International Journal of Research in Engineering, Science and Management
Volume 5, Issue 2, February 2022
https://www.ijresm.com | ISSN (Online): 2581-5792

BIM Concept in Sustainability Analysis

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***Abstract*: With an increasing price of energy and rising environmental problems, the requirements for sustainable building facilities with least environmental effect is also growing. In early conceptual design and preconstruction stages, the most compelling decisions in respect of sustainability in a building facility are made. In this context, Building Information Modeling (BIM) can help in performing complicated structure execution investigations to guarantee an optimized sustainable building plan (Salman Azhar & Farooqui, 2009). In this technical paper, the comprehensive literature investigation, with the help of last several years related papers, is adopted for reviewing and analyzing how to utilize BIM concept in sustainability analysis. This paper includes the sustainability analysis based on BIM; A case study; A BIM-based Sustainability Analysis Conceptual Framework; Advantages of the BIM-based sustainability practice implementation in construction projects and in the last conclusion. Particularly in a case study, EcotectTM, Green Building StudioTM (GBS), and Virtual EnvironmentTM are three building performance analysis software that have been evaluated for their suitability for BIM-based sustainability analysis.**

***Keywords*: BIM (Building Information Modeling), Building performance analysis, Sustainable analysis, LEED, Green building rating.**

1. Introduction

Construction industry consume approximately 40% of all energy utilized in the United States and responsible for 40% of worldwide carbon dioxide (CO2) emissions (Salman Azhar & Farooqui, 2009). Due to the drastically increasing price and emerging environmental issues have driven the demand for sustainable building facilities with less effect on environment through the use of environmentally aware design and construction practice. State such as Florida are requiring all the engineers, planners, architectures, and constructors to meet the energy code for the construction of all Government owned buildings (Salman Azhar & Farooqui, 2009).

The most efficient decision accompanying with sustainable design of a structure are developed in the early design and preconstruction phases. However, conventional CAD designing do not aid the chances of such advance decisions. Generally, after the architectural planning and construction documents, energy and performance analysis are typically achieved. Due to the absence of incorporation between the design and planning process leads to an incompetent process of retroactively adaptable design to achieve a desirable set of performance criteria (Salman Azhar & Farooqui, 2009). To survey building execution in the prior design and preconstruction stages everything being equal, access to an exhaustive set of information in regard to a material, structure, context and technical methods are required. Since Building Information Modeling (BIM) considers multi-disciplinary data to be superimposed inside one model, it sets out a freedom for maintainability measures and execution investigation to be performed all through the design process (Salman Azhar & Farooqui, 2009).

From 2007 the U.S General Service Administration (GSA) has mandatory BIM utilization on every single crucial project to empower “accurate energy estimates in the design process”. Due to these regulations that are frequently imposed to lower life cycle price, can have possible remarkable monetary suggestions on construction, operating costs and design. A new examination study has demonstrated that average BIM Return on Investment (ROI) goes from 634%-1633%, which unmistakably portrays its worthwhile financial advantages (Salman Azhar & Farooqui, 2009).

2. Literature Review

The fundamental purpose of sustainable design is to make structures in sustainable urban communities that are bearable, agreeable and safe. The sustainable plan of these structures directs to decreasing the exhaustion of basic assets (for example energy, water, and crude materials) just as forestalling ecological corruption brought about by infrastructure and facilities for the duration of their life cycle. Currently, the problem is that the AEC business is confronting is to satisfy the need for new and redesigned facilities that are open, secure and solid while limiting their effect on the communities, the economy and the climate (Jalaei & Jrade, 2015).

A few procedures have been established to set up the level of achievement of environmental objectives, and to control the planning and design cycles of green structures. For example, Building Research Establishment Environmental Assessment Method (BREEAM), Green Star from Australia, the Comprehensive Assessment system for Building Environmental Efficiency (CASBEE) from Japan, the Building and Environmental Performance Assessment Criteria (BEPAC) from Canada, and the Leadership in Energy and Environmental Design (LEED) from the United States are created and are presently broadly applied. Thorough inventories of the accessible instruments for natural appraisal techniques can be discovered (for example, the Whole Building Design Guide

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(WBDG) and the World Green Building Council (WGBC) (Jalaei & Jrade, 2015).

However, the current strategies and tools have an all-encompassing use, LEED has established solid validity among the professionals (Pulselli, et al., 2007). The LEED framework included 7500 organization and association individuals, approving its significance as the standard environmental performance proportion of structures and turning into a reference system for the design, construction, and activity of green structures past the U.S. (Jalaei & Jrade, 2015).

For the most part, LEED gives a solitary score that estimates the structure' evaluation, as indicated by the total points indifferent impact categories which are then added to accomplish the complete score. To achieve LEED certification, a project must initially consent to LEED essential items. At that point there is a scope of credits that the project ought to achieve for various LEED certificate levels: certified, silver, gold, and platinum, by meeting increasing least point levels (Kibert, 2005).

For instance, the cumulative points for each level in LEED Canada for newly built buildings range from 26 to 32 points for certified, 33 to 38 points for silver, 39 to 51 points for gold, and 52 to 70 points for platinum. Sustainable site (SS), water conservation (WE), electricity and environment (EA), materials and services (MR), indoor air quality (IQ), and the innovation and design phase are the key categories of LEED requirements (ID). And category has a number of requirements and sub-criteria, some of which are given a certain number of credits and others which are considered prerequisites (Jalaei & Jrade, 2015).

3. Sustainability Analysis based on BIM

Likewise with standard physical models and drawings, assessing building execution dependent on the graphic representation of conventional CAD or object-CAD arrangements requires a lot of human intercession and simplification, which delivers the analysis excessively expensive as well as tedious. A study led by the Center for Integrated Facility Engineering (CIFE) at Stanford University referred to that monetary reasons are among the essential causes for not executing feasible plan and construction methodology by most of review respondents (Salman Azhar & Farooqui, 2009).

A Building Information Model addresses the structure as an incorporated data set of composed data. Past graphically representing the design, a large part of the information required for supporting sustainable design is caught normally as design of the project continues. Moreover, the incorporation of Building Information Model with Performance Analysis instruments incredibly works on the regularly lumbering and troublesome analysis. This methodology gives architects simple admittance to instruments that give prompt feedback on design alternatives prior on in the design procedure (Salman Azhar & Farooqui, 2009).

For projects seeking after LEED® certificate, numerous LEED® credits necessitate that drawings be submitted to help the capability for credit. Although the majority of the drawings can be developed utilizing ordinary CAD programming, BIM programming creates these drawings more productively as a feature of the building information model and have the additional benefit of parametric change innovation, which directions changes and keeps up consistency consistently. Consequently, the client does not require to physically update drawings or links. In addition, such models convey an abundance of data for some different prospect of sustainable design as well as LEED® certification. For example, timetables of building parts can be acquired straightforwardly from the model to decide rates of material reuse, reusing, or salvage. Moreover, progressed visualization methods can persuade doubtful clients that green design executes well and looks great. As indicated by Autodesk, up to 20 credits for LEED® certification can be worked with utilizing BIM (Salman Azhar & Farooqui, 2009).

In sustainable design BIM assist in the following characteristics (Solla, et al., 2016):

- Building orientation (to opt the best building orientation which results in least energy costs).
- Building massing (to analyse building form and develop the building envelope).
- Daylighting analysis.
- Energy modeling (to diminish energy needs and examine environmentally friendly power alternatives like solar energy).
- Water harvesting (to reduce the usage of water in a building).
- Sustainable materials (to decrease material needs and to use recycled alternatives).
- Renewable energy.

1) Building Orientation and Massing

While designing an effective building envelope designed for thermal efficiency and comfort, proper massing and orientation allow fair access to daylight for all building occupants. The main concern is selecting the appropriate orientation and mass for the building in order to decrease energy consumption while still offering support to the users (Bolin, 2016).

2) Daylighting

Daylighting is the utilization of natural light, direct daylight and spread skylight for essential interior enlightenment; this decreases the prerequisite for counterfeit light inside the building, consequently diminishing energy utilization. The daylight standards are relying on estimation of the illuminance, which is denoted by E, of the working surface for particular date and time. In addition, it is also depending on the evaluation of daylight factor, which can be denoted by D, which should be in a range of greater than 2% and less than or equal to 5% for frequently using spaced (Maltese, et al., 2017). Therefore, proper building orientation and massing are critical to a successful daylighting design (Ander, 2016). The design of the daylight is the ratio of the interior or exterior illuminance and daylight factor (Krygiel, et al., 2008)

3) Energy modeling (Krygiel, et al., 2011)

Many of a building's structures revolve around energy consumption. For example, increasing the number of windows on the south façade allows more natural light in, but it also allows more solar heat gain, increasing the need for more air conditioning. To estimate the building's energy demands, the energy model takes into account variables such as the HVAC system, the number of occupants and their activity levels, sun shading devices, and other characteristics. By defining objectives and investigating many design options of the project, decrease and advancement can be made to energy loads. This enhancement can be found in three essential zones; Lighting, heat/cooling and energy.

4) Water Harvesting

The worldwide population is increasing rapidly as well as the demands for water and the availability of the water is limited. Therefore, it is one of the crucial resources. A number of innovations have emerged to help us reduce our water demand while still ensuring that it is used efficiently. The table below compares the water quality of various rating systems utilizing around the globe.

Table 1
Water efficiency comparison among different rating system
(Liu, et al., 2019)

	LEED	BREEAM	China	Green Mark	BEAM Plus
Water consumption	Water use reduction ≥50%	Improvement above baseline ≥55%	Lower limit value of water quota	No requirements	Estimated annual saving ≥30%
Water efficiency devices	No detailed requirements	Detailed water consumption specifications for WCs, urinals, taps, showers, baths and so on	WUE [2] of sanitary fixture reach Grade 2	No detailed requirements	WELS [3] Grade 2 or above
Untraditional water source	No requirements	Using recycled non-potable water for flushing ≥75%	For residential buildings ≥30% For cooling water ≥50% For landscape rainwater inlet ≥60% of evaporation	AHU condensate collection >50% of total, NEWater supply, On-site recycled water, rainwater	Reduction in potable water use ≥10%
Irrigation WCR [1]	Two grade: 50% and 100%	No requirements	No requirements	Areas covered with WEIS ≥25%	≥50%

[1] WCR—Water conservation rate. [2] WUE—Water use efficiency. [3] WELS—Water efficiency labelling Scheme.

5) Sustainable Materials

Designers can quickly question a BIM model for various materials or goods and calculate the volume of each. Many BIM applications have the ability to generate complex schedules. These schedules have to be generated only once during the project's life cycle, and in future it will automatically update details as per any adjustments are made. These schedules' data can be used in conjunction with spreadsheet programmes to measure components quantities as required. For several other purposes such as furnishing and building materials, green building construction is more interested in utilizing organic or semi-organic components (Zuo & Zhao, 2014). The semi-organic components such as defluorinated compounds, phthalate plasticizers, polychlorinated biphenyl, and brominated flame retardants may contain the harmful substance. Therefore, while using this type of components it is recommended to be cautious (Dunagan, et al., 2011).

4. Advantages of the BIM-based Sustainability Practice Implementation in Construction Projects

In recent years, there has been an uptick in cross-field research in BIM and sustainability (Olawumi & Chan, 2018). (Mom, et al., 2014) have found some advantages of using BIM in construction projects (2011). The use of BIM to recognise potential issues relating to building design, construction, and operation is one of the main benefits found by the literature. In addition, BIM may be used to advance sustainable practises in construction projects, such as energy conservation and profiling in buildings (Olawumi & Chan, 2018). BIM, according to (Akadiri, et al., 2012), is a valuable method for choosing sustainable materials for building projects. It is noteworthy that BIM software and associated modelling tools are being used to improve building sustainability parameters such as reducing carbon footprints, improving building energy efficiency, and creating green communities. A BIM-based algorithm created to assess the feasibility of calculating the deconstructability of building designs in order to reduce waste and maximise material use (Olawumi & Chan, 2018).

According to (GhaffarianHoseini, et al., 2017), BIM has aided project stakeholders in obtaining the Australian Green Star ranking and improving the design strategy. In addition, according to (Khaddaj & Srour, 2016), BIM can be used to simulate building maintenance and retrofitting; therefore, when combined with sustainable measures through associated plugins or APIs, it can help move sustainability practises forward to the facility management level. Furthermore, the aim of incorporating these sustainability initiatives into a construction project is to achieve long-term growth as well as the construction of green buildings, which can help reduce the negative effects of built structures on the environment and human lives (Maleki & Zain, 2011). Other advantages of green buildings or sustainable smart cities include improved individual's health, resident efficiency, corporate marketability, and green communities (Ali & Nsairat, 2008).

5. A Case Study

The aim of this study was to determine if leading building performance analysis software is suitable for BIM-based sustainability analysis. EcotectTM, Green Building StudioTM (GBS), and Virtual EnvironmentTM were the three software styles chosen for this project. Holder Construction Company (HCC) obtained the programme, and their BIM division conducted the study. Emory University's Psychology Building (Fig.1), which is located in Atlanta, Georgia, was chosen for this study as it is LEED® Silver certified. Early in the design process, BIM was utilized to decide the best structure orientation, analyse several skin type design options such as curtain wall, masonry, and window design, perform energy and daylighting analysis, and generate a report of LEED® daylighting credit qualification (Salman Azhar & Farooqui, 2009).

The method of integrating BIM and Building Performance Analysis Software is illustrated in figure 2 by outlining several data transfer measures. The boxes on the right show the programme features that were considered in this study (Salman Azhar & Farooqui, 2009).

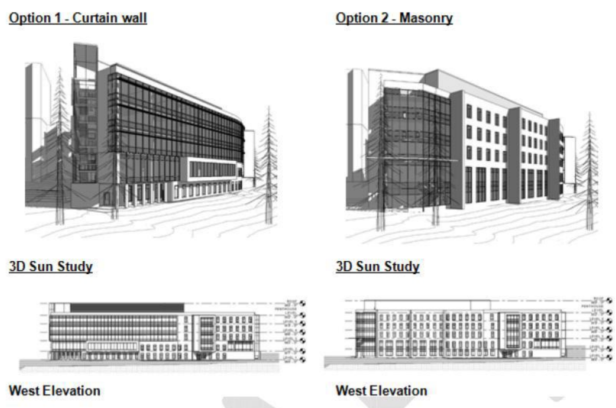

Fig. 1. Use of BIM for Options Analysis and Sun Studies in the Emory Psychology Building (Salman Azhar & Farooqui, 2009)

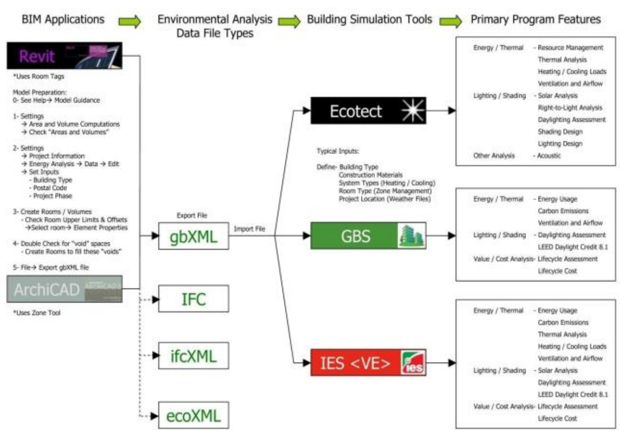

Fig. 2. Integration of BIM and Building Performance Analysis Software (Salman Azhar & Farooqui, 2009)

Each software's "pros" and "cons" are briefly discussed in the following paragraphs.

1) Ecotect™

EcotectTM is a "complete building design and environmental analysis tool" that "covers the full spectrum of simulation and analysis functions needed to better understand how a building design will work and perform," according to Autodesk, Inc. energy analysis, thermal analysis, and lighting/shading analyses are the key programme analysis abilities. Resource control, cooling and heating loads, ventilation and airflow are all considerations taken into account by the energy and thermal analysis features. Solar analysis, right-to-light analysis, daylighting evaluation, shading design, and lighting design are all possible with the lighting/shading analysis software. Other building facility tests, such as acoustic analysis, are also possible with EcotectTM. Figure 3 shows the "pros" and "cons" of using EcotectTM to analyse the efficiency of the Emory Psychology building design (Salman Azhar & Farooqui, 2009).

2) Green Building Studio™ (GBS)

Green Building Studio^{TM}, a web-based energy analysis service also operated by Autodesk Inc., helps users to assess the environmental effect of individual building elements early in the design stage. Lighting and shading analysis, energy and thermal analysis, and value/cost analyses are among the software's main analysis features. The energy/thermal studies look at how much energy is used, how much carbon is emitted, and evaluates ventilation and airflow. The LEED® Daylight Credit 8.1 feature is included in the lighting and shading analyses, which measure daylighting. Lifecycle evaluations and costs are determined by the benefit and expense functions. Figure 4 illustrates the "pros" and "cons" of utilizing GBS^{TM} to analyse the efficiency of the Emory Psychology building (Salman Azhar & Farooqui, 2009).

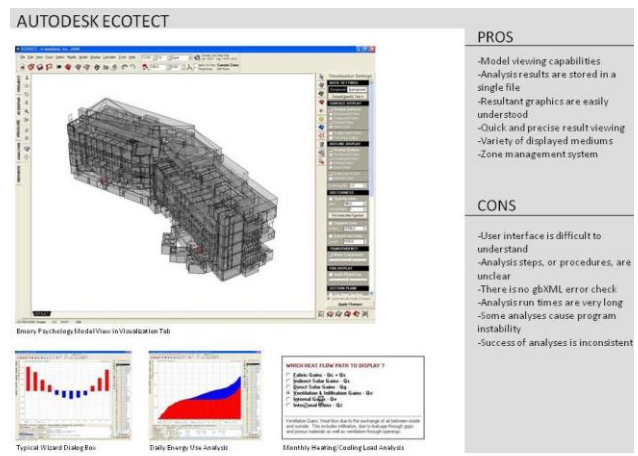

Fig. 3. Autodesk Ecotect™ "Pros" and "Cons" (Salman Azhar & Farooqui, 2009)

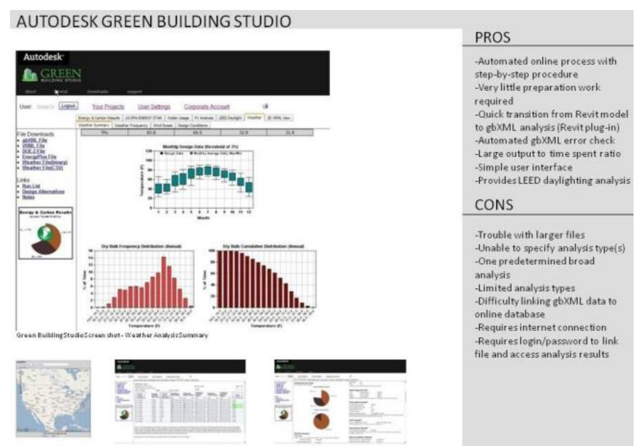

Fig. 4. Green Building Studio™ "Pros" and "Cons" (Salman Azhar & Farooqui, 2009)

3) Virtual Environment™

Virtual Environment^{TM} software from Integrated Environmental Solutions is a set of integrated building performance analysis programme. Solar, lighting, storage, prices, emergence, and a variety of other issues are all addressed with these tools. Energy consumption, carbon emissions, thermal analysis, heating/cooling load calculation, and ventilation / airflow evaluation are among the energy/thermal functions. Solar analysis, daylighting evaluation, and LEED® Daylight Credit 8.1 capabilities are among the lighting / shading functions. Lifecycle evaluation and lifecycle cost are two functions of value/cost analysis. Figure 5 shows the "pros" and "cons" of using VE™ to analyse the efficiency of the Emory Psychology building (Salman Azhar & Farooqui, 2009).

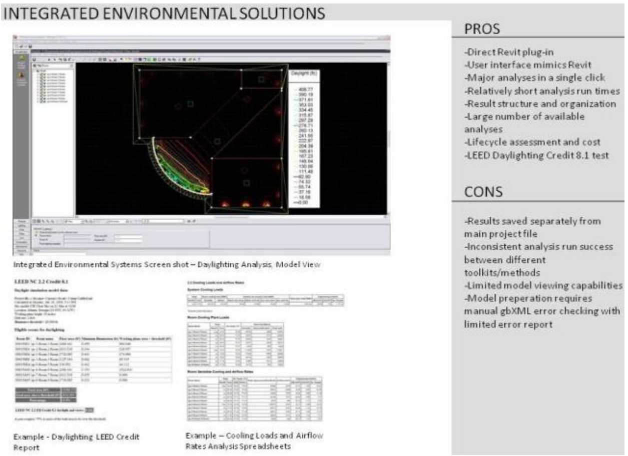

Fig. 5. IES Virtual Environment™ "Pros" and "Cons" (Salman Azhar & Farooqui, 2009)

4) *Evaluation of Building Performance Analysis Software*

An empirical analysis was conducted to assess the efficiency of these tools for different forms of sustainability analysis and to choose the best software. A list of several sustainability functions (as measured by the LEED® rating) was compiled. Each feature was given a weight factor that reflects its relative importance among the other features. Based on their expertise, a team of BIM and LEED® experts from the Holder Construction Company agreed on these weight factors. Following that, the same team analysed each software's features and assigned them a rating score ranging from 1 to 10 (Salman Azhar & Farooqui, 2009). The overall weighted score was then determined as follows:

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

Table 2
Building Performance Analysis Software Evaluation Matrix
(Salman Azhar & Farooqui, 2009)

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**

As shown in Table 1, the best software for BIM-based sustainability research is IES's Virtual EnvironmentTM as it is earned the highest score.

6. A BIM-based Sustainability Analysis Conceptual Framework (Salman Azhar & Farooqui, 2009)

Figure 6 depicts a conceptual structure for BIM-based sustainability research at various stages of a project life cycle (or project phases). The various project phases are shown in the left-hand box (or construction company departments). The various sustainability analysis features are depicted in the middle box, while the interaction of external stakeholders (such as consumers or project partners) in sustainability analysis is depicted in the right-hand side box. Construction companies who want to conduct BIM-based sustainability research may use this method.

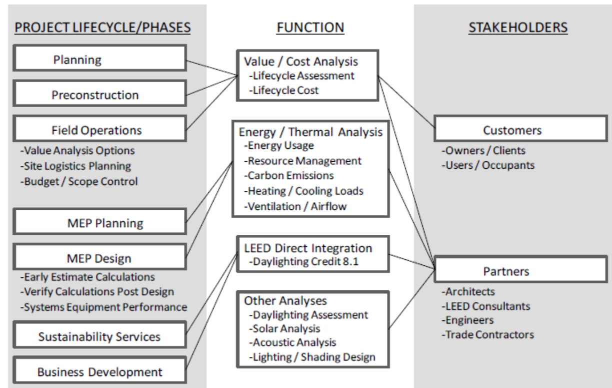

Fig. 6. A conceptual framework for BIM-based sustainability analysis (Salman Azhar & Farooqui, 2009)

7. Conclusion

This preliminary research suggests that BIM can help with complex sustainable design processes like energy analysis, daylighting, and solar access, as well as optimize tedious tasks like material takeoffs, project cost, and construction schedules, all while collecting and coordinating data into a one single integrated model. Green BIM has emerged and proven to be accessible for energy analysis, daylighting, water prevention, and environmental analysis tool during a building's early design stage that helps to keep track of carbon footprints on the environment, according to a study of scientific literature and publications. Based on a comparison of three building performance analysis tools, the Virtual EnvironmentTM software from Integrated Environmental Solutions appears to be the most robust and efficient in terms of analysis capabilities. EcotectTM is the least flexible of the three, despite being better than Green Building StudioTM in a number of categories, such as thermal, solar, and lighting and daylighting. This is due to its lack of Value and Cost, as well as LEED® strengths, which were both weighted heavily in our evaluation. Autodesk's Green Building StudiosTM achieved the lowest overall ranking. It tends to be a more flexible software than EcotectTM, with the exception of Acoustic capabilities.

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