BIM in Sustainable Design: Strategies for Retrofitting/Renovation

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ABSTRACT

Improving the performance of existing buildings has provided a broad market for the green renovation of US building stock which is estimated at 76 billion square feet. Building Information Modeling (BIM) has had tremendous impact on the building industry by increasing productivity and document accuracy alone. The integrative nature of BIM technology renders it an ideal tool for implementing sustainable strategies into the renovation and/or retrofit of existing structures.

By exploring the nature of the relationship of BIM and sustainability, as it applies to the built environment, the intent of this research is to determine what functions of BIM could be utilized to implement sustainable design principles into the retrofit and/or renovation of existing structures. The study sought to establish a sustainable framework for an evaluation and a set of "Best Practices" for the retrofit and renovation of projects seeking sustainable status.

To provide a baseline in determining possible "best practices" a professional survey was conducted, within the state of Florida, along with an analysis of a local existing structure. The survey focused on determining to what extent professionals utilize BIM to implement sustainable design principles in retrofitting/renovation and how BIM and sustainability impacted their practice. The case study investigated the process for conducting a total renovation with a goal of utilizing BIM in as many areas as possible to provide a sustainable outcome. To comply with current LEED rating systems an evaluation was made to determine what level the alterations would achieve under the category of LEED 2009 NC.

Although the LEED rating determination and level of sustainability depends entirely on the scope and nature of the renovation; results of this research show that BIM can be an effective tool in implementing sustainable design principles into the renovation and/or retrofit of existing buildings despite the scope of the renovation.

INTRODUCTION

The built environment, on a global scale, has contributed significantly to the depletion of natural resources, degraded ecosystems, and polluted our atmospheric pollution. This fact underscores the importance of targeting building energy use as a key to decreasing the nation's energy consumption and ameliorating or at least minimizing building's environmental harm (Winter, 2011). Williams charges us: "We must aggressively commit to designing sustainable—that is, designing within the limits of natural resources and natural laws." (Williams, 2007, p. xv).

According to the U.S. Energy Information Administration, the building sector consumes 47.6% of all the energy produced in the United States and 74.9% of all the electricity produced. As a result, the building sector is the largest contributor to climate change by emitting 44.6% of all greenhouse gas (GHG) emissions (McGraw Hill, 2009).

With 76.9 billion square feet of existing building stock and a number of inefficient buildings, green building has a tremendous long-term opportunity to dramatically reduce U.S. energy consumption and greenhouse gas emissions. Cost-effective retrofit potential remains for over 80% of these buildings (Lockwood, 2009).

While Building Information Modeling (BIM) and sustainability are not new concepts within the Architecture, Engineering, and Construction (AEC) industries, their integrated potential is just beginning to be realized. A lot of research has been conducted to further enhance the capabilities of BIM in design and construction. However, there has been very little research done so far on the impact that BIM can have on sustainable construction practices (Bynum, at al, 2013). A fundamental tenet of true sustainable design is the integration of all the building systems. BIM's greatest capacity is its inherent nature of integration, among the building disciplines, as it relates to a sustainable world at the front end of a project, during design, construction, and operation (Krygiel & Nies, 2008). The combination of sustainable design strategies and BIM technology has the potential to change the traditional design practices and to efficiently produce a high-performing building (Azhar, at al, 2010).

SUSTAINABLE RETROFIT

Recognizing that most of the attention to green building, to date, has focused on new commercial and public buildings, it is important to increase our focus on untapped opportunities for greening existing buildings and homes, which comprise the majority of the U.S. building market (EPA Green Building Strategy, 2008). Revisiting our existing buildings and making them cleaner, safer, and more efficient is one of our advantageous opportunities to cut global emissions and conserve natural resources; create jobs and save taxpayer dollars. (Gatlin, 2011).

Retrofits do not yield the same profit margin as do construction projects begun from the ground up, but they are a safer play in the current economic climate. Green renovations are generally less risky because they involve fewer material expenses since the structural components are already in place; in-place tenancy, in many cases; and an overall smaller scale (Lockwood, 2009).

Financial benefits are the primary driver, energy-efficiency improvements, and environmental and social paybacks follow for owners and operators choosing to go green. However, the green building retrofit market posts possible strong growth over next 5 years. McGraw Hill, in their SmartReport of 2009, reports benefits like lower energy use; reduced greenhouse gas emissions, water savings, and better indoor environmental quality.

Other benefits include an increase in the Return on Investment (ROI) due to a decrease in annual operating costs, an increase in building values, an increase in overall occupancy, and finally, an increase in expected lease values. By far the greatest potential savings – far greater than energy or waters savings is in increased workforce productivity. Employees being the largest investment business owners make provide multifaceted potential for savings (Lockwood, 2009).

Finally, to realize the full potential of a green retrofit it is imperative to ensure that buildings are retrofitted at the right point in their upgrade cycle rather than on a timeline driven by government incentives or piecemeal upgrade programs. This is the case because deep retrofits must piggyback on already existing plans and needs for capital and operational upgrades.

STUDY APPROACH

The intent of this research was to determine how BIM could be utilized to implement sustainable design principles into the retrofit/renovation of existing structures. The investigation included determining what functions of BIM make it an appropriate tool to implement sustainable design principles, ascertaining sustainable design principles that relate specifically to the built environment, examining components of built structures to establish how to make it a sustainable structure, and finally by exploring the relationship between BIM, sustainability and the built environment to determine “Best Practices’.

To achieve these goals professional interviews and case studies were conducted to determine the extent the AEC community utilized BIM to implement sustainable design principles and how BIM and sustainability impacted their practice. Interviewees included architects, landscape architects, engineers, and contractors that use BIM in Florida. A case study of an existing building having had a retrofit/renovation was investigated using BIM to perform sustainable analysis to determine strategies that can be implemented to improve the sustainability of the building.

PROFESSIONAL INTERVIEWS

The intent of the interview was to determine the extent the AEC community utilized the BIM to implement sustainable design principles and how BIM and sustainability impacted their practice. If sustainable practices weren’t realized with BIM; why not? Table 1 shows a sample of the interviews questions. In summary, the interview results indicated that the sustainable benefits realized as a result of using BIM are not universal, the perceptions that BIM is changing the AEC professions’ ability to deliver projects with improved sustainability are more common place. Of the firms responding 67% used BIM to its potential and 34% used BIM but did not practice sustainability at all. When asked why the response was they “felt sustainability was a fad like seasonal colors and that sustainability was client driven”.

EXISTING BUILDING CASE STUDIES

A number of case studies of existing buildings were examined. These include Springfield Literacy Center, Springfield, Pennsylvania; Historic "Grant School", Washington, D.C.; Pittsburgh Convention Center, Pittsburgh, PA; and "One Market",

Table 1. Sample Professional Interview Questions.

1	What is your role in your firm and how long have you been in this capacity?
2	What is the discipline your firm practices?
3	What does sustainable design mean to you in the capacity of your profession?
4	In your practice is sustainability a driving factor in your design solutions?
5	If so, in what manner? If not, why has it not been thus far?
6	If not, do you anticipate incorporating them in the near future?
7	Does your practice include retrofit and/or renovation projects? What type?
8	What percentage of your project workload?
9	If you practice sustainable design what principles do you incorporate?
10	Do you use BIM in your professional practice? If so, how long have your been working with BIM? To what extent do you utilize BIM technology?
11	If you do not use BIM why are the reasons why?
12	Have you utilized BIM to implement sustainable strategies into your design?
13	If so, which ones? To what extent? The Results? What were the benefits?
14	What do you think about integrating BIM and Sustainability criteria in practice? How would it impact your work?
15	Would cost of software and training play a role in the decisions to do so?
16	Would you prefer to utilize BIM for new construction or on renovation?
17	Do you think having a national BIM standard is critical to implement sustainability requirements?

Headquarters for Autodesk, San Francisco, CA. In the Springfield Literacy Center, Springfield, Pennsylvania project, early in design of the 50,000 square foot school floor-to-ceiling windows were scheduled for the classrooms. The engineers ran an analysis and demonstrated that daylight could be optimized and glare minimized if the window were smaller and fitted with light shelves. (Novitski, 2009).

In the Pittsburgh Convention Center case study, since the center was not performing as well as predicted, the engineer on the project explained, "By using a detailed energy simulation normalized to actual energy use the contractor was able to pinpoint areas that either hadn't been thought of in the design or weren't being operated as intended. After we fixed those, the energy performance of the building improved (Novitski, 2009).

Autodesk, manufacturer of Revit, used BIM software to convert a 35,000 square foot building into its headquarters with gallery spaces. By utilizing lighting and daylighting analysis tools that integrate with BIM along with utilization of 75% of the existing ductwork the project received a LEED Platinum rating (Novitski, 2009).

SUSTAINABLE FRAMEWORK AND BIM

When dealing with an existing structure and a specific scope of renovation requirements a great percentage of the systems are in place, and not within their life cycle for replacement or renovation. Therefore, a total sustainable make over may not be plausible. However, even with a limited scope the decision to implement and utilize sustainable practices, whether it is with "green" finishes and materials or efficient fixtures, can have a positive effect on bottom line of operational costs not to mention residual benefit to the environment.

Therefore, the following framework has been developed to address whole building renovation with the intent to provide comprehensive evaluation criteria for implementing sustainable principles. Partial or limited scope renovations can utilize pertinent features thereby setting precedent for future renovations on the structure.

The proposed framework to evaluate and implement the sustainable principles into existing renovations and/or retrofits utilizing BIM directly is as follow: It has been organized into two categories: building form and building function.

Building Form

- Orientation - Proper orientation sets up the building for optimization of solar-based passive strategies. (McLennan, 2004, pg 131) BIM assists in properly orienting the project by allowing the site to be located by longitude and latitude.
- Massing - Massing allows good access to daylight while creating an efficient building envelope. (McLennan, 2004, pg 139) BIM allows investigation with simple massing shapes to compare configurations.
- Envelope - The quality, permeability, and conduction resistance of the materials, along with the insulation and the amount of glazing are some of the factors that will combine to determine the efficiency of the building mass and systems. (McLennan, 2004) BIM allows for customized composition assemblies.
- Daylighting - Daylighting is the use of natural light for primary interior illumination. This reduces your need for artificial light within the space, thus reducing internal heat gain and energy use. The BIM model can be utilized for daylighting simulations and shading options for interior and exterior conditions.

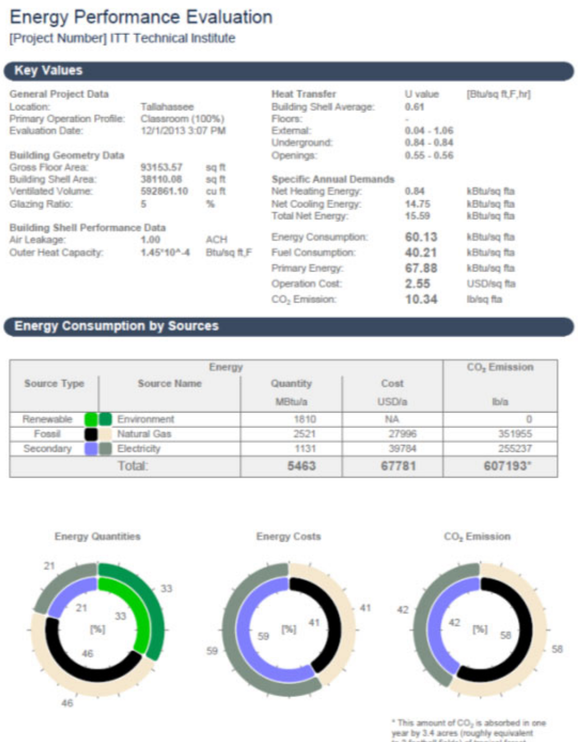
Building Function

- Energy - A building’s energy needs are paramount to helping the project become more sustainable. The energy evaluation uses climatic data from energy websites to calculate consumption rates and costs per energy type.
- Water - Water use demand reduction is critical. Water handling is an area in which there is not direct BIM application. However, the BIM model can provide information extracted from its database to develop strategies that include use of efficient equipment and fixtures, rainwater harvesting, and graywater reclamation.
- Ventilation - Using prevailing breezes when possible for natural ventilation reduces the load on the mechanical equipment.
- Lighting - Efficient lighting involves a complex balance of natural daylighting and electrical lighting. The BIM model allows for the coordination of natural lighting and the available daylighting in determining proper lighting levels.

RESEARCH CASE STUDY: ITT & USGS BUILDING, TALLAHASSEE, FL

To gain insight into the practical application of utilizing BIM to implement sustainable practices into an existing renovation, an actual existing building was chosen to serve as a case study. The process including project goals was documented explaining at each step how BIM was utilized. A cursory review of possible LEEDs credits achieved was also performed to show connection between BIM technology and LEEDs.

The building chosen to serve as the case study for this research is Building A of the Cedars Executive Center office complex. The complex consists of four separate office buildings and is located in Tallahassee, Florida, on North Monroe Street just south of Exit 199 on Interstate 10. Built in 1974, it consists of slab-on-grade, metal pan with concrete slab floor and roof, and 6” CMU construction and blown-in cellulose insulation with stucco and brick veneer exteriors. The building has a total square footage of 38,000 with a footprint of 190’ X 100’. Each of the two stories consists of 19,000 square feet each. The lower floor hosts the Tallahassee campus of ITT Technical Institute with administration offices, classrooms, labs, library, and a student lounge. The project goals for completing a sustainable renovation were to decrease energy consumption by 50%, use as much renewable energies as possible, and to conserve as much water as possible on the site. With the goals set the outline for process went as follows; as-built condition documentation, model the building within BIM, determine existing performance levels, determine strategies to meet project goals, and finally to evaluate all strategies to determine most efficient & compliance project goals (Figure 1).



Energy Performance Evaluation

[Project Number] ITT Technical Institute

Key Values

General Project Data			Heat Transfer	U value	[Btu/sq ft,F,hr]
Location:	Tallahassee		Building Shell Average:	0.61	
Primary Operation Profile:	Classroom (100%)		Floors:	-	
Evaluation Date:	12/1/2013 3:07 PM		External:	0.04 - 1.06	
			Underground:	0.84 - 0.84	
Building Geometry Data			Openings:	0.55 - 0.56	
Gross Floor Area:	93153.57	sq ft			
Building Shell Area:	38110.08	sq ft	Specific Annual Demands		
Ventilated Volume:	592861.10	cu ft	Net Heating Energy:	0.84	kBtu/sq fta
Glazing Ratio:	5	%	Net Cooling Energy:	14.75	kBtu/sq fta
			Total Net Energy:	15.59	kBtu/sq fta
Building Shell Performance Data					
Air Leakage:	1.00	ACH	Energy Consumption:	60.13	kBtu/sq fta
Outer Heat Capacity:	1.45*10^-4	Btu/sq ft,F	Fuel Consumption:	40.21	kBtu/sq fta
			Primary Energy:	67.88	kBtu/sq fta
			Operation Cost:	2.55	USD/sq fta
			CO_2 Emission:	10.34	lb/sq fta

Energy Consumption by Sources

Source Type	Source Name	Energy Quantity MBtu/a	Energy Cost USD/a	CO_2 Emission lb/a
Renewable	Environment	1810	NA	0
Fossil	Natural Gas	2521	27996	351955
Secondary	Electricity	1131	39784	255237
Total:		5463	67781	607193*

* This amount of CO_2 is absorbed in one year by 3.4 acres (roughly equivalent to 3 football fields) of tropical forest.

Figure 1. Case study energy performance analysis.

Figure 2. ITT Building.

Figure 3. Model Floor

Figure 4. BEM Model.

It is important to compare the performance history to the analysis for an accurate baseline; modifications may be necessary prior to comparing strategies. The project goals and budget are the guidelines for the strategies. This will allow each strategy, or combination thereof, to be prioritized by least invasive and/or economical to the higher first cost options. However, all options should be evaluated based on long-term costs, durability, and service to the building.

There are several possible strategies that are employed to achieve the 50% reduction in energy consumption. They generally vary in complexity. The sustainable framework provides elements of evaluation that include orientation, massing, envelope and daylighting specific to the buildings' form. Energy systems, water, ventilation and lighting are the framework elements for the buildings functions

BEST PRACTICES

The following Best Practices for utilizing BIM in sustainable renovation and/or retrofit were identified through research, discussions, observations and case study exercises:

1. Commitment to Understanding - Sustainability necessitates a paradigm shift in thinking about design, construction, and operation process.
2. Understanding of Nature and Climate - The built environment can interact properly with its surrounding climate and natural environment.
3. Understanding of Place and Culture - Generate an operations profile to understand the energy demands.
4. Understanding of Local Jurisdiction and Available Resources - What incentives and renewable energies are readily available
5. Understanding Synergies of Sustainable Design, the Built Environment and LEEDs Rating System through the form and function of the building type.
6. Understanding and Proficiency in BIM - It is a skill set inclusive of work flow collaboration, technology, architecture, construction, sustainability, site analysis, and materials.
7. Understanding of Existing Structures and Nature of Renovation & Retrofit - Diagnosis of Past Performance and investigation into existing conditions.
8. Implementation Process - Have in place an "Order of Operations"
   A. Analysis of Climate, Place & Culture, B. Diagnosis of Existing Structure, C. Reduce Demand Loads, D. Utilize free resources available, E. Maximize use of efficient man-made systems and fixtures, F. Address remaining impacts and consequences

CONCLUSIONS

Revisiting our existing buildings and making them cleaner, safer, and more efficient is one of our advantageous opportunities to cut global emissions and conserve natural resources; create jobs and save taxpayer dollars. In consideration that 80% of reported 71.6 billion square feet of existing buildings are in their prime for renovation this research seeks to determine how BIM could facilitate the implementation of sustainable strategies into renovating the existing US building stock.

The investigation explored the functions of BIM that facilitate sustainable design principles, ascertained sustainable principles relating to the built environment, examined the market for green renovations, and explored the relationship between BIM, the built environment, and sustainability. A "Sustainable Framework" and a "Best Practices" guide were proposed.

This research has determined that a whole building renovation lends itself more susceptible to resulting in a sustainable existing structure. However, the nature of renovation does not always render itself to a complete renovation or retrofit. For a renovation and/or retrofit to result in converting an existing structure into a sustainable structure the project must address the performance, interaction of, and provision for, at least, the mechanical, electrical, plumbing and lighting systems, daylighting, the envelope assemblies including roof and flooring, and finally, the conservation of water.

Although the nature and scope of the renovation has impact, this research found that the inherent nature of integration of BIM made it an ideal tool for implementing sustainable design principles into the renovation and/or retrofit of existing buildings regardless of the scope of the renovation. First and foremost, BIM facilitates the collaboration of many disciplines into the early stages prior to renovation. The most prominent feature is the newly integrated energy analysis with BIM platforms which resolved the conflicts of data file transferring on different applications allowing efficient reconfiguration of the model to compare performance data. All additional features support the energy analysis as the tool for measuring and monitoring performance levels.

Precedents reveal that as BIM technology evolves it will continue to support the accuracy and efficiency of sustainable renovations.

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