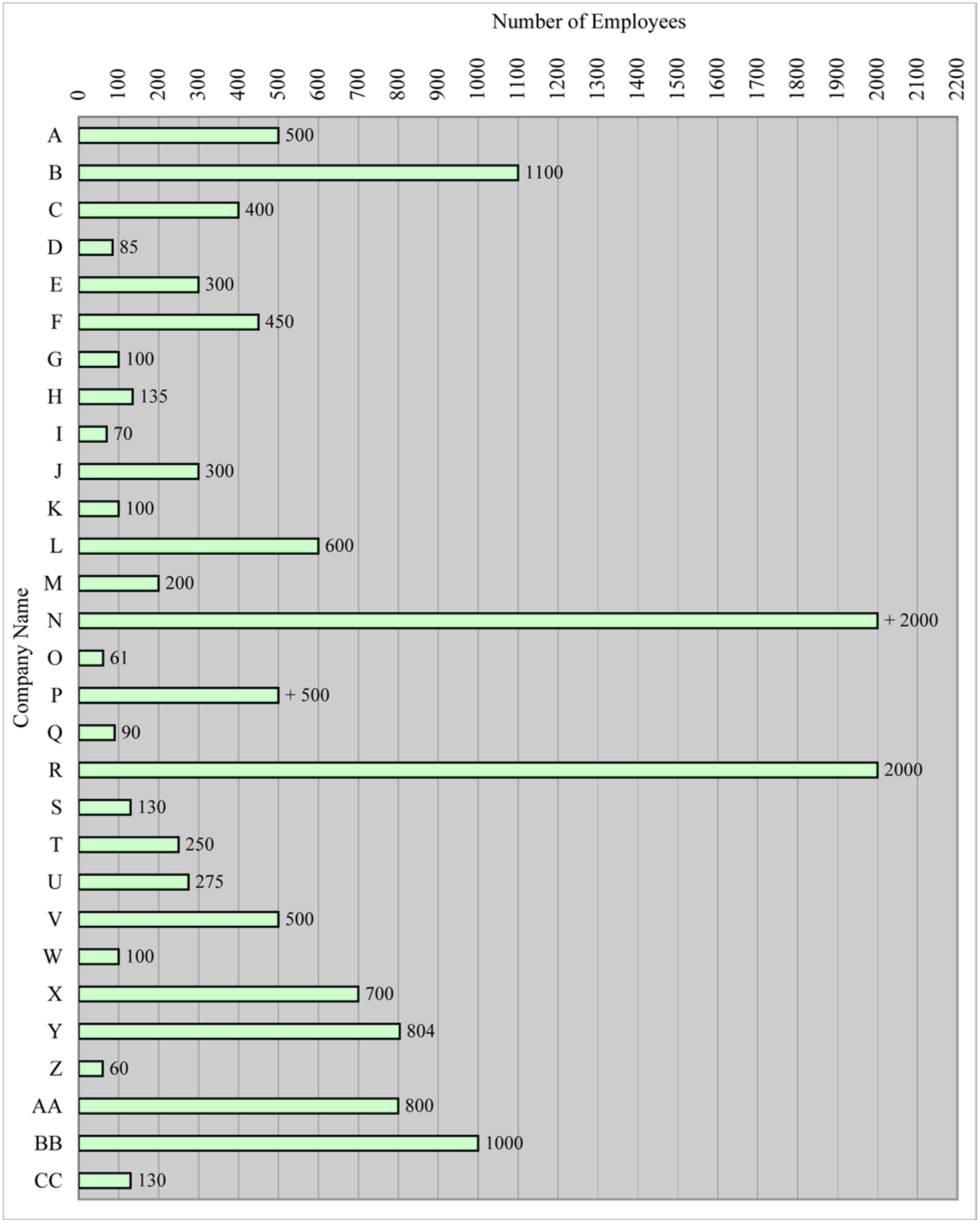

Figure G-3. Specific company sizes: Q1.3

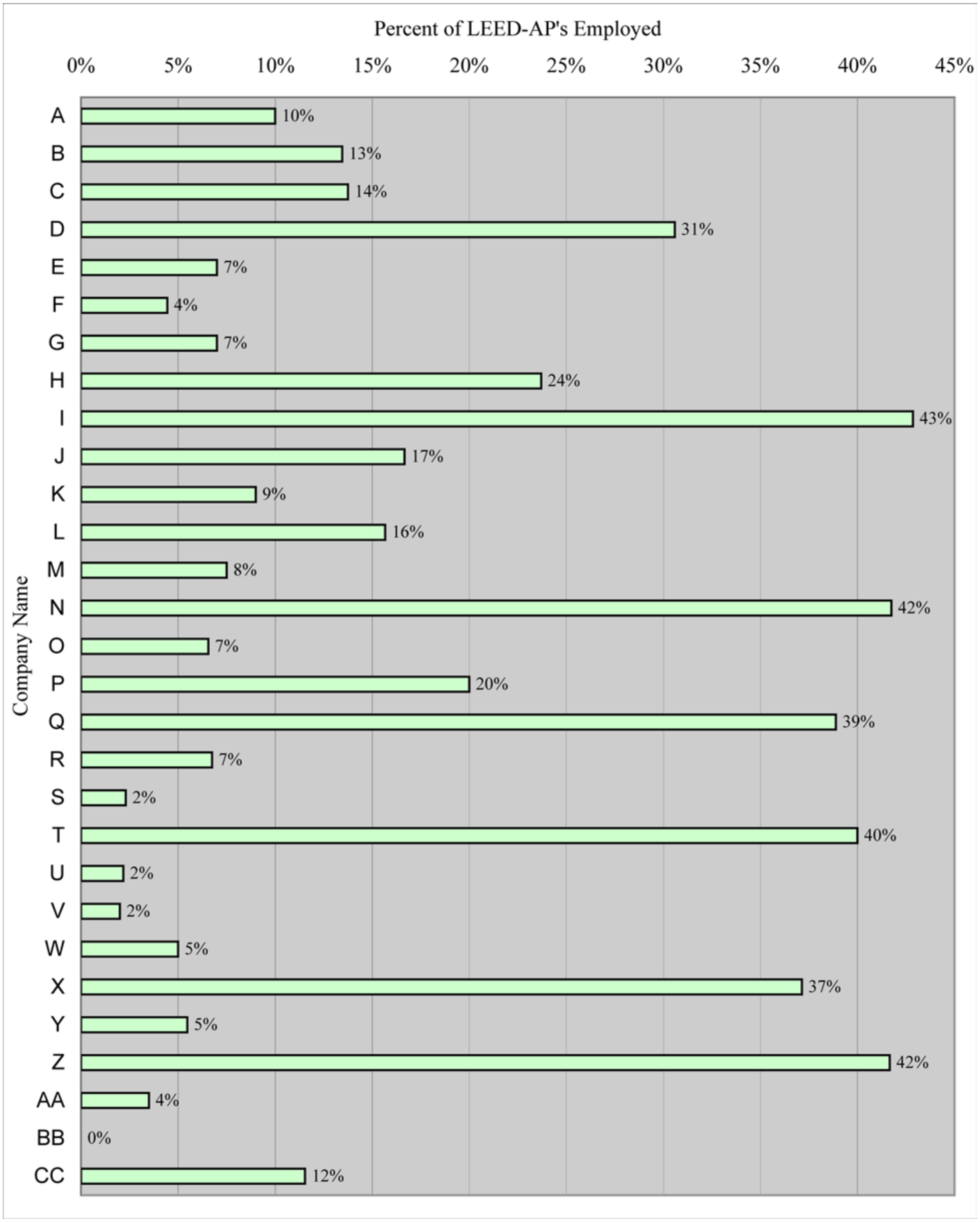

Figure G-4. Specific percentage of LEED-AP’s employed by surveyed companies: Q1.4

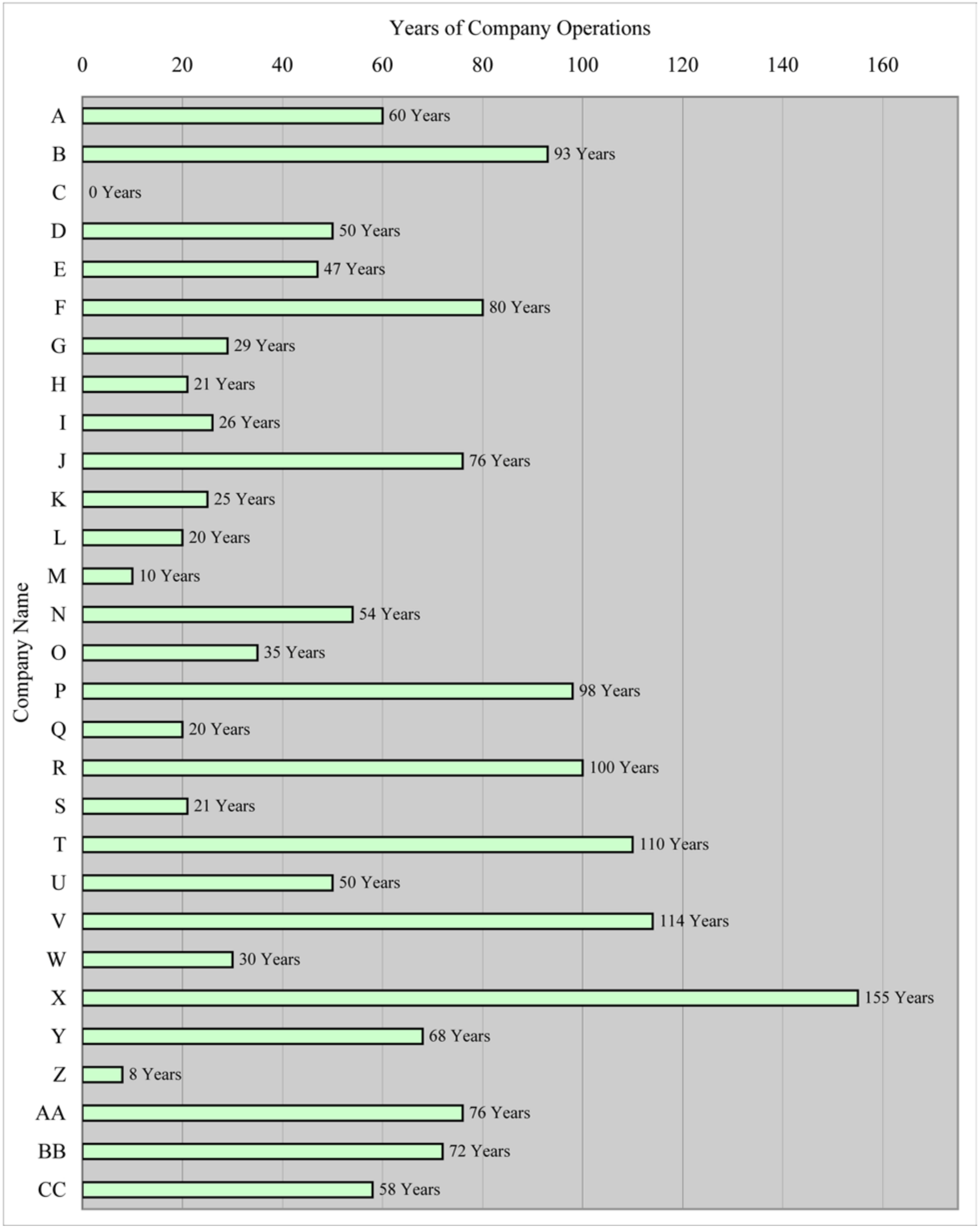

Figure G-5. Specific duration of surveyed company operations: Q1.5

	Question4.1: Does you company utilize BIM, and if so, which software applications?																											
	Vico Software	*Vela Systems:* Vela	*USDOE:* eQuest	*Tekla International:* Tekla	*Synchro Ltd:* Synchro	*Innovaya LLC:* Innovaya	*IES Ltd:* IES <Virtual Environment>	*Graphisoft:* Estimator	*Graphisoft:* Cost Manager	*Graphisoft:* Change Manager	*Graphisoft:* ArchiCAD	*Graphisoft:* 5D Presenter Solibri	*Google:* SketchUp	*Bentley Systems:* MicroStation	*Bentley Systems:* Common Point 4D	*Bentley Systems:* Architecture	*Beck Technology:* DProfiler	*Autodesk:* Revit Structure	*Autodesk:* Revit MEP	*Autodesk:* Revit Architecture	*Autodesk:* Revit (non-specific)	*Autodesk:* Quantity Take-Off (QTO)	*Autodesk:* NavisWorks	*Autodesk:* Ecotect	*Autodesk:* AutoCAD MEP	*Autodesk:* AutoCAD	*ANSYS Inc:* Airpak	Total Response
# of Responses	2	1	2	1	1	1	1	1	1	1	2	1	2	1	1	1	3	1	3	3	14	2	9	1	2	4	1	63
% of Companies	7%	3%	7%	3%	3%	3%	3%	3%	3%	3%	7%	3%	7%	3%	3%	3%	10%	3%	10%	10%	48%	7%	31%	3%	7%	14%	3%	217%
A																					X							1
B																					X							1
C			X				X												X					X			X	5
D																					X				X	X		3
E													X										X					2
F			X														X				X		X					4
G																												0
H																		X	X							X		3
I																					X		X					2
J													X		X					X		X	X			X		6
K																					X							1
L																				X								1
M																												0
N																					X							1
O																												0
P						X											X				X		X					4
Q																					X							1
R	X	X		X	X																X		X					6
S																												0
T														X												X		2
U											X					X					X							3
V																												0
W																												0
X																					X							1
Y	X							X	X	X	X	X																6
Z																	X				X		X					3
AA																			X	X		X	X		X			5
BB																					X							1
CC																							X					1

Figure G-6. Specific utilization of particular BIM applications by surveyed companies: Q4.1

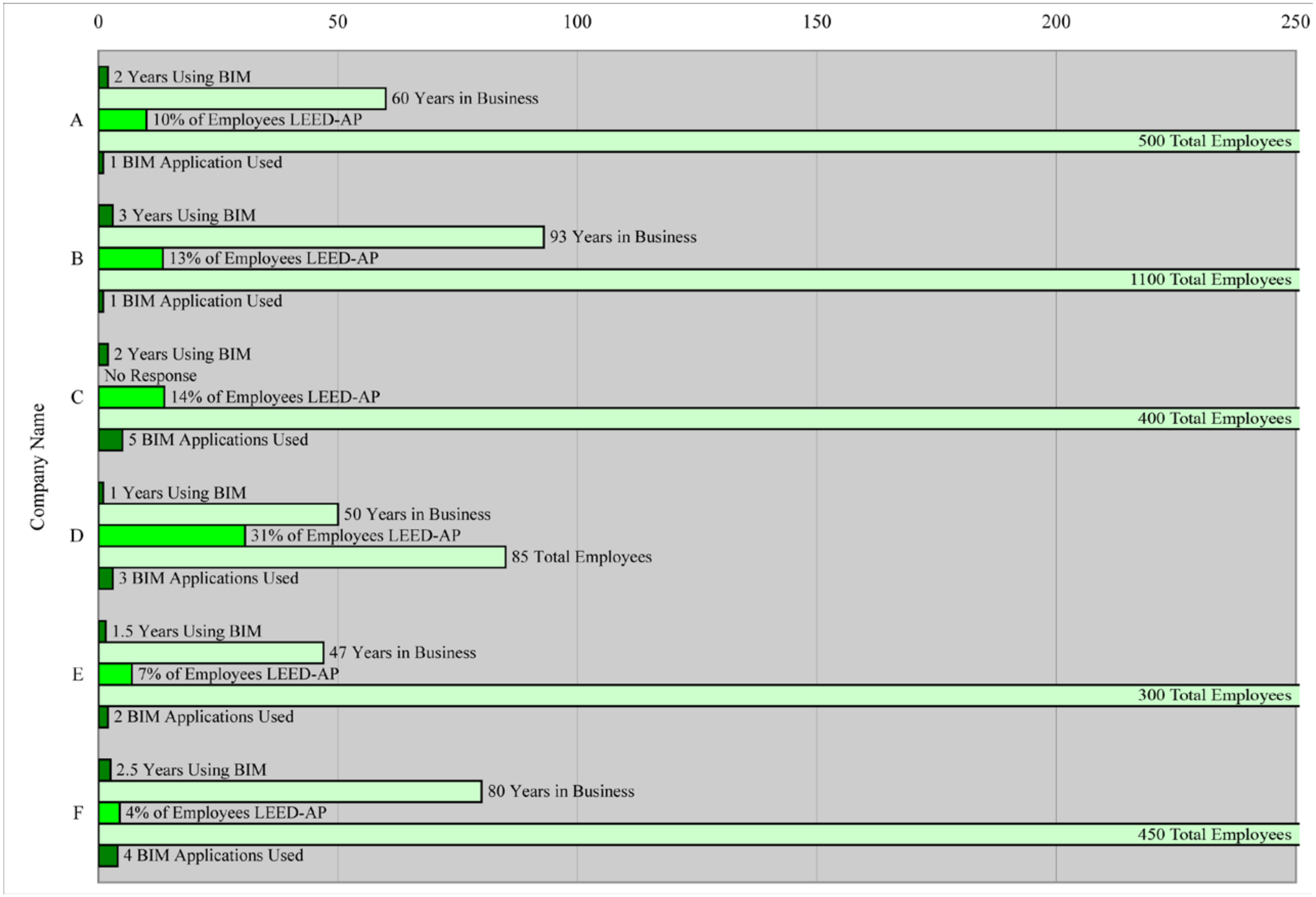

Figure G-7. BIM and other company information

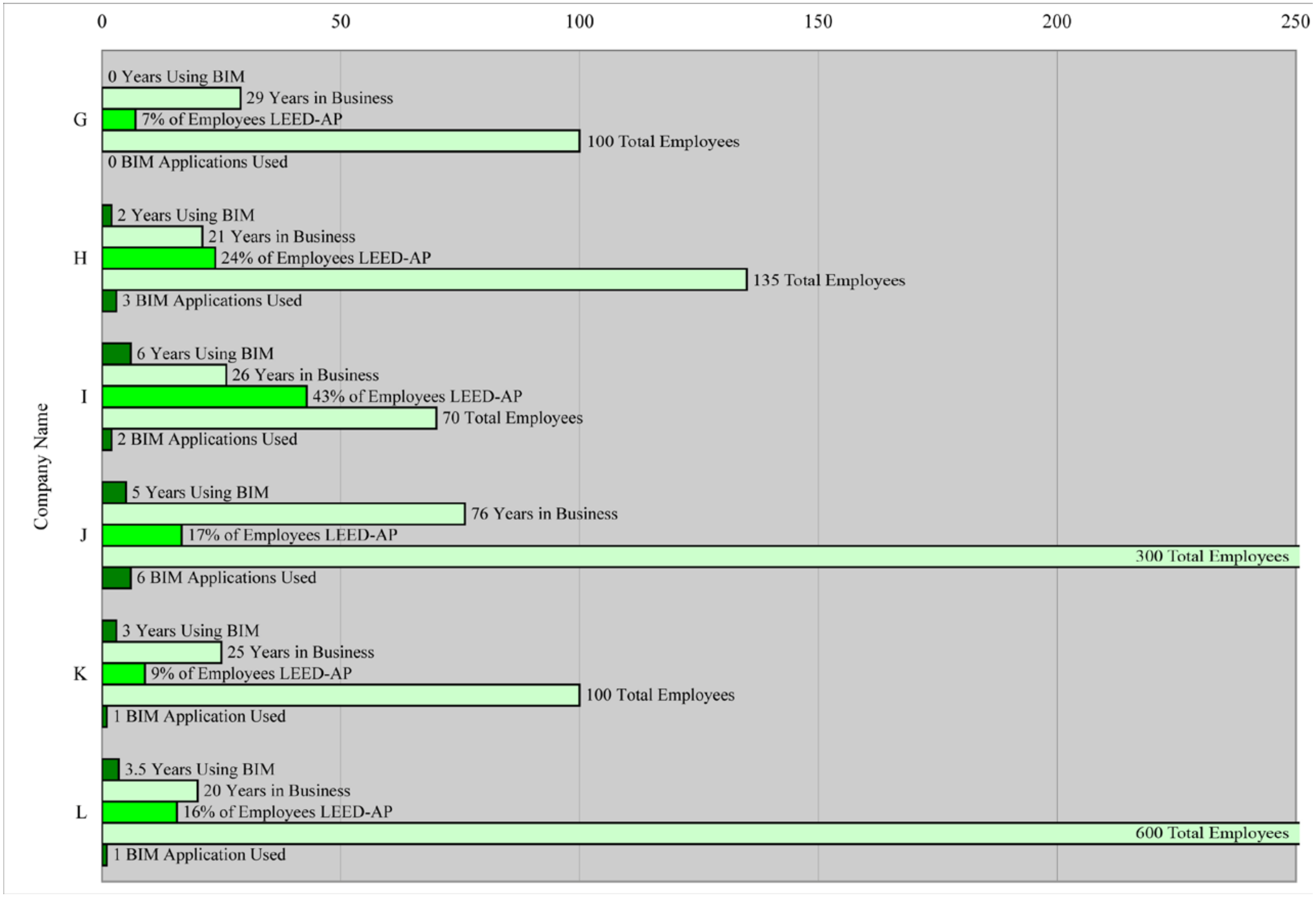

Figure G-7. Continued

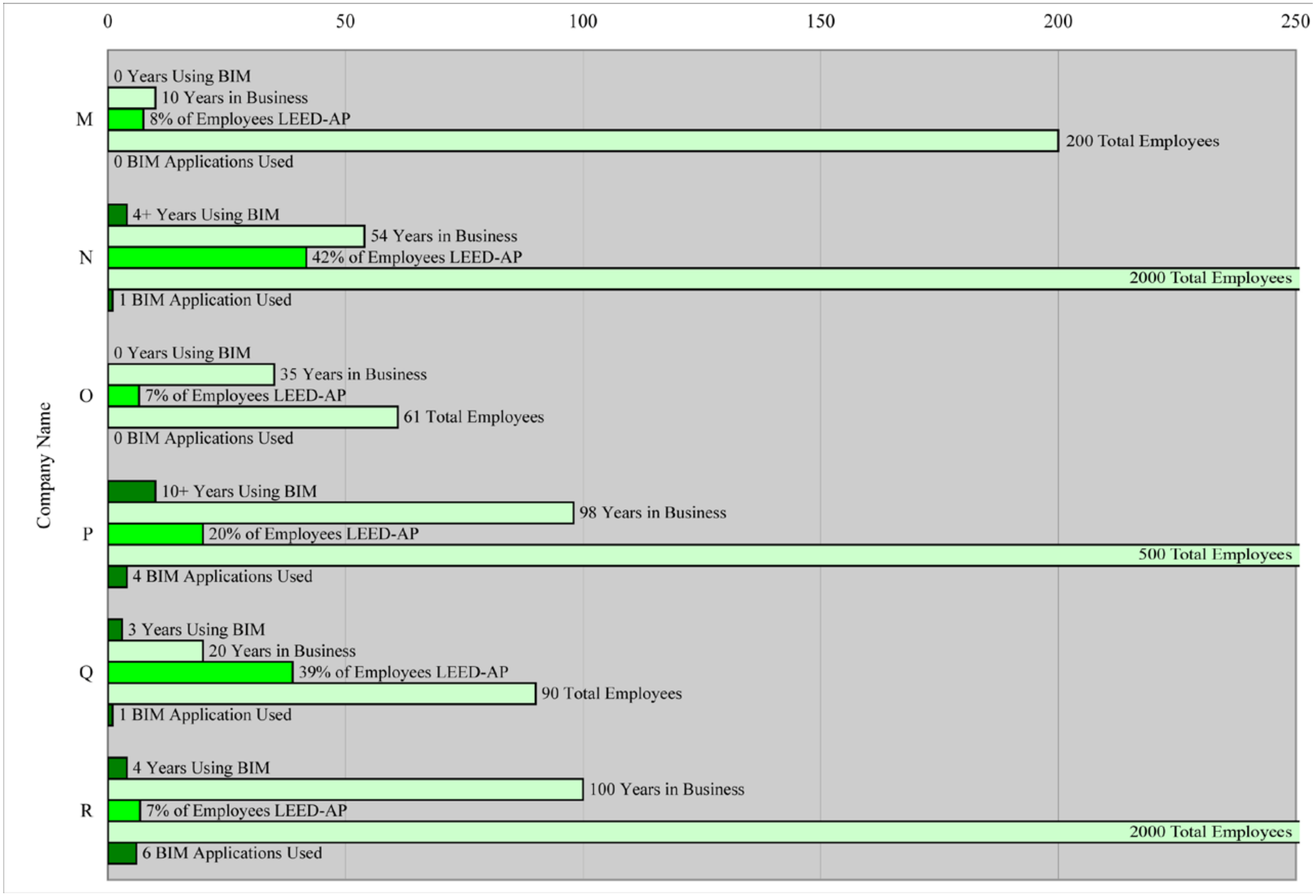

Figure G-7. Continued

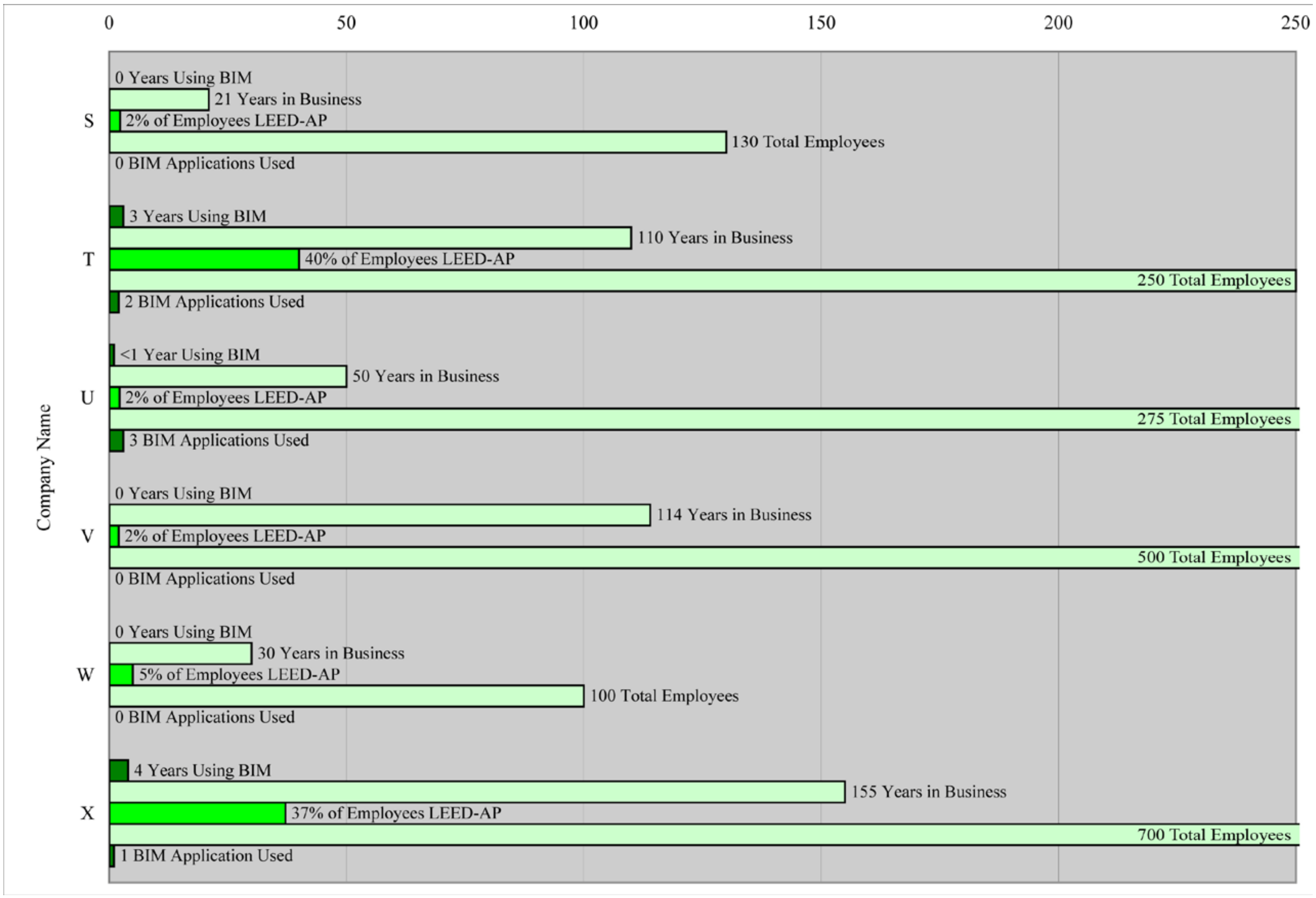

Figure G-7. Continued

Figure G-7. Continued

Table G-1. Verbatim responses regarding reasons for not utilizing BIM: Q4.3

Company Name	Question 4.3: If [your company does not utilize BIM], why not?
G	We are currently researching BIM applications that may be useful in our industry. We have performed one project where we utilized 3D shop drawings to coordinate piping, conduits and ductwork in above ceiling and other interstitial spaces.
M	We're currently investigating its use.
O	The architecture community has been slow to adopt [the use of BIM in our region].
S	BIM is a new technology. [Our company] is a project management/construction management company and does not utilize CAD or BIM software.
V	BIM is a new technology. We have investigated this software and will probably be purchasing something shortly.
W	We are researching its use within the development industry, and we believe that as we move into 2009 and beyond, we will begin to utilize BIM.
All Others	No Response

	Question 4.4: What do you feel are the greatest advantages to utilizing BIM?										
	General		Design					Operations			
	Improved Team Coordination	Improved Productivity	Improved Design Intent Visualization	Improved Integration Between Drawings	Clash Detection Benefits	Planning and Design Tool Benefits	Improved Drawing Detail	Energy Modeling Benefits	General Use of the Model by the Owner	Facilitated Project Turnkey to Owner	Total Response
# of Responses	21	8	14	11	7	7	6	8	3	1	108
% of Companies	72%	28%	48%	38%	24%	24%	21%	28%	10%	3%	372%
A	X								Q5.3		2
B	X		X			X					3
C	X					X		Q5.2			3
D	X				X						3
E	X		X	X	X		X				7
F	X		X					Q5.2			3
G	X										1
H						X					1
I	X						X				2
J	X	X	X		X	X	X			X	9
K	X	X		X							3
L	!	X	X	X		X					5
M			X	X							3
N			X					X			2
O	X	X			X						4
P	X			X			X	Q5.3			6
Q	X			X							2
R	X	X	X						!		6
S	X		X		X	X		X			6
T			X		X						2
U		X		X			X				5
V			X	X							2
W	X				X			X			3
X	X	?	X	?				?			8
Y	X						X	Q5.2			4
Z	X	X	X								4
AA			X								4
BB				!							1
CC	Q4.5			X		X			X		4

Figure G-8. Specific advantages of utilizing BIM: Q4.4

	Question 4.4: What do you feel are the greatest advantages to utilizing BIM?										
	Construction										
	Quantity Takeoff / Cost Analysis Benefits	Improved Construction Sequencing Planning	Improved Construction Quality	Reduced Construction Waste	Improved Constructability Analysis	Reduced Change Orders	Reduced Construction Cost	Improved Prefabrication Planning	Prevention of Trade Stacking	Reduced Requests for Information (RFI's)	Total Response
# of Responses	4	3	3	3	2	2	2	1	1	1	108
% of Companies	14%	10%	10%	10%	7%	7%	7%	3%	3%	3%	372%
A											2
B											3
C											3
D						X					3
E		X							X		7
F											3
G											1
H											1
I											2
J		X			X						9
K											3
L											5
M			X								3
N											2
O				X							4
P	X				X						6
Q											2
R			X				X				6
S	X										6
T											2
U		X						X			5
V											2
W											3
X	X		?				?				8
Y	X										4
Z				X							4
AA				X		X				X	4
BB											1
CC											4

Figure G-8. Continued

Table G-2. Verbatim responses regarding advantages of utilizing BIM: Q4.4

Company Name	Question 4.4: What do you feel are the greatest advantages to utilizing BIM?
A	Coordination.
B	1) Design and construction coordination. 2) Ability to verify the design; verify that areas meet owners requirements, verify sight lines, conduct shadow studies on building and on site, etc. 3) Ability for all team members (Designer, Owner and Constructor) to understand and agree on what we are trying to build.
C	1) Increased coordination and concept presentation to clients and contractors. 2) Increased workload for informed design using [our current] modeling software.
D	When the software gets up to speed and is user friendly. I think it will help with collision detection, work coordination and ultimately to reduce change orders.
E	1) It gives everyone on the job team a clear picture of the finished product. This is especially important for complex installations and to show the Owner what the finished product will look like. 2) It is essential for the coordination of mechanical, electrical and plumbing trades to coordinate piping, conduits, ductwork, equipment and etc. This tool will prove invaluable on my current project. 3) It requires the design team to put more details and information into the building and as a contractor, I have unlimited cut sections to view the building. 4) It helps to synchronize field crews during the construction of the building when you tie the schedule to the model. You can view what is being constructed at certain times to assure that crews are not stacked on top of each other.
F	Visualization and trade coordination.
G	Coordination of trades.
H	Planning and design.
I	Coordination. Capacity for additional information, metrics, and additional tools.

Table G-2. Continued

Company Name	Question 4.4: What do you feel are the greatest advantages to utilizing BIM?
J	BIM is a toolset whose greatest advantage is that it improves information exchange and promotes collaborative project delivery. BIM is revolutionizing what had become a fairly inefficient information exchange process in the construction industry. The visualization that comes with 3D and 4D models as well as the collaborative environment that it promotes gives BIM the opportunity to reduce wasted effort and improve efficiency at every phase of project delivery. In the design phases, improved communication and collaboration can allow owners and designers to better understand each other in terms of program requirements the owner has and design ideas the designers have. Collaborating with contractors can occur at this early stage as well. This collaboration with the contractors done in a highly visual virtual environment (3D and 4D models) can prove far more productive than traditional contractor review. In the construction phase, the virtual environment can again serve as the forum for playing out the design and identifying potential problems, schedule conflicts, or constructability issues. Clash Detection (MEP coordination in the virtual environment) is a low input, high output version of the traditional drawing overlay coordination that makes it very popular as many contractors' first leap into BIM. In the closeout phase, initiatives like COBIE (Construction Operations Building Information Exchange) and FM-10 are attempting to streamline the close-out submittal turnover process and improve the quality of the submittals themselves.
K	Speed, accuracy, and coordination.
L	Consistency, 3D visualization, comprehensive use of all data, ease of production.
M	Better understanding of the design documents intent. Should improve design document coordination and construction quality.
N	Earlier understanding of building aesthetics and performance.
O	Less conflicts, better coordination, less waste, more efficient during construction.
P	Better coordinated and more complete document sets, the potential to do away with 2D document sets entirely, quantities and constructability analysis from the modeled elements, better team building enabled by the required interaction to assemble a multi-disciplinary BIM.
Q	Integrated design and documentation.
R	Better visualization; better quality in the field; fewer field-related issues; better collaboration with the building team; more efficient and cost effective construction; better information passed to the owner.
S	Virtual building design (build the project electronically before building it physically); 3D visualization; estimating; conflict (clash detection) resolution; better coordinated design by design/building disciplines; integrated project delivery. Provide energy and performance modeling. "What-if" scenarios.

Table G-2. Continued

Company Name	Question 4.4: What do you feel are the greatest advantages to utilizing BIM?
T	Conflict identification in mechanical/architectural/marketing.
U	More detailed and accurate information; ability to plan construction sequence with greater accuracy and at higher level of detail; ability to increase prefabrication and shorten construction schedule.
V	Building the building on the computer to identify problems.
W	Collision detection prior to field. Centralized repository. Ability to energy and daylight model without fully recreating models.
X	Improves communication with clients on design issues. Improves our understanding of design solutions. Has the potential to improve quality and efficiency.
Y	Allows for Integrated Project Approach, better coordination, reduced unknowns, but most importantly, identifies costs and minimizes risk.
Z	Visualization, communication, efficiency of time and materials.
AA	So far, using BIM tools helps reduce field generated RFI's and change orders, [as well as] reducing waste compared to traditional coordination processes. Also, 3D visualization helps construction teams interpret design intent much faster.
BB	We model as we will build, in 3D. This is information rich and intelligent.
CC	One of the great benefits of a BIM program is access. We learned after our first few BIM related project that not only do we need to coordinate the physical objects into the model, but we also need to model open space as well. Equipment such as VAV boxes above the ceiling needs to have access. Many pieces of equipment need maintenance access or have [building]> code required clearances. [We] will put these clearances into the model as an object. This ensures that the owner easily maintains the finished project.

	Question 4.5: What do you feel are the greatest disadvantages or obstacles to utilizing BIM?																		
	Ability / Willingness of Others to Use BIM	Cost of Software / Hardware / Training	Ability / Willingness of Company to Use BIM	Interoperability Between Various Applications	Resistance / Adapting to Change: BIM is Too New	Difficult Learning Curve	Liability Concerns: Who Owns Shared Data?	Difficulty in Selecting Appropriate Software	Exaggerated Benefits of BIM	Extensive Time Required to Build the BIM Model	Difficulty in Manipulating Large Files	Lack of Cost Analysis Tools	Lack of MEP Families	Limitations for Engineering Analysis	Model Inaccuracies Cause Downstream Errors	No Compensation for Work Beyond Scope	No Disadvantages	Not Applicable	Total Response
# of Responses	8	8	7	7	5	5	5	3	3	2	1	1	1	1	1	1	1	1	61
% of Companies	28%	28%	24%	24%	17%	17%	17%	10%	10%	7%	3%	3%	3%	3%	3%	3%	3%	3%	210%
A		X																	1
B					X		X									X			3
C		X			X	X							X						4
D		X					X		X	X									4
E	X		X	!		X													4
F											X								1
G	X																		1
H	X		X																2
I																		X	1
J		X		X															2
K			X																1
L						X	X		X			X							4
M		X																	1
N	X		X																2
O		X						X											2
P				X															1
Q			X																1
R						X	X												2
S		X					X			X					X				4
T	Q5.4																X		2
U								X											1
V					X														1
W			X	X	X	X													4
X		X							X										2
Y				X															1
Z					X														1
AA	X			X				X											3
BB	X		X	X										X					4
CC	X																		1

Figure G-9. Specific disadvantages and/or obstacles to BIM: Q4.5

Table G-3. Verbatim responses regarding disadvantages and/or obstacles to BIM: Q4.5

Company Name	Question 4.5: What do you feel are the greatest disadvantages or obstacles to utilizing BIM?
A	Cost / Training.
B	Current contracts do not allow for (or discourage) sharing BIM data. [BIM] changes how our industry operates – many, many people are resistant to change. [Another problem is] not getting paid for doing work that is beyond traditional scope of services.
C	1) Lack of MEP "families." 2) Resistance to change. 3) Investment in software, training, hardware, and the learning curve.
D	The software is over promising what it can do. The use of it is very time intensive and adds cost to the project for MEP design. There are still some legal issues to be worked out. Once this model has been built, who owns it and what is the liability for all other parties?
E	The single greatest disadvantage to BIM is the current lack of knowledge and regulation in the industry. This is particularly true in Indiana. This is the first BIM project for most of the contractors involved on my current project. Aside from the learning curve and convincing people this is the future of design and construction, I do not see disadvantages or obstacles.
F	File size of complex models is difficult to move around and work with.
G	Having subcontractors able to participate.
H	Getting all team players to use it. Must design in BIM, not design in 2-D then convert to 3-D.
I	N/A
J	Open exchange of information. Just as improved information exchange is one of the greatest attributes of BIM, it is also one of the obstacles. There are numerous BIM programs from numerous software developers. For maximum information exchange, these programs must be interoperable. Achieving full interoperability is a challenge. Also, getting buy in on the new technologies and processes, particularly when it comes to purchasing the necessary equipment, software, and training to get your company up to speed.
K	Getting all firm members to get on board and adopt the technology.
L	Learning curve, difficulties caused by lack of sophisticated modeling tools, lack (to date) of reliable metrics/case histories/legal precedents, etc., for forecasting pricing and anticipating legal/insurance issues.
M	Upfront cost and training.
N	Unwillingness among design leaders.

Table G-3. Continued

Company Name	Question 4.5: What do you feel are the greatest disadvantages or obstacles to utilizing BIM?
O	Cost, confusion in the [BIM] market over which software to invest in.
P	Interoperability between programs.
Q	[Not] having enough people with Revit experience to fully staff project teams.
R	Learning curve, especially [with] field personnel; reluctance of design professionals to share the model.
S	Cost and time to build the BIM model; inaccuracies from the design industry; and legal issues related to development of and sharing of BIM model between design, engineering and construction teams.
T	No down side; our principals must understand the capabilities prior to selling the feature in a project.
U	(Poorly-worded question; disadvantages and obstacles are two different things.) We don't perceive any disadvantages. The greatest obstacle is identifying, selecting, and deploying tools that are the "best fit" with our business model.
V	BIM is a new technology that has not "caught on" yet.
W	Learning curve. Business process changes. Lack of software interoperability.
X	Retooling costs. Unrealistic expectations.
Y	Inoperability with other software, namely Revit and other Autodesk products.
Z	Getting started. It's a whole different way of working.
AA	Today's obstacles in using BIM include getting architects thinking, "How can I build the model such that it is more usable downstream by the construction teams and owner?" We spend a lot of time remodeling what should have been done by the architect, which is a wasteful process. Open standards for software is the other big challenge, allowing companies to use the right BIM tool for their organization and still allow the data to be used by other project team members.
BB	Obstacles are lack of interoperability and limitations of software for engineering. Disadvantages are mostly related to the need for more knowledgeable building professionals who are not currently available.

Table G-3. Continued

Company Name	Question 4.5: What do you feel are the greatest disadvantages or obstacles to utilizing BIM?
CC	Common BIM Issues: 1) Interdisciplinary conflicts are discovered prior to construction and resolved on paper. This requires costly and time consuming re-work in the field. 2) Maintenance access and code required clearances needs to be identified and confirmed. 3) Fire / Smoke damper testing and maintenance access need to be identified and confirmed. 4) The timing of various bid package issue dates will determine when the model is “handed off” from the designer to the subcontractor. Identifying this date and communicating the level of detail will provide an essential and smooth transition from design documents to shop drawings. 5) Ensuring the contractors build per the model once it is complete. [We have] a system in place that ensures success: - Involve field personnel (not just CAD technicians) during the coordination process. Field personnel can be helpful to resolve conflicts and understand the effort that goes into the coordination process, thus reinforcing the importance to build per the model. - We provide 2-D laminated color “super plot” drawings in the field to give all construction personnel access to the coordinated information. - Continual communication and meetings with the installation team to make sure the well-laid plans are followed.

	Question 5.1: Do you perceive that utilizing LEED (or other certification) has improved your company's ability to provide your clients with sustainable projects, and if so, how?									
	Rating Systems Provide Sustainable Metrics and Standards	Rating Systems Help Persuade Sustainability by Other Parties	Rating Systems Help Improve Project Planning and Development	Rating Systems Improve Environmental Responsibility Awareness	Rating Systems Help Us Provide Owner-Required Sustainability	Rating Systems Help Improve Sustainability of Non-LEED Projects	No	Not Applicable	No Response	Total Response
# of Responses	18	11	7	5	3	3	1	1	1	50
% of Companies	62%	38%	24%	17%	10%	10%	3%	3%	3%	172%
A							X			1
B	X					X				2
C	X	X								2
D	X	X								2
E									X	1
F	X					X				2
G		X		X						2
H	X									1
I		X		X						2
J	X		X							2
K				X	X					2
L	X	X								2
M	X									1
N			X	X						2
O		X		X						2
P	X		X							2
Q	X									1
R								X		1
S		X	X							2
T						X				1
U	X									1
V		X								1
W	X		X							2
X	X	X								2
Y	?									1
Z	X	X								2
AA	X				X					2
BB	X	X	X							3
CC	X		X		X					3

Figure G-10. Specific perceptions of utilizing certification rating systems such as LEED to achieve sustainability: Q5.1

Table G-4. Verbatim perceptions of utilizing certification rating systems such as LEED to achieve sustainability: Q5.1

Company Name	Question 5.1: Do you perceive that utilizing LEED (or other certification) has improved your company's ability to provide your clients with sustainable projects, and if so, how?
A	No.
B	Yes, LEED is a great tool for capturing the breadth of sustainability, as well as utilizing standardized metrics to measure the extent of sustainability implemented. Using a process of continual evaluation of sustainability, as required in a LEED project, is also utilized on non-LEED projects to provide the most sustainable solutions.
C	Yes, USGBC LEED rating system provides a common, accepted measurement tool to present and guide the project through the process (owner, architect, engineer, contractor, operator).
D	Yes, It is a starting point for discussion. It gives us a topic to inject sustainable concepts and schemes that the owner might not have entertained in the past.
E	
F	The [LEED] check list is a good starting point, but the costs are prohibitive. Usually [we] will implement LEED items without the cost for the LEED process.
G	Yes. LEED has heightened awareness and increased demand for sustainable buildings by clients who would not normally consider life cycle costs as carefully.
H	Yes. LEED establishes minimum thresholds for design and construction.
I	Yes, because it has legitimized sustainable strategies in the minds of our clients.
J	Yes. The LEED initiative is rooted in sustainability and Green construction. Its certification process ensures that LEED projects are designed, constructed, and operated in an environmentally responsible manner.
K	Most of our clients require some level of LEED now. For us, it's a requirement for doing business.
L	Yes. This is the standard by which we can say we do provide, so it becomes understandable by the client.
M	Yes, through better understanding of the sustainable benefits of complying with LEED certification.
N	Yes, we don't always push the envelope on LEED projects, but complying with LEED forces us to raise our standards and make some decisions we otherwise might not have made.
O	Yes. LEED is a good framework to get people thinking sustainably about design and construction.
P	Somewhat. It provides a benchmarking system, better information earlier, planning resources.

Table G-4. Continued

Company Name	Question 5.1: Do you perceive that utilizing LEED (or other certification) has improved your company's ability to provide your clients with sustainable projects, and if so, how?
Q	Yes, by giving us more measurable guidelines in this area.
R	N/A
S	Yes, with expertise to guide the client to make informed decisions with LEED certification.
T	LEED is the only certification [rating system] we have been involved in. However, the sustainable aspect of architectural design is at the forefront in all projects now. Owners may not want to participate in LEED, but we use many of the sustainable principles.
U	Yes; by codifying sustainability goals and objectives.
V	Yes. Four of us in this office are LEED AP's. The short time we have held this accreditation has already assisted in procuring work and speaking intelligently to clients.
W	Yes. Using a rating system provides a framework for development and construction of a sustainable project. It forces consideration of various aspects that may not have been considered without the framework.
X	Yes. The LEED certification process provides practitioners and clients with an industry standard design decision framework to achieve a sustainable project.
Y	Yes.
Z	Yes, it gives us measured goals and parameters to work in which is easier to quantify for the owner. Plus, it makes sustainability marketable.
AA	Yes, because owners are requiring this gives the device to deliver sustainable projects.
BB	LEED has certainly provided a framework for us to make a case for sustainability to our clients. By having specific benchmarks, the performance can be pushed and design success can be quantified.
CC	Absolutely. We have built sustainable projects for the past 10 years, and we learn and improve from every project. We also add to the sustainable building practices our clients set goals for.

Question 5.2: Do you perceive that utilizing BIM has improved your company's ability to provide your clients with sustainable projects, and if so, how?

	No Benefits Realized, but Potential Benefits Exist	Improved Analysis Beneficial for Sustainability	No Benefits Realized	Improved Energy Analysis	Improved Airflow Analysis	Improved Team Coordination	Improved Solar Analysis	Improved Daylighting Analysis	Improved Life-Cycle Cost Analysis	Improved Lighting / Shading / Glare Analysis	Reduced / Eliminated Errors	Improved Thermal Analysis	Total Response
# of Responses	15	9	5	3	2	2	2	1	1	1	1	1	43
% of Companies	52%	31%	17%	10%	7%	7%	7%	3%	3%	3%	3%	3%	148%
A		X									X		2
B	X												1
C		X		X	X		X			X		X	6
D			X										1
E	X												1
F		X		X					X				3
G			X										1
H	Q5.4												1
I		X											1
J		X				X							2
K	Q5.3												1
L	X												1
M			X										1
N		X		X	X		X	X					5
O	Q5.3												1
P		X											1
Q	Q5.3												1
R			X										1
S	Q5.3												1
T	Q5.3												1
U	Q5.3												1
V	X												1
W			X										1
X		X											1
Y	X												1
Z	X												1
AA	X												1
BB		X				X							2
CC	Q5.3												1

Figure G-11. Specific perceptions of utilizing BIM to achieve sustainability: Q5.2

Table G-5. Verbatim perceptions of utilizing BIM to achieve sustainability: Q5.2

Company Name	Question 5.2: Do you perceive that utilizing BIM has improved your company's ability to provide your clients with sustainable projects, and if so, how?
A	Yes, by reducing & eliminating errors.
B	We recognize the potential for BIM to improve the process and evaluation for sustainable design, but have not observed any benefit, yet. The potential to track materials, perform calculations, evaluate decisions, feasibility studies, etc., utilizing the data contained in BIM is promising.
C	Yes, see [question 5.1]. Utilize a common database (BIM) for the model and utilize this model to support more "informed" [and/or] better designs through modeling analysis (lighting, solar, shading, glare, CFD/airflow - thermal comfort, and energy analysis).
D	No.
E	We have not worked on a project that utilized both BIM and LEED, but we do perceive advantages in this process due to the advanced building modeling technology.
F	Energy modeling is key to analyzing first and life cycle costs.
G	We have not yet made that connection between BIM and LEED.
H	Not yet. I do not believe BIM and LEED have not been tied together in one software package.
I	Yes, since it facilitates designing with additional parameters.
J	Yes. First of all, BIM has improved our ability to deliver projects, period. Secondly, achieving LEED certification requires a great deal of individual attention and effort from all parties involved, from owner to designer to contractors. The collaboration that BIM promotes makes a more conducive environment for managing the highly detailed LEED certification processes and procedures than the traditional project delivery, where parties work more isolated from one another.
K	At this point, it has not been a major factor in sustainability.
L	Not enough data yet, but we have good expectations.
M	N/A
N	Sometimes. When we use our models for sun, wind, daylight, or energy studies, we can better understand issues related to energy performance.
O	N/A

Table G-5. Continued

Company Name	Question 5.2: Do you perceive that utilizing BIM has improved your company's ability to provide your clients with sustainable projects, and if so, how?
P	Somewhat. [BIM] technology has the potential to allow earlier analysis, however interoperability between solutions has hamstrung attempts so far to capitalize on this advantage.
Q	Not so much yet.
R	N/A
S	Yes, using BIM will help with visualization, and facilitating the testing for LEED performance metrics.
T	Our office has not linked sustainable practice with the BIM model to date.
U	We have not yet used BIM on a LEED or sustainable project.
V	Not to date. Possible in the future.
W	N/A
X	Yes, through the ability to improve analysis and study environmental design options.
Y	Not yet, but it is coming once we implement energy modeling and daylight harvesting software.
Z	No, but it will in the future.
AA	Not yet, but the potential is there.
BB	BIM has allowed us to pursue better methods for integrated project delivery and performance-based analytical design.
CC	Not entirely. We have primarily used BIM for hospital projects, which don't usually aim for high levels of sustainable building or LEED certification. BIM has not enhanced the sustainability of these projects.

	Question 5.3: Do you feel that BIM is changing the traditional methods of project delivery with regard to sustainable project delivery, and if so, how?											
	Improved Efficiency of Design and/or Project Delivery	Improved Team Coordination	BIM Does Have an Impact, but it Will Become More Useful as BIM Evolves	Improved Energy Analysis	Increased Ability to Acquire Data for LEED or Other Ratings System	Not Familiar with this Topic	No	BIM Does Have an Impact, but Other Factors are More Significant	Improved Preliminary Analysis	Increased Project Data for Improved Analysis	Increased Coordination of Materials Selection and Specifications	Total Response
# of Responses	10	8	6	6	6	4	3	2	2	1	1	49
% of Companies	34%	28%	21%	21%	21%	14%	10%	7%	7%	3%	3%	169%
A												0
B	X				X							2
C	X			X	Q5.1							3
D							X					1
E						X						1
F							X					1
G						X						1
H			X									1
I		X										1
J					Q5.2			X				2
K					X							1
L	X	X										2
M						X						1
N			X									1
O	X	X										2
P				X				X				2
Q	X											1
R						X						1
S					X							1
T	X	X	X						X			4
U	X	X								X		3
V			X									1
W	X		X		X							3
X			X	X							X	3
Y				X								1
Z									X			1
AA	X	X		X								3
BB	X	X		X								3
CC		X					X					2

Figure G-12. Specific potential of BIM for improving the methods of delivering sustainable projects: Q5.3

Table G-6. Verbatim responses regarding the potential of BIM for improving the methods of delivering sustainable projects: Q5.3

Company Name	Question 5.3: Do you feel that BIM is changing the traditional methods of project delivery with regard to sustainable project delivery, and if so, how?
A	Yes. A digital model has a life after construction is complete.
B	Yes. BIM has the potential to change the process and make it more efficient for LEED projects that require extensive documentation, but not necessarily as much for just sustainable design in general. Again, the extensive amount of data potentially included in a BIM model can be used to evaluate the metrics of LEED.
C	Yes. 1) See [question] 5.2. 2) Improved workflow, able to respond quicker to design changes for concepts, energy analysis, etc.
D	No.
E	I do not have the experience to give a good answer to this question.
F	What is sustainable project delivery? I'm aware of CM, CMAR, GC, DB and IPD. BIM is changing delivery methods, but it has nothing to do with sustainability.
G	Although there are changes, I have not found a change unique to sustainable project delivery.
H	Right now they are two separate issues. Eventually they will be tied together.
I	Yes. Coordination and communication between designer and constructor is improving.
J	I think green building initiatives are changing sustainable project delivery with or without BIM. I think BIM will help facilitate changes in sustainable project delivery, but I think green building initiatives are the primary driving force.
K	Yes. We plan on using other applications that work with BIM to help us track projects sustainability, such as Green Building Studio.
L	Early data, but BIM requires early and better input from our consultants, and we have found this a stumbling block on LEED projects, so hopefully both will force better opportunities for successful BIM/Sustainable projects.
M	Not familiar enough with BIM to understand how it may impact sustainability.
N	It can, but right now it's not being used specifically for energy modeling purposes, which often means that it's not modeled exactly how it needs to be modeled. There is an interdisciplinary rift between the architect and the engineer that is keeping the energy modeling knowledge from the teams building the models.

Table G-6. Continued

Company Name	Question 5.3: Do you feel that BIM is changing the traditional methods of project delivery with regard to sustainable project delivery, and if so, how?
O	Yes, [BIM] better facilitates integrated design, which is how a sustainable project should be designed/constructed. Besides, the green building modeling plug-ins for BIM software look very promising.
P	Traditional methods of project delivery for sustainable projects are changing, and BIM is assisting that change, but is not [currently] the major driver. Significant improvements are needed in interoperability between BIM packages and sustainability analysis tools before BIM can truly impact the delivery of sustainable buildings.
Q	It's starting to, by incorporating automated verification routines in the programs.
R	N/A
S	Yes, better documentation for LEED certification and implementing sustainable practices.
T	I think the BIM model has potential to aid in the sustainable design effort. For [us], at this point in time, we find the integration of sustainable design principals in our work a given. Time is critical in development of a project. The extent of BIM development for a particular effort is calculated at the outset of project development. We have had one project which was a collaboration of efforts between [ourselves] and the Construction Manager. The Construction Manager wanted to use the BIM model for marketing and explore the possible uses of an extensively developed model. One problem incorporating the BIM model into the mainstream of construction is that the majority of contractors do not have computer capacity to handle the BIM model. In a recent hospital BIM, design we had to break up the model because of the size.
U	Yes. BIM allows [for] far more detailed analysis of building design, and enables design and construction teams to apply large data sets of sustainable design information for the analysis of individual projects that previously would have cost-prohibitive to perform.
V	Not to date. Possible in the future.
W	YES! I believe BIM and sustainability are converging, and as BIM tools mature, the framework will be included within the tools. The modeling that must be done will be inherent to the tool and therefore streamline the process.
X	Yes, but slowly. Use of BIM provides design practitioners with increased capabilities with respect to environmental design analysis. In addition, we trust that use of BIM will assist in our product selection process by linking the model with specifications.
Y	Absolutely. BIM allows for analyzing many aspects of a building including specifically building performance and alternatives regarding sustainability.

Table G-6. Continued

Company Name	Question 5.3: Do you feel that BIM is changing the traditional methods of project delivery with regard to sustainable project delivery, and if so, how?
Z	Yes, we are able to analyze sustainable decisions earlier in order to decide their value to the end product.
AA	Yes, through more collaboration (IPD), the BIM tools can help teams work together to meet goals of the projects. The simulation features of BIM tools also help teams understand the projects sustainability.
BB	BIM facilitates design integration by coordinating decision making and providing a storehouse of design information. Among other things, this information can be used for building performance simulations to provide analytical feedback on the building's energy and environmental quality throughout the design process.
CC	No. BIM, if used effectively, gives the owner maximum value. It has provided the most value through overhead MEP installation. Not so much for sustainability.

Question 5.4: Do you think that improvements could be made to the BIM applications your company uses in order to better facilitate the delivery of sustainable projects, and if so, what improvements would you like to see?

	Improved and Increased Green Tools & Tips	Improved and Increased Links to LEED	No Response or N/A	Improved Interoperability	Reduced Reliance on External Applications	Reduced Software Costs	Increased Ability for Assessing Code Compliance	Improved File Extension Standards	Improved User Friendliness	Increased Ability to Handle Large File Sizes	Increased Precision and Accuracy	Increased Speed	Do Not Know	Total Response
# of Responses	8	7	7	7	2	2	1	1	1	1	1	1	1	40
% of Companies	28%	24%	24%	24%	7%	7%	3%	3%	3%	3%	3%	3%	3%	138%
A		X		Q5.3										2
B		X		X										2
C				X				X						2
D						X			X					2
E													X	1
F					X	X								2
G			X											1
H		X												1
I	X													1
J	X				X									2
K	X											X		2
L	X													1
M			X											1
N				X										1
O			X											1
P				X										1
Q	X													1
R			X											1
S			X											1
T										X				1
U	X													1
V			X											1
W	X	X												2
X	X			X										2
Y		X												1
Z		X												1
AA		X												1
BB				X							X			2
CC			X				Q4.5							2

Figure G-13. Specific recommendations to improve BIM for sustainability: Q5.4

Table G-7. Verbatim recommendations to improve BIM for sustainability: Q5.4

Company Name	Question 5.4: Do you think that improvements could be made to the BIM applications your company uses in order to better facilitate the delivery of sustainable projects, and if so, what improvements would you like to see?
A	Yes. 40% of LEED Credits can be tracked and analyzed through a Revit Model. There should be better software data integration between these two.
B	Yes. Perhaps additional software that extracts material costs that are related to LEED requirements, etc. Interoperability needs to be improved to allow design to be exported to any analysis package (daylighting, energy modeling, etc.).
C	1) Tighter integration of BIM software with supporting analysis software. 2) Better standards and utilization of gbXML. 3) Tighter controls of architectural model to support use by REVIT MEP and associated programs.
D	Get the software to be cost affordable and not so user unfriendly, and then we can work on the sustainable side.
E	I do not know of any improvements at this time.
F	Integral cost, schedule and energy options in the modeling software.
G	N/A
H	Software that ties BIM and LEED together.
I	Yes. Tools that address specific metrics that are used in sustainable design would be helpful.
J	Yes. Many BIM applications are fairly new and almost all BIM applications are continually [changing] with the needs of the industry. I think we will see some of these applications begin to incorporate modules for management of sustainable project delivery.
K	Yes. More speed with 64-bit code and more online video tutorials.
L	Yes. Revit could have more explicit sustainability "pointers". Our firm should also explore available lateral applications.
M	N/A
N	The link from BIM to energy modeling programs needs more work in fixing bugs and in tracking energy related data.
O	N/A

Table G-7. Continued

Company Name	Question 5.4: Do you think that improvements could be made to the BIM applications your company uses in order to better facilitate the delivery of sustainable projects, and if so, what improvements would you like to see?
P	Yes, where should I start. First, exports from BIM applications like Revit into tools like Ecotect, GBS, or IES need to actually map all applicable values to the analysis models in those programs. Currently, things like materials (which have a MAJOR impact on building performance) do not map at all. This isn't acceptable. Secondly, changes made in these analysis programs must be able to map back to tools like Revit. We need a non-linear workflow enabled by the software. I should be able to export from Revit to Ecotect, only fill out information that is NOT defined in Revit already, and run my simulations. Any information created or generated in the analysis program that relates to modeled elements should be able to be exported back into Revit so future exports from Revit will have that information populated already. Also, any changes to things like materials, size of shading devices, etc. should have some ability to map back into Revit as well, so that optimizations made in Ecotect do not require duplicate effort to update the Revit model.
Q	More directed sustainability guidelines.
R	N/A
S	Perhaps. We have not yet used BIM in relationship to sustainability.
T	I think the BIM model has potential to aid in the sustainable design effort. For [our company], at this point in time, we find the integration of sustainable design principals in our work a given. Time is critical in development of a project. The extent of BIM development for a particular effort is calculated at the outset of project development. We have had one project which was a collaboration of efforts between [ourselves] and the Construction Manager. The Construction Manager wanted to use the BIM model for marketing and explore the possible uses of an extensively developed model. One problem incorporating the BIM model into the mainstream of construction is that the majority of contractors do not have computer capacity to handle the BIM model. In a recent hospital BIM design we had to break up the model because of the size.
U	Greater maturity in available sustainability analysis tools.
V	
W	Yes. Since BIM utilizes a centralized Database as its core, the tracking, measuring and reporting required by various rating systems such as LEED or Green Globes could be incorporated into the tools to reduce the administrative burden.
X	Better interoperability between BIM authoring applications and energy analysis tools. Wizards which assist the practitioner in determining what application to use to in facilitating environmental design studies.

Table G-7. Continued

Company Name	Question 5.4: Do you think that improvements could be made to the BIM applications your company uses in order to better facilitate the delivery of sustainable projects, and if so, what improvements would you like to see?
Y	Integration capability of LEED, Energy Star and CHPS rating systems analysis. This could help determine quickly where a project may fall with the designated point systems based on the ["I" of BIM, Information] incorporated within the model.
Z	The ability to submit LEED or certification documentation directly from the BIM or analysis application to avoid additional administrative steps.
AA	The simulation part of BIM tools is the important part of sustainable projects. This is more important to designers during the design process, but contractors should have a way to track LEED requirements during construction.
BB	There is still a big need for improving interoperability between BIM and analysis software to maximize the benefit of using model data to influence design. Furthermore, the level of precision and accuracy of some analysis tools is not conducive to the design process. A balance is needed.
CC	

APPENDIX H
THE EFFECTS OF SUSTAINABILITY LEGISLATION ON THE DESIGN AND CONSTRUCTION PROFESSIONS

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Abstract

This research explores the extent to which sustainability legislation and incentives are beginning to impact the Architecture / Engineering / Construction (AEC) industry. How, where, and why are voluntary sustainable design measures becoming standard practice due to the increasing pressures from environmentalist concerns, legal pressure, and owner requests? What are the legal stipulations which will affect the future practice of the design and construction professions in specific jurisdictions where the law prescribes it? This document identifies specific state and municipal legislative acts, as well as specific buildings built as a result of such legislation, as precedence studies, in order to explore the effects of sustainable mandates and incentives on the AEC industry.

Introduction

Many states, including Arizona, California, Connecticut, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, and Rhode Island, have begun to introduce requirements or recommendations regarding sustainable construction techniques for state-owned buildings. Likewise, numerous municipalities, including Atlanta, Austin, Boston, Boulder, Chicago, Dallas, Los Angeles, Portland (Oregon), San Diego, San Francisco, San José, and Seattle, have adopted similar measures that require or recommend that city-owned buildings be built according to green building criteria. Many localities also have created incentive programs for privately-owned green building construction, including the use of direct subsides, density bonuses, and expedited permitting. What are the specific details regarding recent legislation and what impact might they have on the building design and construction professions?

First, this research document examines five (5) states in which legislation has recently been passed that will require sustainable methods be utilized in the design and construction process. What types of buildings do the legislation address and what is required of them? What are some examples of recently constructed buildings which have already displayed positive benefits of such legislation? Then, this research will examine a series of executive orders which also require sustainable methods be utilized in certain types of municipal buildings and explore what exactly these laws stipulate. Finally, this research will present five (5) extremely progressive city-wide initiatives and the impact they are having on the local scale. Figure H-1 shows the states which have enacted state-wide sustainable legislation, and Figure H-2 shows the states which have enacted executive orders mandating sustainable practices. Both figures were obtained from the AIA.org article: *Architects and Sustainable Design-Green Building Executive Orders in the State*s (AIA 2007).

Figure H-1. State legislation requiring sustainable design and construction

Figure H-2. Executive orders requiring sustainable design and construction

State Legislation Mandating Sustainable Design and Construction

Arkansas

On March 29, 2005, Arkansas passed House Bill 2445 and was confirmed by the Senate on April 6, 2005. The bill is entitled An Act to Promote the Conservation of Energy and Natural Resources in the Design of State Building Projects Through the Use of Sustainable Building

Rating Systems. It requires state agencies initiating or financing a public building project or rehabilitation project to consider the utilization of Leadership in Energy and Environmental Design (LEED) or Green Globes rating systems whenever possible and appropriate. The bill also establishes a Legislative Task Force on Sustainable Building Design and Practices. It goes on to mention that the Arkansas State Government spends in excess of seventy million dollars annually on natural gas and electricity and that those expenses are increasing at a rate of 4% per year over the last ten years. The Arkansas Legislature adamantly believes it is in the best interest of the State to initiate a process to encourage improved building practices in order to reduce energy expenditures and environmental impacts (Arkansas Legislature 2005).

Connecticut

House Bill 5848 (Public Act 06-187), passed in October 2006, mandates that all state facilities, exempting schools, parking garages, and maintenance facilities, valued at over $5 million must comply with green buildings standards (Connecticut Legislature 2006). The new green standards have not yet been drafted by the state and will be comparable to a LEED Silver Rating or a Two Globes rating by Green Globes. Until the state draws up its own specifications, it is using either rating system for certification on its public projects. All projects must also exceed the current energy efficiency standards by at least 35%. Work is currently underway to write legislation to include the greening of Connecticut public schools (Greer 2007).

Maryland

On March 26, 2005, Maryland passed House Bill 196 and was confirmed by the Senate with SB 92 on April 4, 2005. This legislation requires that state-funded building projects meet high-performance building standards by either achieving a minimum of a Silver LEED rating (33 out of 69 possible points), achieving at least a two globe rating according to the Green Building

Initiative's Green Globes program, achieving at least a comparable numeric rating according to a similar rating system, or by meeting nationally recognized, consensus-based, and accepted green building guidelines, standards, or systems approved by the state (Maryland Legislature 2005).

Nevada

Assembly Bill No. 3, signed on June 17, 2005 by Governor Guinn, requires that publicly funded state buildings must be certified or must meet the equivalent of the base level or higher in accordance with LEED or an equivalent standard. In addition, every other year at least two state-financed public buildings must be designated as demonstration projects, and when completed, must meet or exceed silver LEED certification or an equivalent standard. It goes on to specify a series of energy usage requirements similar to LEED or Green Globes that must be met regardless of the certification system used to verify the environmentally sustainable features of new public construction (Nevada Legislature 2005).

Washington

Engrossed Substitute Senate Bill (ESSB) 5509, signed on April 8, 2005 by Christine Gregoire, requires state-funded projects over 5,000 sq ft, including school district buildings, to use high-performance building standards. ESSB 5509 states that all major facility projects of public agencies receiving any funding in a state capital budget must be designed, constructed, and certified to at least the LEED Silver standard. Public schools have the option of meeting the LEED Silver requirements or by utilizing the Washington Sustainable School Design Protocol. Public agencies are required to monitor and document ongoing operating savings resulting from sustainable design and construction. The Bill emphasizes the Washington legislature's belief that public buildings can be built and renovated using high-performance methods which have been shown to that save money by reducing energy and utility costs, improve school performance by increasing student test scores, and make workers more productive by reducing worker absenteeism (Washington State Legislature 2006).

State Executive Orders Mandating Sustainable Design and Construction

Arizona

Executive Order 2005-05, signed on February 11, 2005 by Governor Janet Napolitano, specifies that all new state-funded buildings must acquire at least 10% of their energy from a renewable source including solar, wind, thermal, or biomass, and could offset this by purchasing renewable energy credits. The design of new state-funded buildings must include standards for energy efficiency and must attain a LEED Silver rating or better. However, the executive order is only applicable to the Executive Branch of the state government, with a simple suggestion that the other state government branches comply (Napolitano 2005).

More recently, on January 11, 2007, the Arizona House Legislature introduced House Bill 2275. In a move far wider reaching than the executive order from two years previous, it would require all of Arizona's cities and towns to adopt and annually update a building energy code for residential and commercial construction that conforms to the International Energy Conservation Code (IECC) adopted by the international code council (Arizona Legislature 2007).

Many local Arizona firms have already acknowledged the impact that the growing sustainable buildings market and related legislation will have on the construction industry. As of September 2006, Adolfson & Peterson Construction in Tempe, AZ employed 20 LEED Accredited Professionals (LEED APs) and Kitchell Contractors of Phoenix employed 22 LEED APs. Other local firms are increasing the number of LEED APs; many local subcontractors have begun educating their personnel about LEED and establishing programs that are LEED-compliant in order to gain competitive advantages as sustainable legislation begins to take effect (Popeck 2006).

California

Executive Order S-20-04, signed on December 14, 2004 by Governor Arnold Schwarzenegger, specifies that California publicly owned and funded buildings reduce grid-based energy purchases by 20% by 2015. Items which must be considered include: "designing, constructing and operating all new and renovated facilities to meet or exceed LEED Silver certification; identifying the most appropriate financing and project delivery mechanisms to achieve these goals; seeking out office space leases in buildings with a U.S. EPA Energy Star rating; and purchasing or operating Energy Star electrical equipment whenever cost-effective." (Schwarzenegger 2004)

Colorado

Executive Order D 005 05, signed on July 15, 2005 by Governor Bill Owens, requires that all state agencies and departments must "evaluate their current business operations and develop and implement policies and procedures to promote environmentally sustainable and economically efficient practices." (Owens 2005) State agencies are to adopt LEED standards, where applicable, for all existing buildings and new construction and must institute an energy management program to monitor utility usage and associated costs. The executive order also establishes the Colorado Greening Government Coordinating Council which will include representatives from each state agency and department. The Council is responsible for development of programs and policies intended to reduce energy consumption throughout state agencies. The agencies, in turn, must submit an annual report to the Council which outlines relevant projects and their resultant environmental and fiscal benefits.

Florida

Executive Order 05-241, signed on November 10, 2005 by Governor Jeb Bush, suggests that the state investigate methods for increasing conservation and energy efficiency. Included in the energy plan is a requirement that the State must evaluate all applicable laws, regulations, executive orders, and even the Florida Building Code, in order to assess the value of the savings resulting from the executive order (Bush 2005). Subsequently, the State Department for Environmental Protection has since recommended that the State require all new government buildings to meet LEED standards (AIA 2007). More recently, on July 13, 2007, Governor Charlie Crist signed three aggressive executive orders in regard to greenhouse gas emissions, vehicular emissions, and efficient electricity production. But in regard to the construction industry, the most critical aspect of Crist's recent decisions is that the Florida Building Code must be revised to require construction to be 15% more fuel efficient by 2009 (Loder and Pittman 2007).

Maine

Governor John Baldacci signed an executive order on November 24, 2003 which stipulates that any state funded construction or renovation is required to adhere to the most current version of LEED. It includes an exception which stipulates that additional expenses resulting from improving sustainability must be justified as the most cost efficient across the building life cycle, in consideration of not only first costs, but also operating costs (Baldacci 2003). A separate executive order specifically addresses sustainability in public school construction.

Michigan

Executive Order 2005-4, signed on April 22, 2005 by Governor Jennifer M. Granholm, states that all Executive Branch buildings will be required to meet an energy savings target as set by the Department of Management and Budget. The targets are to attain a 10% reduction in energy use by December 31, 2008 and a 20% reduction in grid-based energy purchases by December 31, 2015, when compared to energy use and energy purchases for the state fiscal year ending September 30, 2002. The executive order sets as a minimum LEED Certification (26 out of 69 possible points) for all new construction and renovation for all Executive Branch buildings (Granholm 2005).

New Jersey

New Jersey has implemented a wide variety of legislation which strive for improved sustainability of state funded building construction and renovations. Executive Order 24, signed on July 29, 2002 by Governor James E. McGreevy, requires all New Jersey public schools to incorporate LEED 2.0 in order to achieve energy efficiency and sustainability (McGreevey 2002). Assembly Bill 3841, filed on December 14, 2006, mandates that new state buildings achieve LEED Silver certification (Waste News 2007a). Also filed on December 14, 2006 was Assembly Bill 3852, which mandates that state government agencies be carbon-neutral by 2012 (Waste News 2007a). Assembly Bill 1633, signed by the governor on January 12 2006, addresses New Jersey brownfield sites and analyzes the measures taken for remediation in annual inventory and progress reports (Waste News 2007b). More recently, Senate Bill 2146 requires that all state buildings over 15,000 sq ft receive LEED Silver certification. (New Jersey Legislature 2006a). Also, Senate Bill 2152 would require the creation of a green-building sub-code to supplement the State Uniform Construction Code (New Jersey Legislature 2006b).

New Mexico

Executive Order 2006-001, signed on January 16, 2006 by Governor Bill Richardson, mandates that all new and renovated Executive Branch buildings over 15,000 sq ft and/or using over 50 kWh at peak times be LEED Silver certified. All other new construction, renovations, repairs, and replacements of state buildings must utilize cost effective, energy efficient, green building practices to the maximum extent possible. The executive order also specifies that city planning be done with greater care, specifically in regard to siting new government and school facilities with respect to existing infrastructure to minimize energy usage and environmental impact (Richardson 2006).

New York

Executive Order 111, signed in June 2001 by Governor George Pataki, encouraged state agencies to be more energy efficient and environmentally aware. With regards to State Buildings Energy Efficiency Practices, the Order requires that, to the maximum extent practical, "the design, construction, operation and maintenance of new buildings, state agencies and other affected agencies shall… follow guidelines for the construction of green buildings, including guidelines set forth in Tax Law 19, which created the Green Buildings Tax Credit, and the U.S. Green Building Council's LEED rating system." (Pataki 2001) State agencies and all other affected entities must also employ energy efficiency practices and strive to meet the ENERGY STAR building criteria throughout the operation and maintenance of all buildings that they own, lease, or operate (AIA 2007).

Pennsylvania

House Bill 3047 was sent to the House Committee on Environmental Resources and Energy on Oct. 18 2006. It specifies that all "major facility projects" achieve specified levels of high performance building standards. The Bill defines "major facility project" as any of the following: “a State-funded new construction project in which the 13 building to be constructed is larger than 10,000 gross square feet; a State-funded building renovation project where the State funding exceeds either 50% of the construction cost or $500,000 in State funds. A State-funded commercial interior tenant fit-out project that is larger than 10,000 square feet of leasable area” (General Assembly of Pennsylvania 2006). This aspect of the Order increases its scope substantially compared with much other recent legislation in that *all* federal buildings must comply with such environmental standards. The Bill also requires that all major facility projects receive an Energy Star Rating or 85 or above (General Assembly of Pennsylvania 2006).

Rhode Island

Executive Order 05-14, signed on August 22, 2005 by Governor Donald L. Carcieri, requires that the design, construction, operation and maintenance of any new, substantially expanded, or renovated public building must achieve LEED Silver certification. It is interesting to note here that “public buildings” are not exclusive of Executive Branch buildings, but are defined as “any building owned by the State or any department, office, board, commission, or agency thereof, including state-supported institutions of higher learning” (Carcieri 2005).This exemplifies a significant similarity to the Pennsylvania HB 3047, which also requires all federal buildings adhere to sustainable standards. A final stipulation in Executive Order 05-14 is the evaluation of feasible energy efficiency measures on the basis of their total life-cycle costs for new or renovated public buildings (Carcieri 2005).

Wisconsin

Executive Order 145, signed on April 11, 2006 by Governor Jim Doyle, mandates that the Department of Administration (DOA) establish and adopt guidelines based on LEED for new construction and LEED-EB for existing state facilities, office buildings/complexes, and campus buildings within 6 months (Doyle 2006). The DOA, in consultation with other agencies, set energy efficiency objectives for 2007-2009, with a goal for a 10% energy reduction per square foot by 2008, and a 20% energy reduction per square foot by 2010 (State of Wisconsin DOA 2006). The DOA will also work with the Building Commission and Energy Center of Wisconsin to ensure that new facilities are constructed to be 30% more energy efficient than commercial code. The Order also strives to develop a set of sustainable building operation guidelines, including benchmarking and annual reporting to measure and ensure energy efficiency and sustainable design of new facilities (State of Wisconsin DOA 2006).

Municipal Case Studies

Many cities across the Unites States have put into place legislation mandating sustainable building guidelines for municipal design and construction including, Atlanta, Austin, Boston, Chicago, Dallas, Houston, Los Angeles, Seattle, and many more (Buildings.com 2005). Included below is a discussion regarding five case studies from unique cities with strict sustainability legislation.

Goodyear, AZ

The first public school building in Arizona to achieve a LEED Silver rating as a result of Governor Napolitano's Executive Order 2005-05 is the Desert Edge High School in the Agua Fria Union High School District. Emc2 Architects and Adolfson & Peterson Construction collaborated on this 90,000 sq ft expansion, which is 28% more energy efficient than a typical high school with estimates of energy cost savings of about $58,000 a year, savings which increase annually as energy costs continue to rise. Construction techniques which were utilized diverted over 84% of the construction waste from the landfill. Water conservation techniques are estimated to save approximately one million gallons of water per year resulting in $4,000 in annual savings. The school district worked with Green Ideas Environmental Building

Consultants to incorporate a high-efficiency central cooling and heating plant along with an extensive daylighting scheme and daylight sensors for the classroom areas to reduce energy usage (Popeck 2006).

New York City, NY

New York City Local Law 86, also known as the Green City Buildings Act, became effective on January 1, 2007. The act is significant to the construction industry because it will affect a wide array of occupancy groups as well as many of New York City's new and renovated municipal buildings by requiring that they achieve the high standards of either LEED-NC or LEED-EB in sustainable building design, construction and operation (NYC Legislature 2005).

The act has the potential to dramatically affect the New York construction industry because the building materials and architectural design required by the act are sometimes substantially different than those used in traditional buildings. The City owns approximately 1,300 buildings and leases over 12.8 million square feet of space, and the New York City Council has estimated that this legislation will affect approximately $12 billion in construction over the next ten years (Greer 2007). As presented in Table H-1, various building types and construction cost will influence the level of sustainability required under New York City's Green City Buildings Act.

In fact, this law has inspired individual agencies to establish sustainable building guidelines for their building construction programs: The Department of Education and School Construction Authority (SCA) has recently revised its standards with the help of Dattner Architects of New York, DVL Consulting Engineers of Hackensack, and New York's Viridian

Table H-1. Requirements of the NYC Green City Buildings Act

Estimated Construction Cost	Occupancy Group	LEED Certification Required	Additional Energy Cost Reduction
> $2 million but < $12 million	B-1, B-2 ,C ,E, F-1a, F-1b, F-3, F-4, H-1	Silver or better	N/A
	G, H-2	Certified or better	N/A
> $12 million	G	Certified or better	Minimum 20% reduction in energy costs. Additional 5% or 10% (whichever is achievable) reduction required if payback within 7 years.
> $12 million but < $30 million	B-1, B-2 ,C ,E, F-1a, F-1b, F-3, F-4, H-1	Silver or better	Minimum 20% reduction in energy costs. Additional 5% reduction required if payback within 7 years.
	H-2	Certified or better	Minimum 20% reduction in energy costs. Additional 5% reduction required if payback within 7 years.
> $30 million	B-1, B-2 ,C ,E, F-1a, F-1b, F-3, F-4, H-1	Silver or better	Minimum 25% reduction in energy costs. Additional 5% reduction required if payback within 7 years.
	H-2	Certified or better	Minimum 25% reduction in energy costs. Additional 5% reduction required if payback within 7 years.

Energy & Environmental to create the Green Schools Rating System with standards equal to LEED Certified or better. A major objective for the development of the guidelines was to reduce the cost and complexity of installing green measures. Some architects, including New York-based AKRF, are already designing projects for the SCA using the new standard. Michael Deane, Turner Construction’s East Coast manager for sustainable construction, finds it inevitable that this type of legislation will spill over into the private sector. The Director of D.C.’s Office of Environmental Coordination Robert Kulikowski believes this new law “is critical because it impacts a variety of issues that are important for a sustainable New York.” (Greer 2007) Unfortunately, “not all contractors are thrilled with the move toward more green building, largely because of concern about higher costs”, says Jason Kliwinski, Director of Sustainable Design and Operations at the Prisco Group, an architect group in Hopewell, N.J. "The perception is that green building codes will increase the cost of doing business. It actually costs the same or less" in the long run (Greer 2007).

District of Columbia

The District of Columbia Legislature Bill 515 would establish the Green Building Act of 2006, which specifies revisions of construction codes for the inclusion of sustainable building practices. The Bill would set up the Green Building Fund, which would provide staffing and operation costs for technical assistance, plan reviews, inspections, and monitoring of green buildings. It also stipulates that priority leasing should occur in buildings that meet the required standards. In addition, it would provide education, training, outreach, and incentives to the public and private sectors on green building practices (DC Legislature 2006). It was finally signed by the Mayor on December 28, 2006 (Waste News 2007).

Beginning in 2010, all new and substantially improved private and publicly owned commercial buildings and postsecondary educational facilities greater than 50,000sq ft will have to meet or exceed LEED-NC or LEED-CS Certified standards. The District of Columbia is the first district to make such requirements for privately-owned buildings. All other public educational facilities will be required to meet the LEED for Schools Certified standards by 2012 (DSIRE 2007).

Despite the fact that the District of Columbia's Green Building Act of 2006 will not begin to take effect until 2010, many local design firms are already preparing for the changes it will require. Alberto Cavallero, design principal in KlingStubbins Washington, D.C., office, says he expects “the new LEED requirements will particularly affect the design of buildings such as high-end residential projects for which aesthetics drive value. These regulations will likely cause a shift in the types of building amenities owners choose to accentuate. Because LEED point-garnering attributes such as sun shades, wind turbines, rooftop gardens and improved views will now be required, owners will likely ask architects and engineers to get more creative with design" (Bacon 2007). The new requirements are already having an impact on the local AEC community. In one project, the designers of 1225 Connecticut Avenue, a $30 million renovation of an eight-story office building in Washington's downtown business district, were asked by the owner to go back and re-design the renovation to meet LEED-certified standards, long after the original design documents were already complete (Bacon 2007).

Scottsdale, AZ

Resolution 6644, signed on March 22, 2005 by Mayor Mary Manross, is the first city-wide law in the nation which requires that all municipal buildings of any size attain LEED Gold Rating (39 out of 69 possible points) and attempt to achieve a Platinum Rating (52 or more points). The Scottsdale City Council has required a payback period related to first cost increases in expenses due to sustainable design measures of no more than five years. If this extremely high goal is simply unattainable for a particular project, the City Council will recommend a more suitable LEED rating, or possible simply recommend which sustainable aspects of certification are the most viable for that specific project (Scottsdale Arizona Legislature 2005).

Portland, OR

Scottsdale Arizona's Resolution 6644 requiring LEED Gold for municipal buildings has prompted sustainability advocates in Portland, Oregon to revise its 2001 Green Building Policy on April 27, 2005 to require that all city-owned buildings achieve Gold level certification. Previously, the legislation stipulated a LEED Silver for federally funded projects. Portland is now only the second city in the nation to require such a high standard for design and construction. Vancouver, British Columbia is the only other North American city to put into place such stringent legislation. Portland's Revised Green Building Policy also stipulates that new city-funded private sector buildings and major renovations to city-owned buildings also acquire a LEED Silver rating, with support provided to new private building projects for assistance in achieving LEED Silver. The revised Green Building Policy goes on to also require that all municipal buildings exceed the Portland baseline code requirements for waste recycling by 75%, and exceed the baseline requirements for stormwater management, water savings, and energy savings by 30% (Portland Oregon Legislature 2005).

In January 2006 Howard Hall of Oregon's Lewis & Clark College received the first LEED Gold rating in the state earning 45 out of 69 possible points (52 are required for Platinum). According to the college, the 51,000 sq ft building designed by Thomas Hacker Architects and built by Portland-based Hoffman Construction Co. enjoys a 40% reduction in energy consumption by utilizing techniques such as a raised floor system for HVAC circulation and energy efficient elevator systems. Howard Hall is the second building on the Lewis & Clark campus to earn a LEED rating. Roberts Hall, a 24,700 sq ft residential complex, earned a LEED Silver rating in 2002 under the original Green Building Policy of 2001 (DJC 2006).

Incentives for Sustainable Design and Construction

In addition to the wide array on mandated, legislated requirements for designing and constructing sustainably, there seems to exist just as many government incentive programs to encourage sustainability. In the U.S., about 53 cities either offer incentives for sustainability or require some degree of sustainability (Ramstack 2007). Some sustainability advocates prefer that legislation be enacted in order to force more intelligent construction methodologies, whereas others in the AEC community prefer incentives, so as not to restrict the design process while providing leeway for project constraints such as monetary limitations or feasibility issues. While this topic is beyond the scope of this paper, it is intriguing enough to note for further reference that a fairly thorough collection of sustainability-related incentives can be found in the AIA State

Government Network 2006 report titled *State of Washington High Performance Public Buildings Law*, pages 40-53 (AIA State Government Network 2006).

Summary

Many state, county, and city governments have demonstrated their commitment to green building practices. There exists a large amount of legislation which encourages sustainable design and construction, and even more legislation which requires it. In many locations, such legislation typically applies to government buildings, but in other locations, the public and private sectors are also becoming subject to sustainability requirements. Some legislation requires LEED; whereas other legislation recommends LEED, Green Globes, or similar; whereas other legislation even calls for the authoring of a new rating metric specific to that municipality. Additionally, as an increasing number of building owners are beginning to require certain degrees of sustainability for their projects when not necessarily required by law, sustainability seems to have migrated from a niche market into the mainstream.

The current increase in sustainable building legislation is beginning to have a substantial impact on both the design and construction aspects of the industry. Some professionals are embracing the movement as a potentially profitable emerging market, whereas others are viewing it as burdensome to an already difficult profession. Some view it as an ethical decision to be environmentally responsible.

As sustainable practices and techniques proliferate into the mainstream, the expenses required in order to achieve sustainability have declined, and will likely continue to decline. As sustainability standards become more commonplace, the difficulty in achieving such standards have decreased, and will likely continue to decrease. As sustainability laws are eventually incorporated into more and more buildings codes, they will begin holding AEC professionals to a higher degree of accountability by legislating higher standards. Hopefully this recent spur of legislation will preclude a future where it is required that all building projects meet or exceed sustainability benchmarks; a future when environmental responsibility becomes second-nature to AEC professionals and their clients; a future when sustainable building practices become the standard procedure.

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BIOGRAPHICAL SKETCH

Mr. Christopher M. Hostetler has always seemed to have a natural inclination to design and create, whether building with Legos as a child, or while concocting culinary creations throughout the years in the restaurant and hospitality industry. Creating synergies from combining building blocks or raw ingredients in meaningful ways to produce the final product, it comes as no surprise that he became attracted to the study of architecture shortly after enrolling in his first drafting class in high school.

Fascinated by the intricacies which merge the aesthetic and the practical to elevate great architecture to the level of occupiable art, he decided to pursue a Bachelors degree in Architecture at the University of Florida, where he became interested in sustainability, BIM, design-build methodologies, historic renovation, brownfield reclamation, and urban restoration. Striving to learn more concerning not only the design, but also the construction aspects of the built environment, he pursued a Master of Science in Building Construction, which he recently attained from the University of Florida.

He is currently awaiting decision from several possible employers, anticipating the potential to utilize his knowledge and skills to help improve the overall sustainability of the design and construction professions.