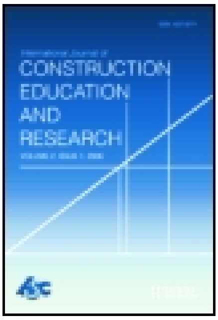

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BIM for Sustainability Analyses

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Buildings consume close to 40% of total energy used in the United States and account for 30% of greenhouse gas emissions. With the rising cost of energy and growing environmental concerns, the demand for sustainable buildings with minimal environmental impact is increasing. The most effective decisions related to the sustainable design of a building can be made in the early design and preconstruction stages. In this context, Building Information Modeling (BIM) can aid in performing complex building performance analyses to ensure an optimized sustainable building design. This research project investigated the viability of BIM-based sustainability analyses. The objectives were: 1) determination of current state and benefits of BIM-based sustainability analyses; 2) evaluation of various building performance analyses softwares; and 3) development of a conceptual framework to illustrate the use of BIM for sustainability analyses throughout the project life-cycle. Necessary data were collected via a questionnaire survey, a case study and semi-structured interviews. It is expected that the research findings would be useful for architecture and construction organizations interested in using BIM technology for sustainable design.

Keywords building information modeling, building performance analyses, green building ratings, sustainability analyses, sustainable design

Introduction

In the United States, commercial and residential buildings consume close to 40% of total energy, 70% of electricity, 40% of raw materials, and 12% of fresh water supplies, and account for 30% of greenhouse gas emissions (Autodesk, 2008). The rising cost of energy and growing environmental concerns have pushed the demand for sustainable buildings with minimal environmental impact through the use of environmental sensitive design and construction practices (Autodesk, 2005). Organizations such as the U.S. General Services Administration (GSA) are increasingly requiring that architects, planners, and constructors meet these energy codes in the delivery of federally owned buildings. States such as Florida are following suit, requiring all State owned buildings to meet standardized energy requirements (Autodesk, 2008). This type of "green legislation," together with the increase in green building construction, is forcing architects, planners, and builders to consider the environmental impact of the buildings they design and construct (Schueter & Thessling, 2008).

The most effective decisions related to the sustainable design of a building can be made in the early design and preconstruction stages. Traditional CAD planning

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environments typically do not have the capability of performing such analyses in early stages of design development (Azhar *et al.*, 2009). Building performance analyses are typically performed, if at all, after the architectural design and construction documents have been produced. This lack of continuous analysis of substainability in the design process leads to an inefficient process of retroactively modifying the design to achieve a set of performance criteria (Schueter & Thessling, 2008). In order to assess building performance in the early design and preconstruction phases realistically, access to a comprehensive set of knowledge regarding a building's form, materials, context, and technical systems are required. Because Building Information Modeling (BIM) allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures and performance analyses to be performed throughout the design process (Autodesk, 2008; Schueter & Thessling, 2008).

For example, architects can use a building information model to analyze a building's mass and form to optimize envelope and balance glazing ratios. Engineers can use this model to reduce energy demands through energy modeling, which uses the 3D model to calculate light reflectance and penetration. Contractors can analyze site conditions, including wetlands and protected habitats, and use the site model to coordinate logistics better to eliminate potential issues. Subcontractors can use BIM technology to reduce waste and combine shipments to further reduce carbon footprints (Hardin, 2009).

Since 2007, the GSA has required BIM use on all major projects and, although not required at this time, they are encouraging "accurate energy estimates in the design process" (Autodesk, 2008). These regulations, which are often implemented to reduce life cycle costs, can have potentially significant financial implications on design, construction, and operating costs (Autodesk, 2005).

BIM can reduce the costs associated with sustainability analyses by making the information required for sustainable design, analysis and certification routinely available simply as a byproduct of the standard design process (Autodesk, 2005). BIM provides the opportunity to realize numerous benefits throughout the project conception, design, construction, and post-occupancy phases of a building (Azhar *et al.*, 2008). Linking the building information model to energy analysis tools allows for evaluation of energy use during the early design phase. This is not possible using traditional 2D tools, which require that a separate energy analysis be performed at the end of the design process, thus reducing the opportunities for the early modifications that could improve the building's energy performance (Azhar *et al.*, 2009).

Research Objectives, Scope and Methodology

The main objective of this research was to explore the viability of BIM for sustainability analyses. The sub-objectives were: 1) determination of current state and benefits of BIM-based sustainability analyses; 2) evaluation of various building performance analyses softwares; and 3) development of a conceptual framework to illustrate the use of BIM technology for sustainability analyses throughout the project life-cycle. The research scope was limited to commercial and healthcare building projects. The necessary data were collected via literature review, a questionnaire survey, a case study, and semi-structured interviews with industry professionals. The detailed methodology for each sub-objective is explained in the relevant sections.

BIM-Based Sustainability Analyses

Evaluating building performance based on the graphic representations of conventional CAD or object-CAD solutions requires a great deal of human intervention and interpretation. This renders the analyses too costly and/or time-consuming (Autodesk, 2005). A building information model represents the building as an integrated database of coordinated information. Beyond graphically depicting the design, much of the data needed for supporting sustainable design is captured naturally as design of the project proceeds. In addition, the integration of the building information model with performance analyses tools greatly simplifies the often cumbersome and difficult analyses. This approach gives architects easy access to tools that provide immediate feedback on design alternatives early on in the design process.

Hardin (2009) established three main areas of sustainable design with a direct relationship to BIM. These areas are "material selection and use," "site selection and management," and "systems analysis." In addition, Krygiel and Nies (2008) indicated that BIM can aid in the following aspects of sustainable design.

- Building orientation (to select the best building orientation that results in minimum energy costs)
- Building massing (to analyze building form and optimize the building envelope)
- Daylighting analysis
- Water harvesting (to reduce water needs in a building)
- Energy modeling (to reduce energy needs and analyze renewable energy options such as solar energy)
- Sustainable materials (to reduce material needs and to use recycled materials)

The combination of sustainable design strategies and BIM technology has the potential to change the traditional design practices and to produce a high-performance facility design. One such effort in the Columbia campus of the University of South Carolina resulted in approximately $900,000 savings over the next 10 years at current energy costs (Gleeson, 2008).

The terms *sustainability analyses* or *building performance analyses*, as used in this paper, refers to various assessments and evaluations conducted to determine a building's environmental performance. These analyses include contextual analyses, such as daylighting, building massing, and site orientation, as well as internal analyses such as optimization of a building's HVAC system. Figure 1 describes the typical flow of information taken into account when conducting performance analyses using a building information model. The building information model contains basic information such as building geometry, building materiality, building systems, and internal loads. Based on this information, as well as additional information that is entered into the performance analyses software, environmental evaluation of a building can be performed. Such an evaluation could greatly help designers to optimize the environmental performance of the building.

For projects pursuing Leadership in Energy and Environmental Design (LEED®) certification, many LEED® credits require that drawings be submitted to support the qualification for credit. Although most of these drawings can be prepared using conventional CAD software, BIM software produces these drawings more efficiently as part of the building information model and have the added advantage of parametric change technology, which coordinates changes and maintains consistency at all times. Thus user does not have to intervene to update drawings or links.

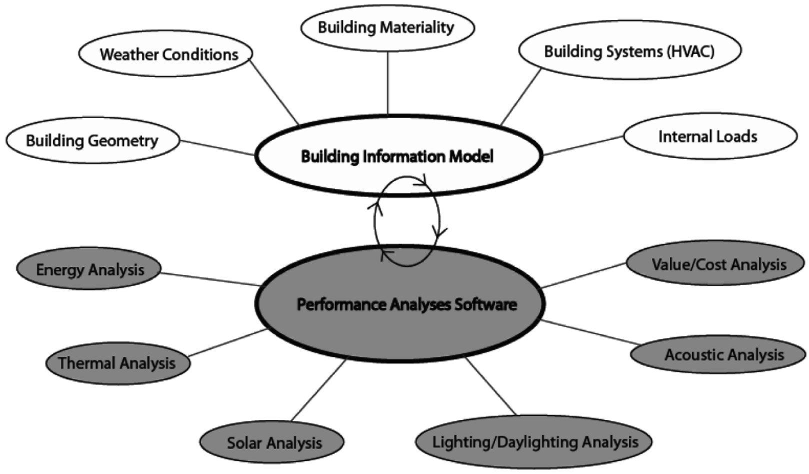

Figure 1. Typical information flow in BIM-based building performance (or sustainability) analyses.

Similarly, such models carry a wealth of information for many other aspects of sustainable design and/or LEED® certification process. For instance, schedules of building components can be obtained directly from the model to determine percentages of material reuse, recycling, or salvage. According to Autodesk (2005), up to 20 points for LEED® certification can be facilitated using BIM.

BIM-Based Sustainability Analyses: Current State and Benefits

In order to evaluate the current state and benefits of BIM-based sustainability analyses, a questionnaire survey was conducted. The target audience was design and construction firms who use BIM technology and/or sustainable design/construction practices in most of their projects. These firms were identified through a published list of the top 100 green contractors as of 2008 (Tulacz, 2008), a list of recipients of the VICO™ (a BIM software; Vico Software, Inc., Boulder, Colorado) newsletter, members of the AGC BIMForum.org, members of BIMWiki.com, members of the LinkedIn.com BIM Experts User Group, and direct contacts made within the architecture and construction industries.

Questionnaire Design

The questionnaire was designed based on the skip-logic method, in which the selection of the next question is based on the answer of the previous question. The skip-logic method prevents respondents from answering questions which they are not qualified to answer. The questionnaire was distributed via a web-based service Zoomerang™ (http://www.zoomerang.com). It was launched on January 9, 2009. Reminders were sent on January 21 and February 10, 2009 to ensure maximum participation. The survey was closed on February 28, 2009. Till the survey closing date, 163 individuals visited the survey website; and 91 complete and 15 partial responses were received. It was decided by the research team to exclude partial responses to ensure maximum consistency in the reported results. The survey response rate is 56% which is good enough to draw meaningful conclusions.

Among the 91 survey respondents, the majority worked for either architecture (34%) or construction companies (36%). It was followed by engineering (16%) and design/build firms (10%). The remaining respondents (4%) worked for government organizations and BIM consultants.

The questionnaire had two skip-logic questions. The first skip-logic question identified the survey respondents currently using BIM. Of the 91 respondents, 72 (79%) were using BIM technology in their projects; while 19 respondents (21%) were non-BIM users. No further questions were asked from the later group and the rest of the respondents were directed to the second skip-logic question which identified the respondents currently using BIM-based sustainability analyses in their projects. Of these 72 respondents, 30 (42%) were employing BIM-based sustainability analyses; while 42 (58%) were not using BIM for this purpose. The rest of the questions were asked to the 30 respondents who were using BIM-based sustainability analyses and the important results are discussed in the following section.

Important Results

In the first question, survey respondents were asked to select the types of building performance analyses (or sustainability analyses) they typically use in their projects. The results are shown in Figure 2. The most common analyses were found to be *energy analysis, daylighting/solar analysis, building orientation analysis, massing analysis* and *site analysis*. Fifteen (50%) respondents also indicated that they prepare LEED® documentation as part of the building performance analyses. Two respondents selected the *other* option and their responses were *structural and mechanical systems analyses*.

Next question explored about the project stage(s) in which sustainability analyses are typically performed. Twenty respondents (67%) indicated that they are using BIM-based sustainability methods at the *design/preconstruction stage*. Nineteen respondents (63%) answered that they are employing these methods at the planning/pre-design *stage*. Nine (30%) answered *construction stage* and 3(10%) answered *post-construction stage*. Two respondents (7%) selected the *other* option and their responses were *GIS Mapping* and *Building Automation.* These results are illustrated in Figure 3.

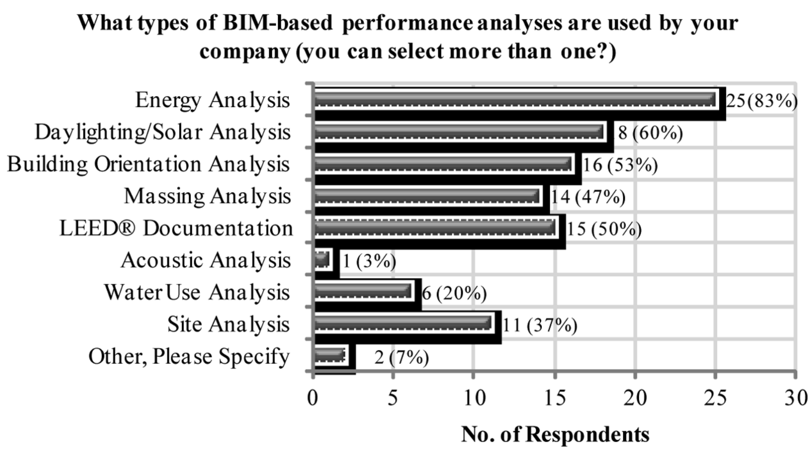

Figure 2. Types of BIM-based performance analyses typically used in the respondents' firms.

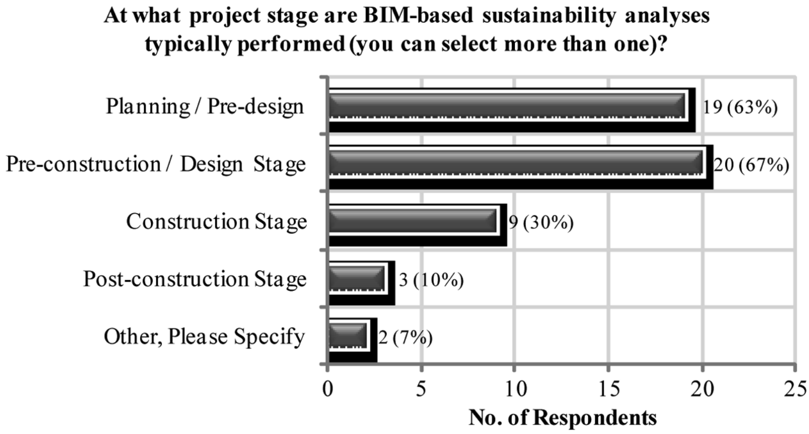

Figure 3. Project stages for BIM-based sustainability analyses.

In the following question, respondents were asked to subjectively estimate the amount of time savings realized through the use of BIM-based sustainability analyses as compared to the traditional analyses. The available choices were *significant time savings, some time savings, no time savings, some time losses*, and *significant time losses*. Of the 30 respondents, 15 (50%) stated that they are realizing *some time savings*, 8 (27%) respondents stated they are experiencing *significant time savings*, while 5 (17%) respondents selected *no time savings.* Two respondents (7%) chose *some time losses*. These results are shown in Figure 4.

In addition to time savings, respondents were also asked to subjectively estimate the monetary savings. The available choices were *significant cost savings, some cost savings, no cost savings, some monetary losses*, and *significant monetary losses*. Similarly to the last question, the majority of respondents, 15 (50%), answered that they are achieving *some cost savings.* Eight respondents (27%) answered that they are achieving *significant cost savings.* The remaining 7 respondents (23%) answered that they are achieving *no cost savings.* No respondents selected *some monetary losses* or

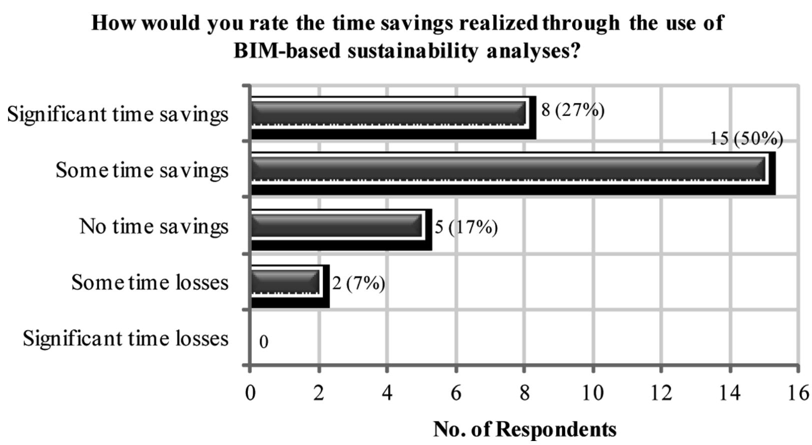

Figure 4. Time savings realized through BIM-based sustainability analyses.

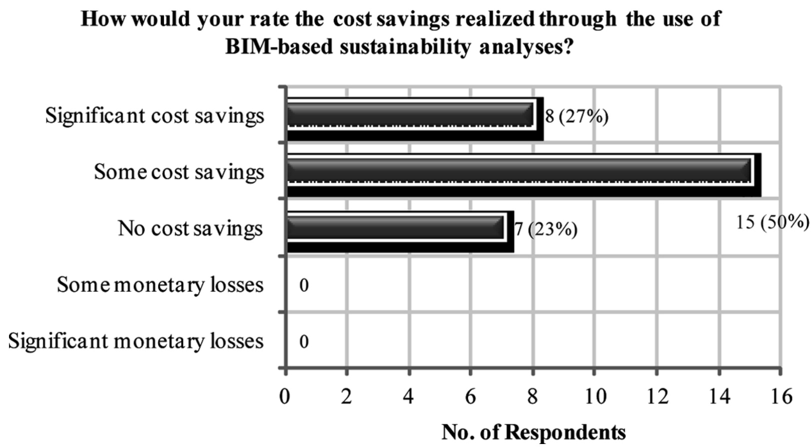

Figure 5. Cost savings realized through BIM-based sustainability analyses.

significant monetary losses as shown in Figure 5. Based on the results of these two questions, it can be inferred that most of the firms are experiencing *some-to-significant* time and cost savings through BIM-based sustainability analyses as compared with the traditional methods.

Respondents were asked to select the building performance analyses software(s) being used by their firms. Fifteen respondents (50%) selected *Autodesk® Green Building Studio (GBS)™*. Eleven respondents (37%) chose *Integrated Environmental Solutions®, Virtual Environment (VE)™*. An equal amount, 11 (37%), stated that they are using *Autodesk® Ecotect™*. Seven respondents (23%) selected *other software*, which were *Hevacomp™*, *Energy Plus™*, *Delight™*, *Radiance™*, *HEED™*, *Homer™*, *Virtual DOE™*, *Bentley HEVACOMP^M*, *Bentley TAS™*, and *Climate Consultant™*. These results are illustrated in Figure 6 which clearly indicates that the three most popular building performance analyses softwares are *Green Building Studio™, Virtual Environment™*, and *Ecotect™*. Hence, in the second part of this

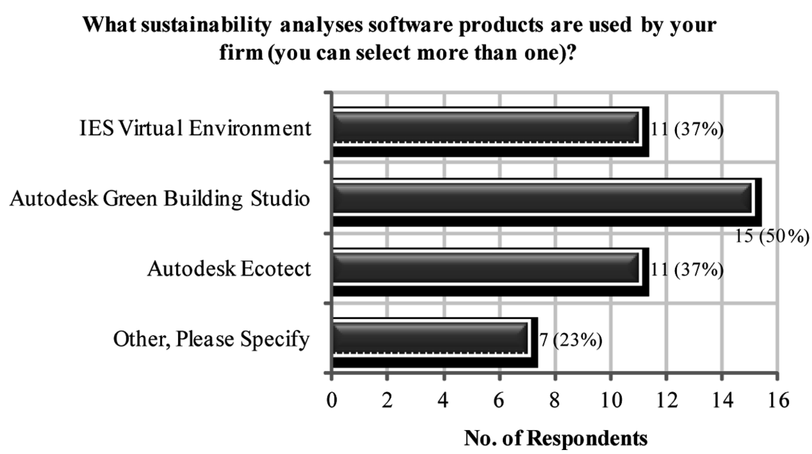

Figure 6. Building performance analyses software preferences.

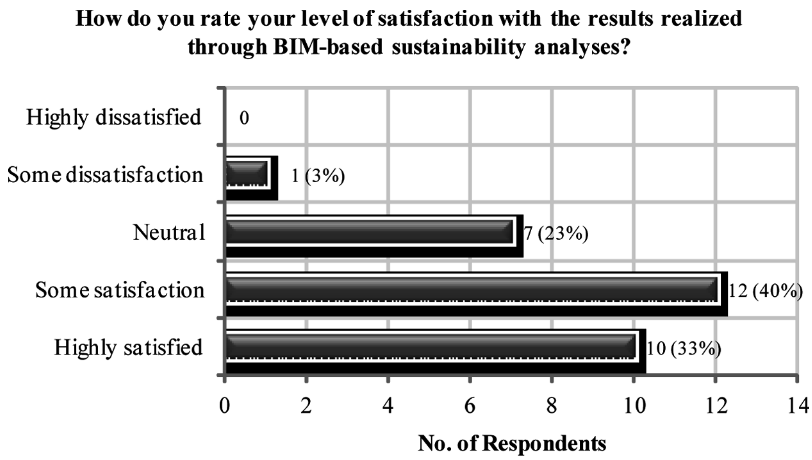

Figure 7. Level of satisfaction for BIM-based sustainability analyses compared with traditional methods.

research project, these three softwares were evaluated for their functionality and performance for BIM-based sustainability analyses.

At the end, respondents were asked to rate the level of satisfaction realized through BIM-based sustainability analyses as compared to the traditional methods of sustainability analyses. The results are shown in Figure 7. Ten respondents (37%) were *highly satisfied*, while 12 respondents (44%) achieved *some satisfaction*. Seven respondents (23%) were *neutral*, while one respondent (4%) was found to be *dissatisfied*. As a whole, it can be concluded that most of the respondents were satisfied up to a certain degree.

Major Findings

The major findings of the questionnaire survey are as follows:

- The majority of practitioners who are employing BIM-based sustainability analyses are primarily architects and contractors.
- Practitioners typically use BIM-based sustainability analyses at the planning and design stages.
- The analyses types with the most prevalent use are energy analysis, daylighting/solar analysis, building orientation analysis, massing analysis and site analysis.
- Practitioners implementing BIM-based sustainability analyses are realizing some-to-significant time and cost savings compared with the traditional methods.
- The software types which seem to have the most prevalent use, at the time of this research, were Autodesk Ecotect™, Autodesk Green Building Studio (GBS)™, and Integrated Environmental Solutions (IES)®, Virtual Environment (VE)™.
- Practitioners are achieving some-to-high degree of satisfaction in regard to results when compared with the traditional sustainability analyses.

Evaluation of Building Performance Analyses Softwares—A Case Study

The rationale for this evaluation was to gage the viability of leading building performance analyses softwares for BIM-based sustainability analyses. Based on the results of the questionnaire survey, three softwares namely Ecotect™, Green Building Studio™ (GBS) and Virtual Environment (VE)™ were chosen. The project selected for evaluating these softwares was Emory Psychology Building which is a LEED® certified, 110,000 square foot, $35,000,000 facility on the campus of Emory University in Atlanta, GA. The project architect is *HOK®*, Atlanta and general contractor is *Holder Construction Company (HCC)*, Atlanta. The architect developed the building information model of the facility at the early design phase to determine the best building orientation and to evaluate various skin type design options such as masonry, curtain wall and window styles as shown in Figure 8, perform energy and daylighting analyses, and created a LEED® daylighting credit qualification report. Later on, this model was acquired by HCC to further perform the various sustainability analyses and evaluate these softwares.

Figure 9 depicts the process of building information model and building performance analyses softwares integration by outlining various data transfer steps. The boxes on the right hand side indicate software features evaluated in this analysis.

As shown in Figure 9, the gbXML (or Green Building XML schema) is a computer language which facilitates the transfer of building information stored in building information models to various building performance analyses softwares. It enables integrated interoperability between building design models and a wide variety of sustainability analyses tools. Today, gbXML has the industry support and wide adoption by the leading BIM vendors such as Autodesk®, Vico®, and Bentley®. With the development of export and import capabilities in several major building performance modeling softwares, gbXML has become a defacto industry standard schema. Its use dramatically streamlines the transfer of building information to and from building performance analyses softwares, eliminating the

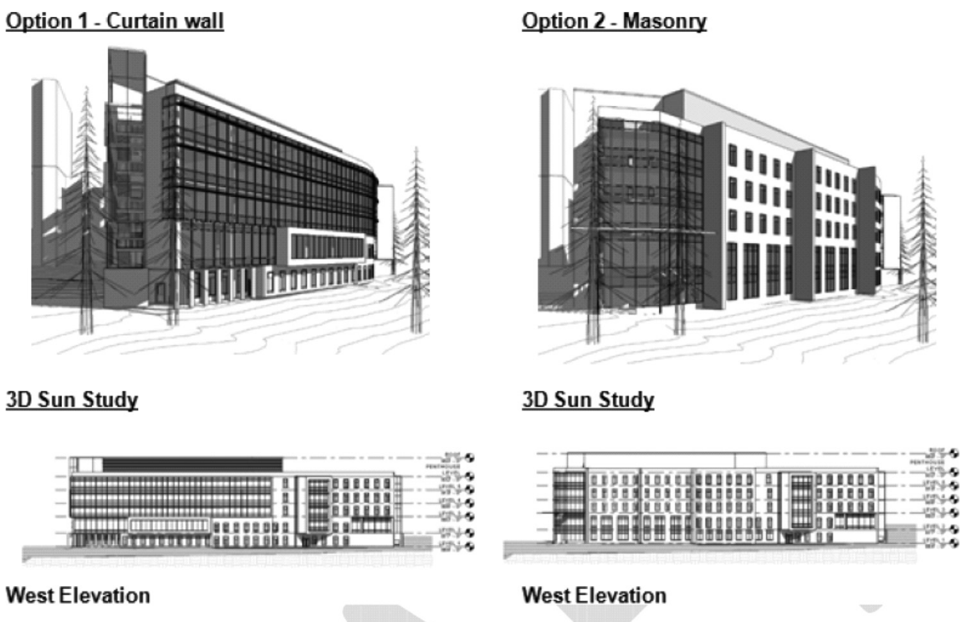

Figure 8. Use of BIM for Options Analysis and Sun Studies in the Emory Psychology Building (Courtesy of: HOK® and Holder Construction Company, Atlanta, GA).

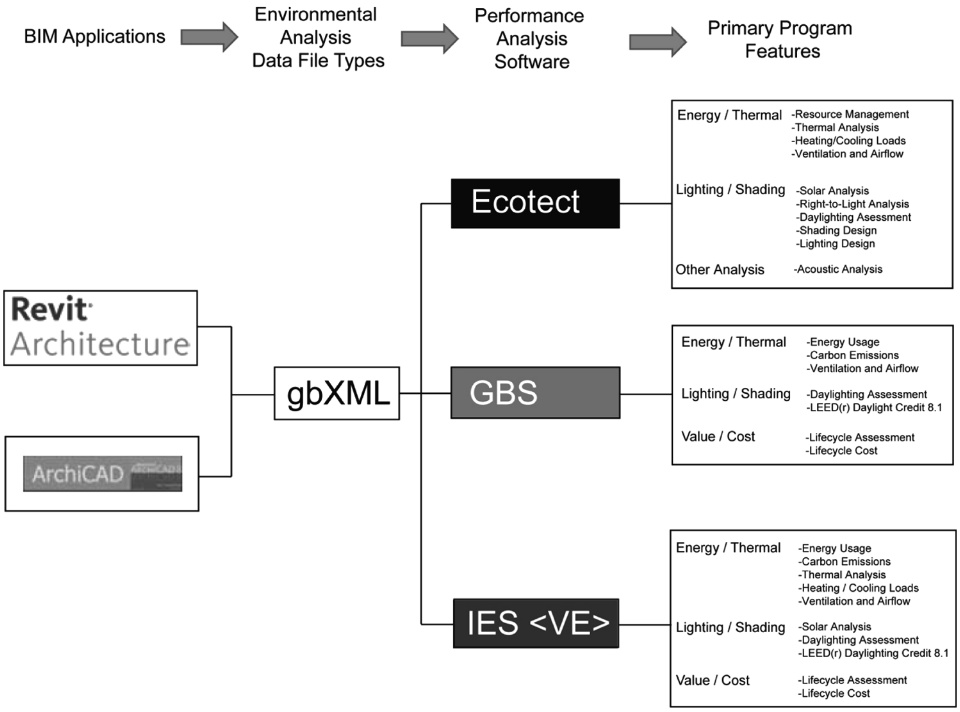

Figure 9. Integration of BIM applications and building performance analyses softwares. (Source: Holder Construction Company, Atlanta, GA)

need for time consuming plan take-offs. This removes a significant cost barrier to designing resource efficient buildings and specifying associated equipment. It enables building design teams to truly collaborate and realize the potential benefits of BIM technology (Stephen, 2009).

The following paragraphs briefly discuss the salient features of each software while Table 1 depicts their pros and cons. This information is collected by reading the software manuals and conducting semi-structured interviews with professionals from HOK® and HCC®.

Ecotect™

Ecotect™, owned by Autodesk®, Inc., is "a complete building design and environmental analyses tool that covers the full range of simulation and analyses functions required to truly understand how a building design will operate and perform" (Autodesk, 2008). The primary program analyses capabilities include energy analysis, thermal analysis, and lighting/shading analysis. The energy and thermal analysis features take into account factors such as resource management, heating and cooling loads, and ventilation and airflow. The lighting/shading analysis tools allow for solar analysis, right-to-light analysis, daylighting assessment, shading design, and lighting design. Ecotect™ also allows for other facility assessments such as acoustic analysis. Figure 10 depicts a sample screen shot of the performance analysis of Emory Psychology Building using Ecotect™.

Table 1. Pros and cons of building performance analyses softwares used for evaluation

Product	Pros	Cons
Autodesk Ecotect™	• Incorporates model viewing capabilities • Analysis results stored in a single file • Resultant graphics are easily understood and are easily available • Incorporates a zone management system	• User interface difficult to understand • Analysis steps are unclear There is no gbXML error check • Analysis run times are very long • Some analysis types caused program instability • Analysis success is inconsistent
Autodesk Green Building Studio (GBS)™	• Automated online process • Very little preparation work required • Easy Revit™ to gbXML transition • Automated gbXML error check • Large output-to-time spent ratio • Simple user interface • Provides LEED® Daylighting credit 8.1 test	• Program became unstable when using large file sizes • Unable to specify individual analysis types (i.e., it provides one predetermined, broad analysis) • Requires internet connection • Requires login/password to link file and access analysis results
IES Virtual Environment (VE)™	• Incorporates a direct Revit™ plug-in • User interface mimics Revit™ • Powerful single-click analyses • Short analysis run times • Results are displayed in an organized manner • Incorporates lifecycle cost assessment analysis • Incorporates LEED® Daylighting Credit 8.1 test	• Results are saved separately from the main project file • Inconsistent analysis success between different methods • Limited model viewing capabilities • Model preparation requires manual gbXML error check resulting in a limited error report

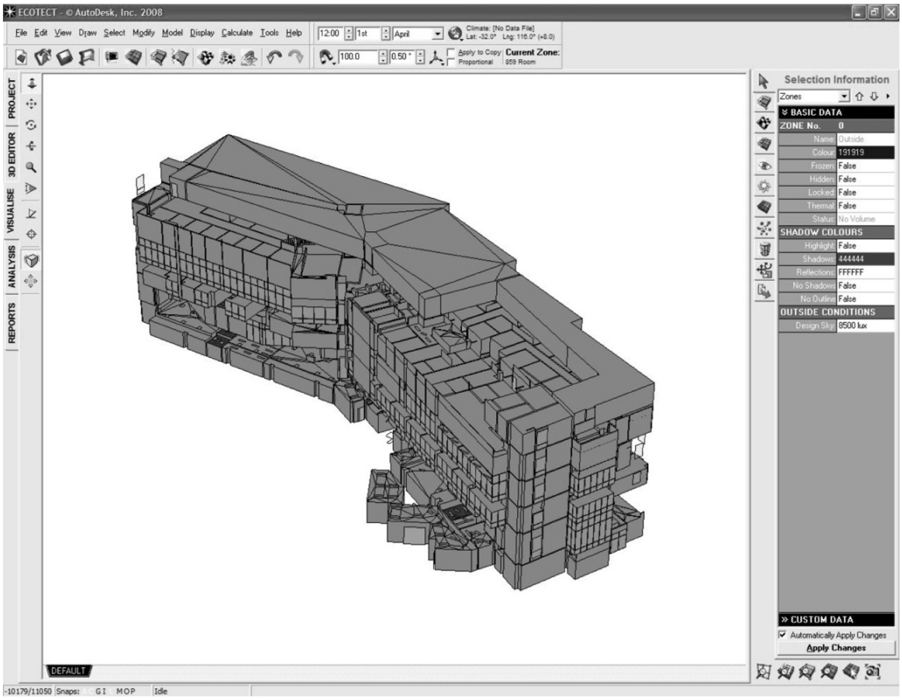

Figure 10. Ecotect^{TM} interface—Emory Psychology Building evaluation (Courtesy: HCC, Atlanta).

Green Building Studio^{TM} (GBS)

Green Building Studio^{TM}, also owned by Autodesk® Inc., is a web-based service that allows users to evaluate the environmental impact of individual building components early in the design process. The software's primary analyses capabilities include energy and thermal analysis, lighting and shading analysis, and value/cost analysis. The energy/thermal analysis evaluates energy usage, carbon emissions, and ventilation and airflow. The lighting and shading analyses assess daylighting and include the LEED® daylight credit 8.1 feature. The value and cost functions determine lifecycle assessments and lifecycle costs. Figure 11 shows the performance analysis of Emory Psychology building using GBS^{TM}.

Virtual Environment^{TM}

Integrated Environmental Solutions (IES)®, Virtual Environment (VE)^{TM} software is a suite of integrated building performance analyses tools. These tools provide analyses for issues including solar, lighting, energy, costs, egress, and many others. The energy/thermal functions include energy usage, carbon emissions, thermal analysis, heating/cooling load evaluation, and ventilation/airflow evaluation. The lighting/shading functions include solar analysis, daylighting assessment, and LEED® Daylight Credit 8.1 capabilities. The value/cost analysis functions include life-cycle assessment and lifecycle cost. Figure 12 illustrates a screenshot of daylighting analysis using IES® Virtual Environment^{TM}.

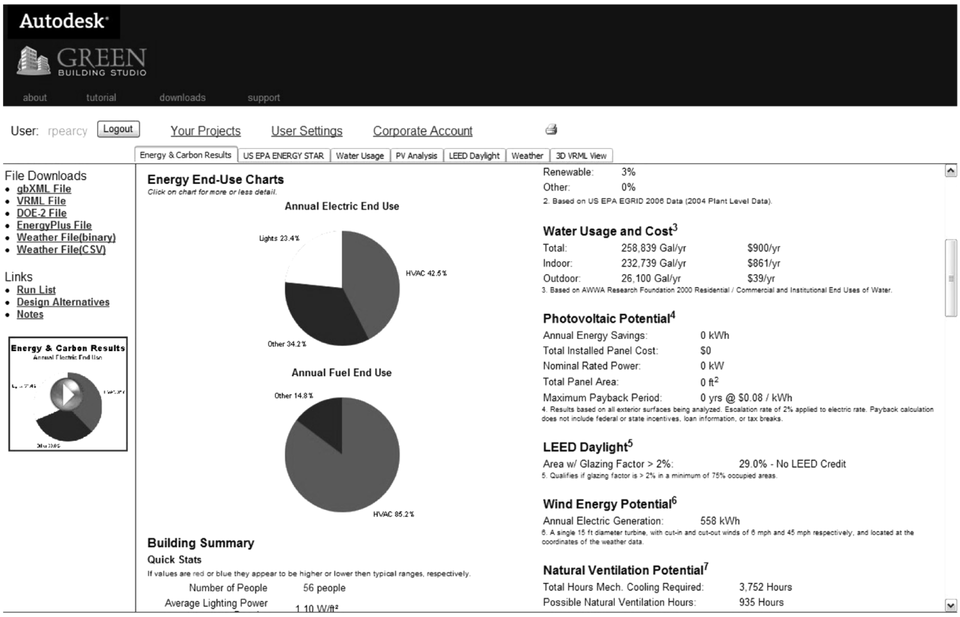

Figure 11. Green Building Studio^{TM} interface displaying energy end-use information from Emory Psychology Building study (Courtesy: HCC, Atlanta).

The pros and cons of each software are shown in the following table. These pros and cons were identified through study of software manuals and semi-structured interviews with professionals from HOK and HCC.

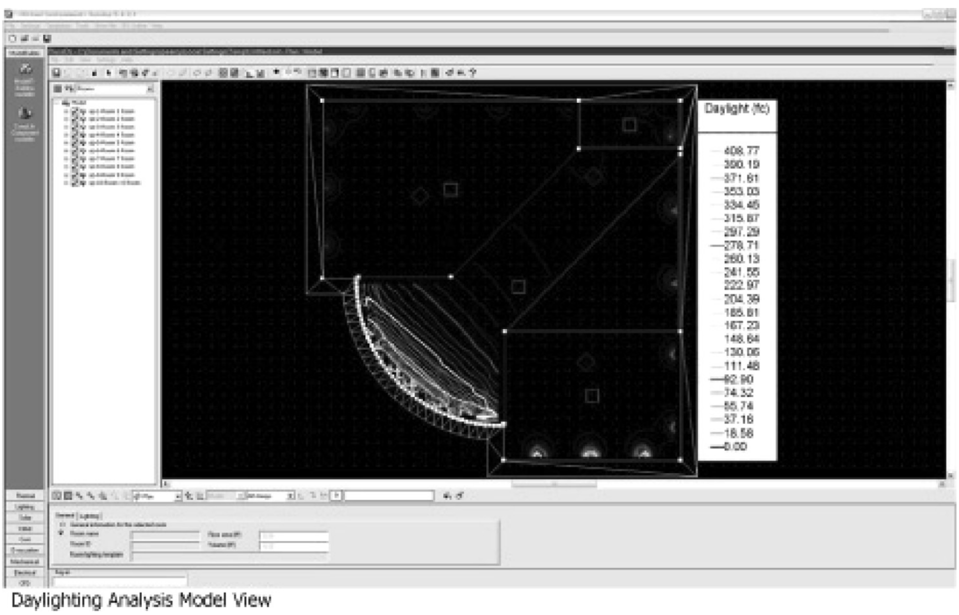

Figure 12. Daylighting analysis using IES$^{®}$ Virtual Environment^{TM} (Courtesy: HCC, Atlanta).

Building Performance Analyses Softwares Evaluation Matrix

To evaluate the performance of these softwares for various types of sustainability analyses and to select the best software, an analytical analysis was performed. A check list of various sustainability features was prepared as shown in Figure 13. Each feature was assigned a weight factor between 1 to 10, which represents its importance with respect to sustainability analyses and LEED rating®. These weight factors were subjectively decided by a team of BIM and LEED experts of the Holder Construction Company based on their experience. After that, the same team evaluated these features in each software and gave them a ranking score between 1 to 10. Then the grand total weighted score was calculated as follows:

$$\text{Grand total weighted score} = \Sigma[\Sigma(\text{Ranking score for each feature}) \times (\text{Weight factor of that feature})]$$

Figure 13 shows this evaluation matrix with individual and grand total weighted score for each software. In terms of overall rating and versatility, IES® Virtual Environment™ was considered as the best software for BIM-based sustainability analyses. Ecotect™, although stronger than Green Building Studio™ in numerous categories, including Thermal, Solar, and Lighting and Daylighting, is apparently the least versatile of the three. This is due to its lack of Value and Cost and LEED® rating capabilities, both heavily weighted items. Green Building Studios™, by Autodesk®, received the lowest overall score. However, it appears to be a very versatile program, lacking only in Acoustic capabilities.

Performance Analyses Software vs. Analyses Types	Weighting (1-10)	Performance Analysis Software		
Analyses Types		Ecotect™	Green Building Studio™	Virtual Environment™
Energy	6			
Energy Usage		1	3	3
Carbon Emissions Calculations		3	3	3
Resourse Management		3	1	
Total Score		***7***	***7***	***6***
Thermal	7			
Thermal Analysis		3	1	3
Heating / Cooling Load Calculations		3	1	3
Ventilation and Airflow		3	3	3
Total Score		***9***	***5***	***9***
Solar	2			
Solar Analysis		3	1	3
Right-to-Light Analysis		3	1	1
Total Score		***6***	***2***	***4***
Lighting and Daylighting	3			
Daylighting Assessment		3	1	3
Shading Design		3	1	1
Lighting Design		3	1	1
Total Score		***9***	***3***	***5***
Acoustic	2			
Acoustic Analysis		3		1
Total Score		***3***	***0***	***1***
Value and Cost	8			
Lifecycle Assessment			3	3
Lifecycle Cost			1	3
Total Score		***0***	***4***	***6***
General	8			
LEED Integration Tools			1	1
Total Score		***0***	***1***	***1***
Grand Total Weighted Score		**150**	**130**	**180**

Figure 13. Building performance analyses softwares evaluation matrix.

It is important to note that the results produced from these three softwares have not been directly validated against DOE Energy Plus™ software (a traditional building performance analyses software). However, one of these software, GBS™, is based on the DOE-2 engine. The comprehensive GBS™ error check report helped reduce the number of errors while creating a useable gbXML file. Therefore, the authors are confident that the results are 'in the ballpark'. Meanwhile, though Ecotect™ and IES-VE™ are not based on the DOE-2 engine, they provide inputs that allow users to define materials, room types, system types, *etc.*, for more detailed study within the programs.

A Conceptual Framework for BIM-based Sustainability Analyses

Based on the data collected in the first two phases of this research and overall discussion with the industry experts, a conceptual framework for BIM-based sustainability analyses during different phases of a project life-cycle is demonstrated in Figure 14. The framework is divided into two primary columns. The left side column, titled "Implementation of performance analyses types by project phase in BIM-based coordination, and responsible stakeholders" contains a list of each project phase from both the design and construction industry standpoints, as well as a list identifying which project stakeholder is responsible for initiating the use of BIM-based sustainability analyses. The columns to the right contain a checklist of the various types of BIM-based sustainability analyses. Within these columns, a "diamond shape" identifies relationships which exist between the project phases and the analyses types. This conceptual framework could serve as a guide for various project stakeholders that might be interested in performing BIM-based sustainability analyses at the different project phases. It can also help to identify the roles and responsibilities of various stakeholders in regards to sustainability analyses and could serve as a foundation for a more detailed framework to establish a "link" between BIM-based sustainability analyses and LEED® rating process. The second phase of this research project will investigate this aspect.

Implementation of Performance Analyses Types by Project Phase in BIM-based Coordination, and Responsible Stakeholders			Sustainable Design Related Analysis Types						
			Energy Analysis	Daylighting / Solar Analysis	Acoustic Analysis	Material Documentation	Value / Cost Analysis	Site Analysis	Water Use
Project Phase		Responsible Stakeholders							
Preconstruction	*Pre-design*								
	Programming	Architect / Engineer					◆	◆	
		Owner					◆		
	Design								
	Schematic Design	Architect / Engineer	◆	◆	◆		◆	◆	◆
		Contractor					◆		
	Design Development	Architect / Engineer	◆	◆	◆	◆	◆	◆	◆
		Contractor					◆		
	Contract Documents								
	Construction Drawings	Architect / Engineer	◆			◆	◆		
		Contractor							
	Construction Specifications	Architect / Engineer	◆			◆	◆		
		Contractor							
Construction	*Construction Administration*	Architect / Engineer				◆			
Occupancy		Owner	◆	◆		◆	◆		◆

Figure 14. A conceptual framework depicting BIM-based sustainability analyses throughout project life-cycle.

Concluding Remarks

This exploratory study indicates that BIM can facilitate the very complex process of sustainable design as well as automate the drudgery of activities like material take-offs, cost estimation and construction schedules, while capturing and coordinating information into a single integrated model. It is found that the majority of practitioners who are implementing BIM-based sustainability analyses are primarily architects and contractors. The analyses types with the most prevalent use are energy analysis, daylighting/solar analysis, building orientation analysis, massing analysis and site analysis. Most of these practitioners realized some-to-significant time and costs savings as compared to the traditional methods. The software types which seem to have the most prevalent use are Autodesk Ecotect™, Autodesk Green Building Studio (GBS)™, and Integrated Environmental Solutions (IES)®, Virtual Environment (VE)™. Based on the evaluation of these softwares, Virtual Environment™ appears to be both the most versatile and powerful software in terms of sustainability analyses capabilities. Ecotect™, although stronger than Green Building Studio™ in numerous categories is apparently the least versatile of the three. Green Building Studio™ received the lowest overall score. However, it appears to be more versatile program than Ecotect™. The conceptual framework presented in this paper could be used as a guide to identify the types of sustainability analyses which can be performed at different phases of the project life-cycle.

Disclaimer

The opinions and recommendations expressed in this paper are the authors' personal opinions and do not necessarily represent the official position of any organization. This paper does not endorse any software in any capacity.

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