BIM-based Sustainability Analysis: An Evaluation of Building Performance Analysis Software

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With the rising cost of energy and growing environmental concerns, the demand for sustainable building facilities with minimal environmental impact is increasing. The most effective decisions regarding sustainability in a building facility are 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. In this exploratory research, three building performance analysis software namely Ecotect™, Green Building Studio™ (GBS) and Virtual Environment™ are evaluated to gage their suitability for BIM-based sustainability analysis. First presented in this paper are the main concepts of sustainability and BIM. Then an evaluation of the three above-mentioned software is performed with their pros and cons. An analytical weight-based scoring system is used for this purpose. At the end, a conceptual framework is presented to illustrate how construction companies can use BIM for sustainability analysis and evaluate LEED® (Leadership in Energy and Environmental Design) rating of a building facility.

Key Words: Building performance analysis, Sustainable design, Building Information Modeling, LEED, Green building rating

Introduction

Buildings consume close to 40% of all energy used in the United States and account for 40% of global CO_2 emissions (Schueter and Thessling, 2008). The rising cost of energy and growing environmental concerns have pushed the demand for sustainable building facilities 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 building facilities. States such as Florida are following suit, requiring all State owned buildings to meet standardized energy requirements (Autodesk, 2008). This type of "green legislation" is increasingly 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 with sustainable design of a building facility are made in the early design and preconstruction stages. Traditional CAD planning environments, however, do not support the possibility of such early decisions. Energy and performance analysis are typically performed, if at all, after the architectural design and construction documents have been produced. This lack of integration into the design process leads to an inefficient process of retroactively modifying the design to achieve a set of performance criteria (Schueter and 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 analysis to be performed throughout the design process (Autodesk, Inc., 2008; Schueter and Thessling, 2008).

Building Information Modeling (BIM) represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a building facility. The resulting model, a Building Information Model, is a data rich, object-oriented, intelligent and parametric digital representation of the building facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility (Azhar *et al.*, 2007). BIM uses parametric object modeling technology to create relationships between objects within a virtual building model. These relationships include physical and functional characteristics as well as project life cycle information. A recent research study has indicated that average BIM Return on Investment (ROI) ranges from 634%-1633%, which clearly depicts its lucrative economic benefits (Azhar et al., 2008).

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 traditional energy (or sustainability analysis), while also realizing the benefits associated with energy analysis, 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 facility. Linking the building model to energy analysis tools allows for evaluation of energy use during the early design phases. 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.

Research Objectives and Scope

The main objective of this research is to explore the suitability of BIM for sustainability analysis. The sub-objectives include the evaluation of three building performance analysis software types. These include Ecotect™, Green Building Studio™ (GBS) and Virtual Environment™ . In addition to these sub-objectives is the development of a conceptual framework illustrating how construction companies can use BIM for sustainability analysis and evaluate LEED® (Leadership in energy and Environmental Design) rating of a building facility. The research scope is limited to commercial and healthcare building projects.

Methodology

The data for this research is collected via literature, review of software manuals and semi-structured interviews with industry professionals. Holder Construction Company (HCC), Atlanta is a major contributor in this research. HCC is a medium size general contracting company with current annual revenues close to $1 billion. HCC is a market leader in the Southeast regarding the use of BIM technology and won the AGC National BIM award in 2007.

BIM-based Sustainability Analysis

As with traditional physical models and drawings, evaluating building performance based on the graphic representations of conventional CAD or object-CAD solutions requires a great deal of human intervention and interpretation, which renders the analysis too costly and/or time-consuming (Autodesk, 2005). A survey conducted by the Center for Integrated Facility Engineering (CIFE) at Stanford University cited that economic reasons are among the primary causes for not implementing sustainable design and construction procedures by the majority of survey respondents (CIFE, 2004).

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 Building Information Model with Performance Analysis tools greatly simplifies the often cumbersome and difficult analysis. This approach gives architects easy access to tools that provide immediate feedback on design alternatives early on in the design process.

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)

For projects pursuing 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, the user does not have to manually update drawings or links. Similarly, such models carry a wealth of information for many other aspects of sustainable design and/or LEED® certification. For instance, schedules of building components can be obtained directly from the model to determine percentages of material reuse, recycling, or salvage. In addition, advanced visualization techniques can convince skeptical clients that green design performs well and looks good. According to Autodesk (2005), up to 20 points for LEED® certification can be facilitated using BIM.

Building Performance Analysis Software: A Case Study

The rationale of this evaluation is to gage the suitability of leading building performance analysis software for BIM-based sustainability analysis. The three software types selected for this purpose were Ecotect™, Green Building Studio™ (GBS) and Virtual Environment™. Holder Construction Company (HCC) acquired these software and the analysis was performed by their BIM division. The project selected for this purpose was Emory University's Psychology Building (Figure 1) which received a LEED® Silver certification. BIM was used in the early design phase to determine best building orientation, evaluate various skin type design options such as masonry, curtain wall and window styles, perform energy and daylighting analysis, and create a LEED® daylighting credit qualification report.

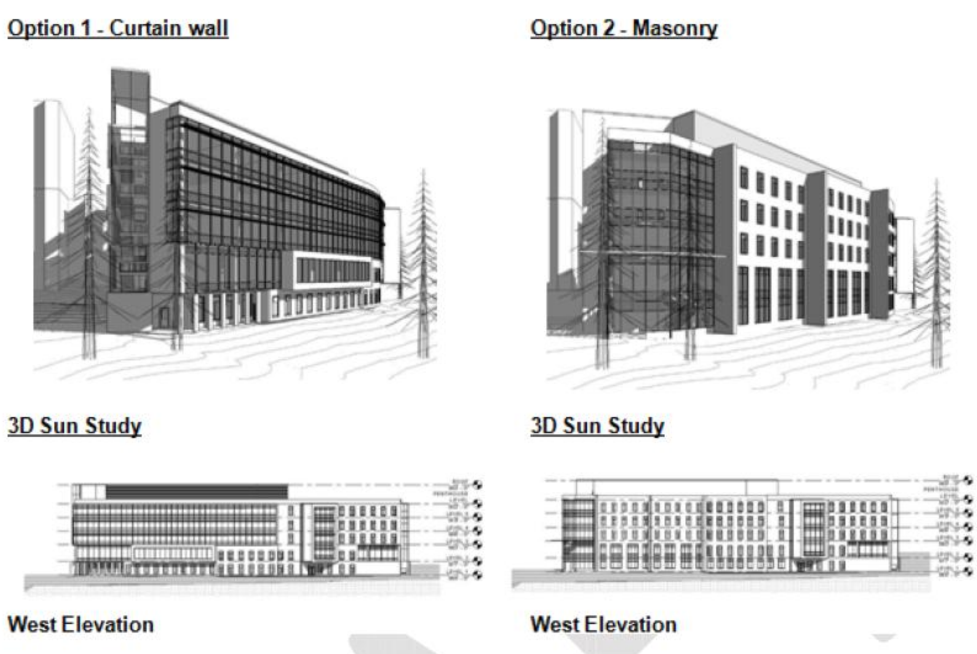

Figure 1: Use of BIM for Options Analysis and Sun Studies in the Emory Psychology Building
(Courtesy of: Holder Construction Company, Atlanta, GA)

Figure 2 depicts the process of BIM and Building Performance Analysis Software integration by outlining various data transfer steps. The boxes on the right hand side indicate software features evaluated in this analysis.

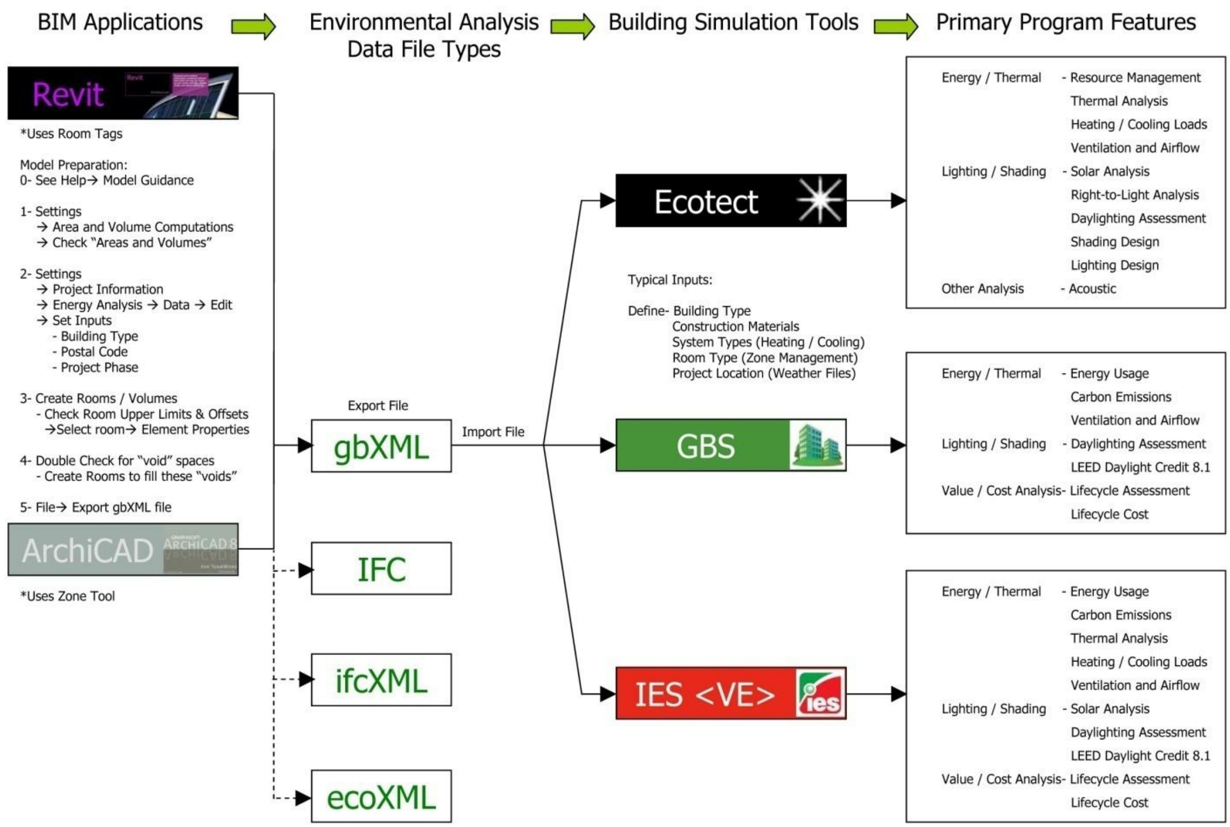

Figure 2: Integration of BIM and Building Performance Analysis Software
(Courtesy of: Holder Construction Company, Atlanta, GA)

The following paragraphs briefly discuss each software and their respective "pros" and "cons".

Ecotect™

Ecotect™, owned by Autodesk, Inc., is "a complete building design and environmental analysis tool that covers the full range of simulation and analysis functions required to truly understand how a building design will operate and perform" (Autodesk, 2008). The primary program analysis capabilities include energy analysis, thermal analysis, and lighting/shading analyses. 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 building facility assessments such as acoustic analysis. Figure 3 depicts the performance analysis of Emory Psychology building using Ecotect™ with its "pros" and "cons".

Green Building Studio™ (GBS)

Green Building Studio™, also owned by Autodesk Inc., is a web-based energy analysis service that allows users to evaluate the environmental impact of individual building components early in the design process. The software's primary analysis capabilities include energy and thermal analysis, lighting and shading analysis, and value/cost analyses. The energy/thermal analyses evaluate 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 4 shows the performance analysis of Emory Psychology building using GBS™ with its “pros” and “cons.

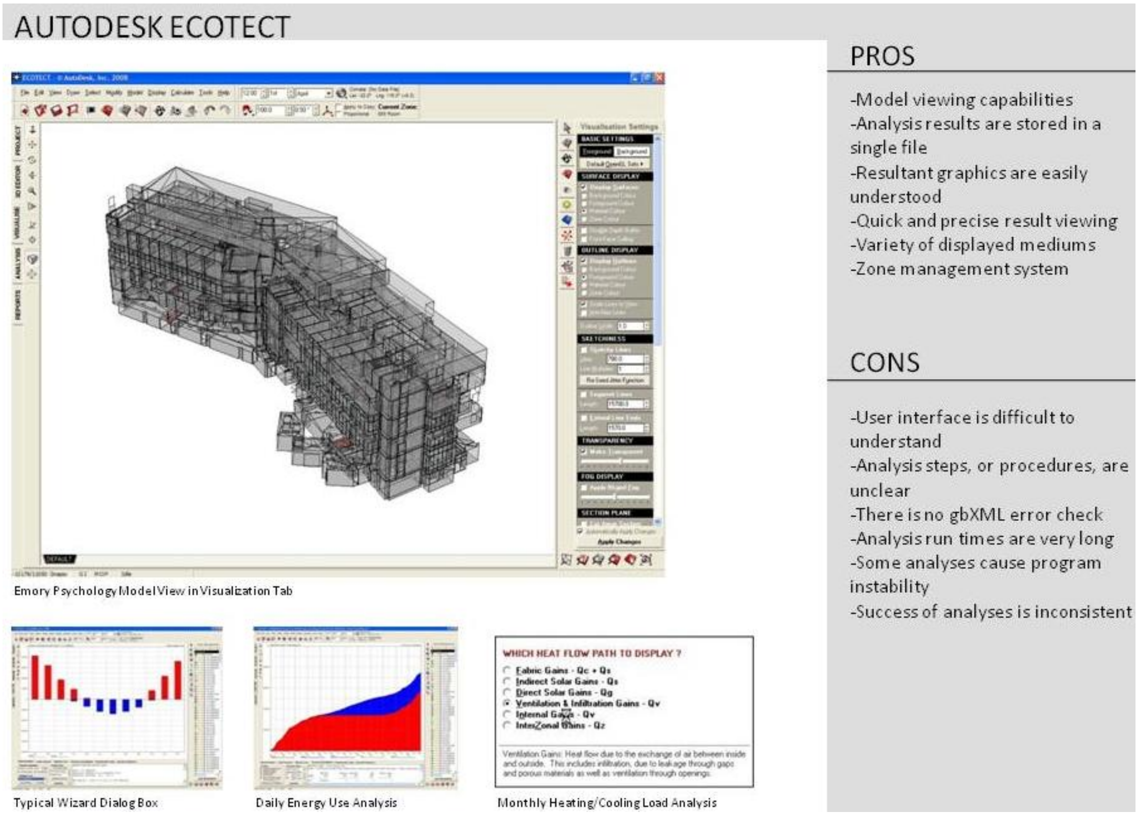

Figure 3: Ecotect™ “Pros” and “Cons” (Courtesy: HCC, Atlanta, GA)

Virtual Environment™

Integrated Environmental Solutions’ Virtual Environment™ software is a suite of integrated building performance analysis 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 lifecycle assessment and lifecycle cost. Figure 5 illustrates the performance analysis of Emory Psychology building using VE™ with its “pros” and “cons.

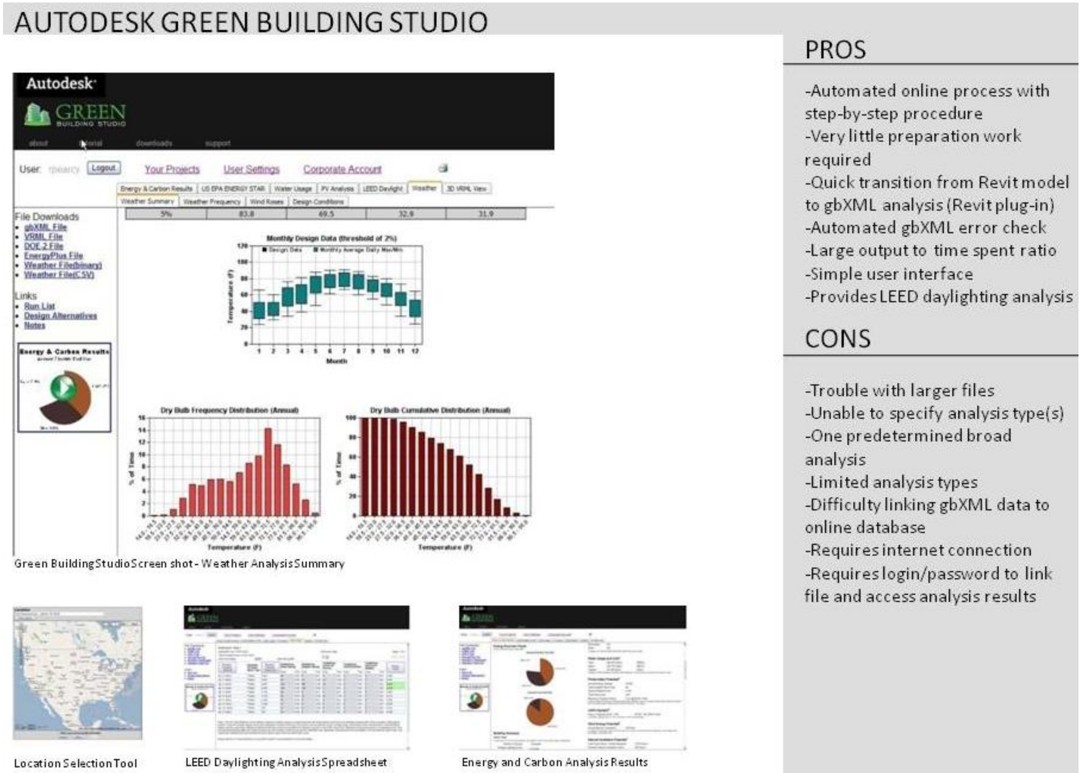

Figure 4: Green Building Studio™ "Pros" and "Cons" (Courtesy: HCC, Atlanta, GA)

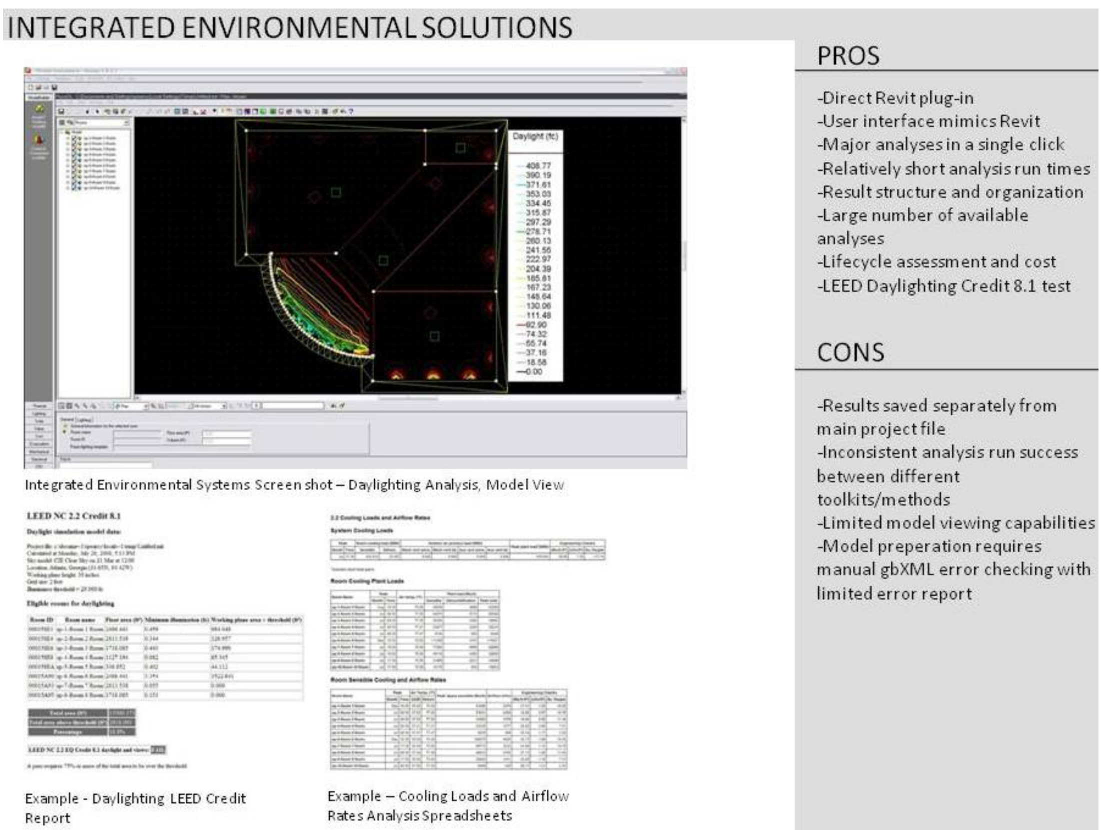

Figure 5: IES Virtual Environment™ "Pros" and "Cons" (Courtesy: HCC, Atlanta, GA)

Evaluation of Building Performance Analysis Software

To evaluate the performance of these software for various types of sustainability analysis and to select the best software, an analytical analysis was performed. A check list of various sustainability features (with regard to LEED® rating) was prepared. Each feature was assigned a weight factor which represents its importance within the given features. These weight factors were subjectively decided by a team of BIM and LEED® experts in 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 total weighted score was calculated as follows:

Total Weighted Score = Σ (Ranking score for each feature) x (Weight factor of that feature)

As shown in Table 1, the IES's Virtual Environment™ got the maximum score and hence may be considered as the best software for BIM based sustainability analysis.

Table 1: Building Performance Analysis Software Evaluation Matrix (Source: HCC, Atlanta)

Sustainable Design Features	Weighting (1-10)	Ecotect™	GBS™	VE™
Energy	6			
Energy Usage		1	3	3
Carbon Emissions Calculations		3	3	3
Resource Management		3	1	0
Total Score		**7**	**7**	**6**
Thermal	7			
Thermal Analysis		3	1	3
Heating / Cooling Load Calcs		3	1	3
Ventilation and Airflow		3	3	3
Total Score		**9**	**5**	**9**
Solar				
Solar Analysis	2	3	1	3
Right-to-Light		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	0	1
Total Score		**3**	**0**	**1**
Value and Cost	8			
Lifecycle Assessment		0	3	3
Lifecycle Cost		0	1	3
Total Score		**0**	**4**	**6**
LEED	8			
LEED Integration Tools		0	1	1
Total Score		**0**	**1**	**1**
Total Weighted Score		**150**	**130**	**180**

A Conceptual Framework for BIM-based Sustainability Analysis

A conceptual framework for BIM based sustainability analysis during different stages of a project life cycle (or project phases) is illustrated in Figure 6. The left hand side box indicates the various project phases (or construction company departments). The middle box depicts the various sustainability analysis features while the right hand side box indicates the interaction of external stakeholders (such as customers or project partners) in sustainability analyses. This framework can be used by the construction companies who want to perform BIM-based sustainability analysis. Please note that this conceptual framework is still in its infancy stage. As this is an on-going research project, it is hoped that this framework will be further refined and validated.

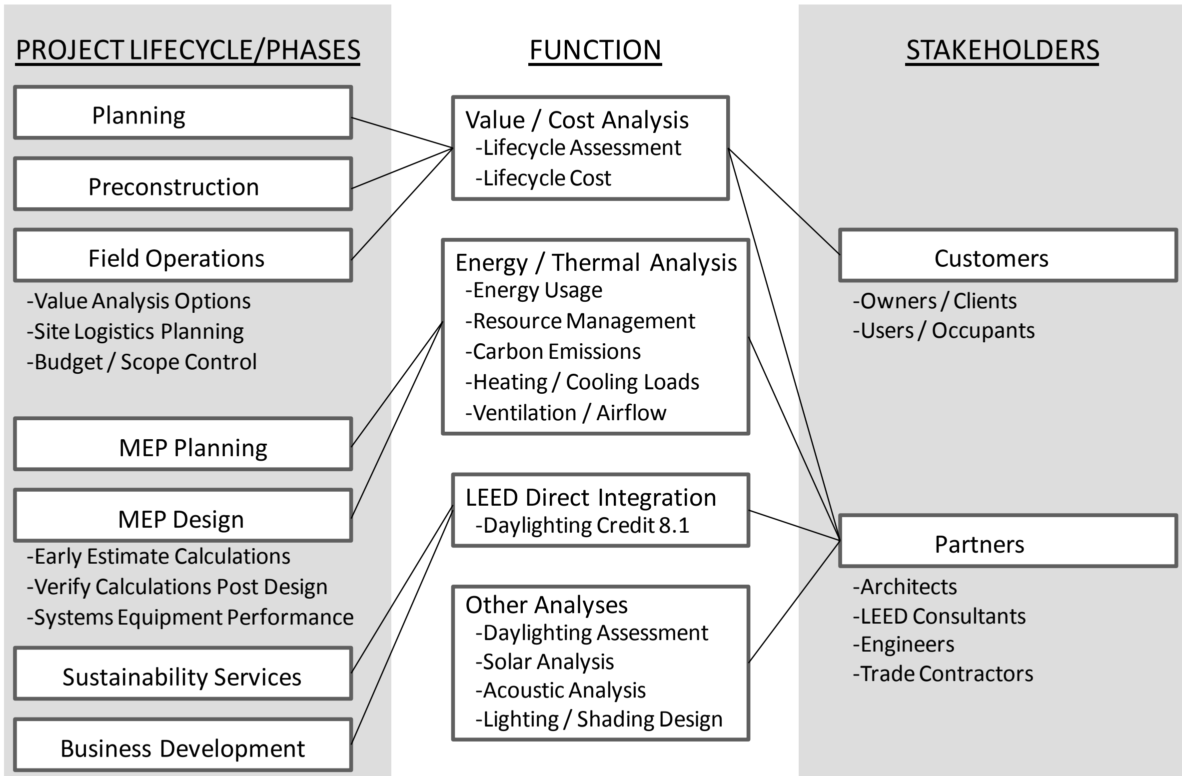

Figure 6: A Conceptual Framework for BIM-based Sustainability Analysis

Concluding Remarks

This exploratory study indicates that BIM can facilitate the very complex processes of sustainable design such as daylighting and solar access, as well as automate the drudgery of activities like material takeoffs, cost estimation and construction schedules while capturing and coordinating information into a single integrated model. Based on the evaluation of three building performance analysis software, it was found that Integrated Environmental Solutions' Virtual Environment™ software appears to be both the most versatile and powerful in terms of analysis capabilities. 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*® capabilities, both heavily weighted items in our analysis. Green Building Studios™, by Autodesk, received the lowest overall score. However, it appears to be more versatile program than Ecotect™, lacking only in *Acoustic* capabilities. The results produced from the three software (namely Ecotect™, IES-VE™ and GBS™) have not been directly validated against DOE Energy Plus™ 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. This study was limited in scope and involved professionals from one company only; hence it may have overlooked several factors. The study is expected to be completed in summer 2009 and authors plan to publish complete findings in the ASC journal.

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 research does not endorse any software in any capacity.

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