Using Building Information Modeling technology to empower sustainable design

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Abstract

The increasing awareness of the accelerating rate of depletion of natural resources, climate change and carbon dioxide emissions from the built environment is resulting in the high level of demand for sustainable buildings. The most important decisions regarding a building's sustainable features are made during the design stages. Designers historically relied on physical models and manual calculations to optimize building designs for optimal energy and resources consumption and maximizing user comfort. But since the advent of computers, digital tools had an ever growing role in performing engineering simulations and rapidly exploring new design options to reach the best solution. Under optimum conditions, simulations and design tools would be well integrated that each time an architect altered any design aspect, the building's predicted environmental performance would be updated and displayed instantly. Along the way, other aspects of a building, such as how well a building uses daylight, how its materials l affect the planet, and how much it will cost to build, could be tracked and optimized. And all of this would be done while sharing a design seamlessly across disciplines, enabling design teams to explore more options, with more accuracy in less time.

Still facing problems, CAD technologies are getting closer every day to that target. Within this context, Building Information Modeling (BIM) is increasingly being looked upon as a robust tool to achieve that target. Relying on powerful parametric-object based-engines and comprehensive integrated database structures, BIM has a great potential to offer significant enhancements to sustainable design aspects. In this paper, analysis of the possible enhancements BIM could present to enhance sustainable design activities are presented. First, main concepts of BIM technology are presented. Then strategies to approach a sustainable building design will be illustrated. Finally, the possible applications of BIM data rich models in sustainable design will be deduced and illustrated.

Keywords

Building Information Modeling; BIM, Computer Aided Design; CAD, Sustainable design, Green buildings

1. Introduction

The environmental impact of the building design, construction, and operations industry is enormous. Buildings account for 40% of global CO2 emissions[1]. In 2006, the commercial building sector in the United States alone produced more than 1 billion metric tons of carbon dioxide, an increase of more than 30% over 1990 levels. Each day 5 billion gallons of potable water are used solely to flush toilets.[2] Development alters land from natural, biologically diverse habitats to hardscape that is devoid of biodiversity. The far-reaching influence of the built environment necessitates action to reduce its impact. Green building practices can substantially reduce or eliminate these negative environmental impacts, while maintaining users' comfort.

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[3]. In order to assess building performance in the design and preconstruction phases realistically, access to a comprehensive set of knowledge with respect to building's form, materials, context, and technical systems are required. Because Building Information Modeling (BIM) allows for organizing design data in an integrated database that is data rich, object-oriented, intelligent parametric digital representation of a building facility. It allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures and performance analysis to be performed from early design stages; like site selection and building form exploration up to the final refinements made to material specifications.

BIM can reduce the costs associated with traditional sustainability analyses, while also realizing the benefits associated with these analyses, by making the information required for sustainable design, analysis and certification routinely available simply as a byproduct of the standard design process[4]. Linking the building model to analysis tools allows for evaluation of energy use during the early design phases. This paper aims at identifying how BIM models can be adopted in design activities of sustainable building design, from the early stages of design up to its final stages, and what enhancements does it provide over traditional tools.

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[1] S. Azhar, J. Brown and R. Farooqui, 'BIM-based Sustainability Analysis: An Evaluation of Building Performance Analysis Software', in *Proceedings of the 45th ASC Annual Conference*, 2009.
[2] *LEED 2009 for Retail Commercial Interiors* (USGBC, 2011).
[3] A. Schlueter and F. Thesseling, 'Building Information Model Based Energy/exergy Performance Assessment in Early Design Stages', *Automation in Construction*, 18 (2009).
[4] *Building Information Modeling for Sustainable Design* (Autodesk whitepaper, 2005).

2. Building Information Modeling concepts

The National Institute of Building Standards (NIBS)[5] puts forward a definition of a Building Information Model as follows: [6]

"BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward."

Also U.S. General Services Administration (GSA) in its published report (GSA BIM Guide) defines Building Information Modeling as follows: [7]

"Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design."

These definitions establish a clear separation between regular 3D geometric models that contain very little intelligence. BIM models contain a high level of intelligence, a 3D model includes a three-dimensional geometric representation of the building, whereas a BIM is organized as a prototype of the building, in terms of building floors, spaces, walls, doors, windows and a wide array of information associated with each of these elements. The main characteristics of BIM can be summarized as follows:

2.1. BIM operates on digital databases

The term "Information model" has its roots in the arena of information technology and management of digital databases. An Information Model provides the framework for organizing content, once you have created it for your content repository, you will be able to label information in ways that will enhance search and retrieval. The information can be reorganized in many ways, depending upon who is doing the search.[8] Every element in a BIM model comes with editable attributes that are stored as data in a table. The links between the data in different elements of a BIM assembly are consistently managed and interconnected. See Figure 1. Such applications start with capturing information about the building, then present them back and make it available for use and reuse at every phase in the project. [9]

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[5] The National Institute of Building Sciences (NIBS) is a U.S. non-governmental, non-profit organization, authorized by Congress to encourage a more rational building regulatory environment and to accelerate the introduction of existing and new technology into the building process.
[6] *GSA BIM Guide Overview* (U.S. General Services Administration, 2007).
[7] Ibid.
[8] JoAnn T. Hackos, *Content Management for Dynamic Web Delivery*, 1st edn (Wiley, 2002), p. 124.
[9] M. Ibrahim, 'CAD Smart Objects: Potentials and Limitations', in *21th eCAADe Conference Proceedings*, 2003.

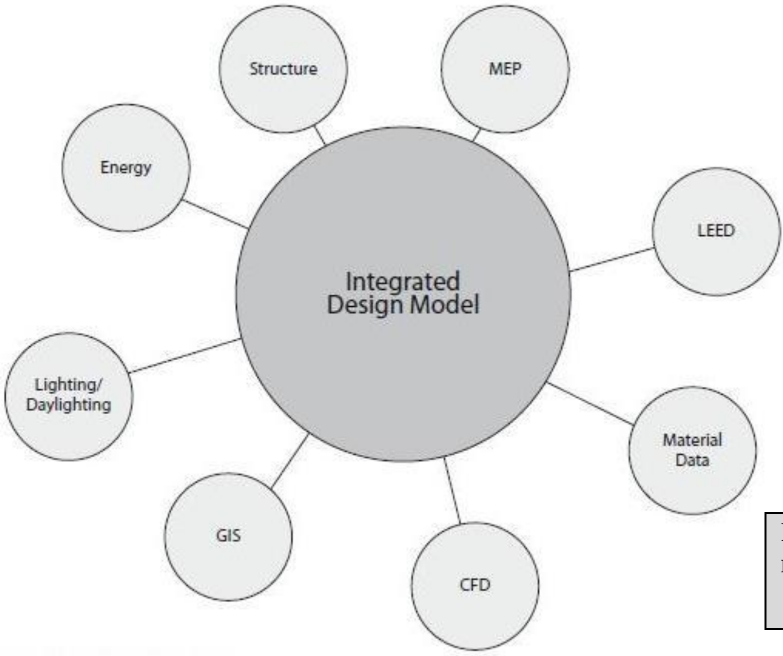

Figure 1 The integrated design model as a central database

Storing and managing building components in the form of a database gives a BIM process the following advantages:[10]

- Better change management

Maintaining an internally consistent representation of the building as a database improves drawing coordination and reduces errors in the documents.

- Better coordination

Ambiguities in the design documents are resolved between the design and construction teams before construction.

- Information reuse

Reuse of building information leads to connections from BIM authoring solutions to other applications for energy analysis, structural analysis, cost reporting, facility management, and many others.

2.2. BIM is object based

Traditional CAD models are recognized as the digital representations of well-understood drawings of building objects. Thus the models represent the shapes and dimensions by assembling lines into solid models. As an example, Figure 2 gives the elevation view of a building in CAD. The objects can be clearly classified by different layers in the design—Layer for exterior walls, another one for windows, etc. Every aspect of element's geometry must be edited manually, and it will take substantial amount of time to conduct these changes, while some errors and omissions may occur in this process.

[10] *Building Information Modeling* (Autodesk white paper, 2002).

BIM models include a 3D geometric representation of the building, it is organized as a prototype of the building, in terms of building floors, spaces, walls, doors, windows and a wide array of information associated with each of these elements. Embedded information can describe the geometry, as well as, materials, specifications, price, manufacturer, and any other related data associated with how the object is actually used. A window as a smart object understands its relationship to a wall and reacts accordingly. Figure 3

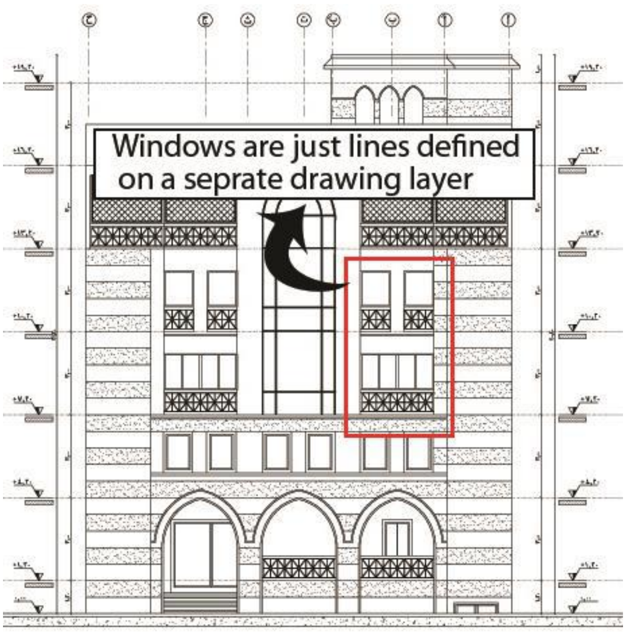

Figure 2 CAD elevation showing drawing entities created on separate layers

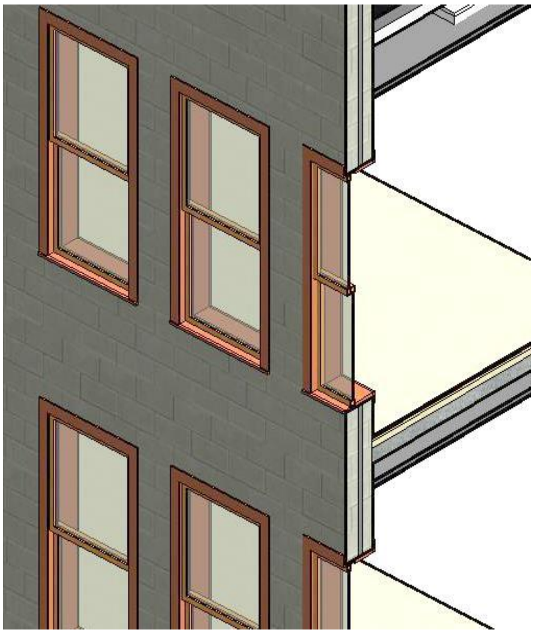

Figure 3 In a BIM model, building elements are classified ccording to their real nature

2.3. BIM provides more enhanced parametric modeling

There are differences between the parametric modeling tools used in BIM and those used in other industries. Each building system has typical building rules that are more predictable than for general manufactured objects. BIM tools have their own predefined set of object types; each having possibly different behaviors programmed with them, like walls, windows etc. BIM builds upon the concept of parametric geometric modeling, offering a more comprehensive approach to building design as follows;[11]Object-based parametric modeling addresses geometry, but objects also need to carry a variety of properties if they are to be interpreted, analyzed, and priced. For example, design properties address space and area names, properties for spaces such as occupancy, activities, and equipment performance needed for energy analysis. Figure 4 shows a door created in Autodesk Revit. Door properties include geometric definition as well as material and phase of construction.

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[11] Chuck Eastman and others, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors* (New Jersey: John Wiley & Sons, 2011), pp. 58–62.

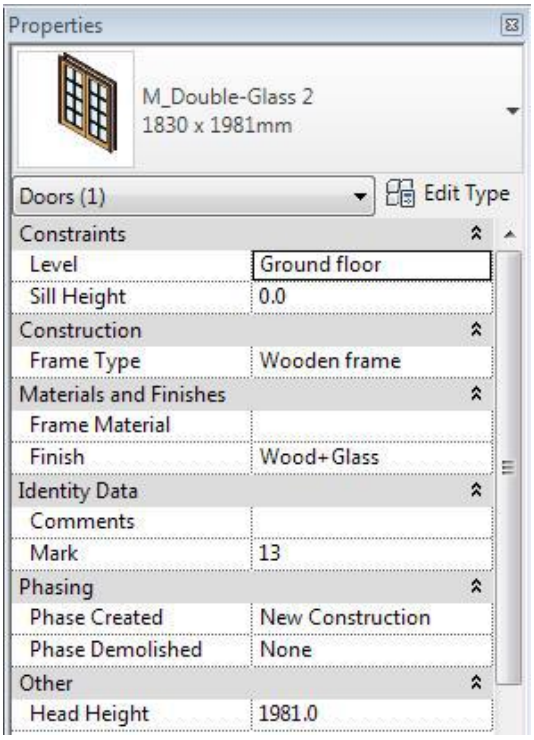

Figure 4 Snapshot of the properties of a door element created in Autodesk Revit

3. Sustainable design

Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs.. Many standardized systems were developed to provide guidance and regulation in the sustainable building design field. One of the most recognized examples of these rating systems is "Leadership in Energy and Environmental Design" (LEED). The USGBC introduced the LEED green building rating system in 1998 as LEED for New Construction (LEED-NC).[12] Under this system, buildings are evaluated through a 100 base point credit system in five categories of environmental performance, plus 6 possible in "Innovation in Design" and 4 regional priority points. The categories and credits available are:[13]

- Sustainable Sites (26 points)
- Water Efficiency (10 points)
- Energy and Atmosphere (35 points)
- Materials and Resources (14 points)
- Indoor Environmental Quality (15 points)
- Innovation and Design (6 points)
- Regional priority (4 points)

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[12] https://new.usgbc.org/leed

[13] *LEED 2009 for New Construction and Major Renovations* (USGBC, 2009)

To show credit achievement, the team must document in an online system. There are four levels of LEED certification: LEED Certified, LEED Silver, LEED Gold and LEED Platinum. The level of LEED certification a building earns is determined by the number of points awarded to the project in each of the categories. No points are awarded and the certification is not received until construction is complete.[14] Based on these criteria, a series of simple design concepts - that can utilize available CAD and analyses tools – can be applied to help guide a project toward a more sustainably driven outcome as follows:

3.1. Building massing and orientation

Proper massing and orientation allows good access to daylight for all the building occupants while still creating an efficient building envelope optimized for thermal efficiency and comfort. Massing spans across many other design considerations, but the primary concern here is choosing the right mass and orientation for the building to help reduce the building's energy needs, while in the same time providing comfort for the users.

3.2. Daylighting

Daylighting is the use of natural light for primary interior illumination. This reduces the need for artificial light within the space, thus reducing internal heat gain and energy use. Natural light is the highest-quality and most efficient light source available and it is free. An effective day lighting design relies heavily on proper building orientation and massing already discussed.

3.3. Water efficiency

Water is one of our most critical resources; the amount of water available is finite. And as our population continues to grow, so do our demands on our water. A variety of technologies have been developed to allow us to reduce our water demand and make sure it is used efficiently. For example:

- Selection of efficient equipment: There are a number of efficient systems for the variety of water uses on the market, for example, dual flush toilets
- Rainwater harvesting: Rainwater can be reused with little energy and simple filtering systems for irrigation purposes. Also it can be reused for toilet flushing.
- Graywater reuse: Graywater is the water from your showers, sinks, drinking fountains, dishwasher and so on. Treatment and reuse of this water onsite can be a great strategy for reducing water usage.

3.4. Energy modeling

Many of the systems within a building revolve around the energy use. For instance, if you increase the windows on the south façade, you allow in more natural light, but you are

[14] Salman Azhar and others, 'Building Information Modeling for Sustainable Design and LEED® Rating Analysis', *Automation in Construction*, 20 (2011).

also letting in additional solar heat gain, increasing your need for more air-conditioning. The energy model combines factors such as HVAC system, the number of occupants and their activity levels, sun shading devices and other factors to predict the building's energy demands. By setting goals and exploring many design options of the project, reduction and optimization can be made to energy loads. This optimization can be found in three primary areas; Lighting, heat/air-conditioning and power. By investigating use of energy across these 3 areas, the designer can explore options to lower power demands such as:

- Better insulation strategies for the building envelope
- More efficient heating and air-conditioning equipment
- More efficient light fixtures
- Energy-efficient appliances, and equipment

3.5. Sustainable materials

There are a lot of factors to consider while choosing materials such as:[15]

- Does the product throughout its lifecycle include any substances that have the potential to harm human health or the environment?
- Does the product perform its intended function efficiently?
- Is the product produced with recycled materials, reducing the demand for consuming new raw materials?

4. Traditional practice

As the project team goes through various design iterations, the team eventually creates a series of models. The term "Model" is used here generally to refer to a collection of specific ideas and concepts. In a green building design environment, design teams to pull data out of these models, or to insert these models in analysis applications to analyze these data and present it in a meaningful way. Examples of these models are:

- The solar analysis model

This model is created to understand the value of shading and various shading schemes against the building façade.

- The digital design model

This model is a 3D graphical representation of the building, used to communicate design to the client and owner groups.

[15] Eddy Krygiel and Brad Nies, *Green BIM: Successful Sustainable Design with Building Information Modeling* (Indiana: John Wiley & Sons, 2008), p. 201.

- The energy model

The energy model is created to understand the energy loads and demands on the building. This model also explains also how some of these systems are integrated.

- The daylighting model

The daylighting model is designed to study specific amounts of daylight in the building.

- The construction documents model

Although this example is not a true model, it is the communication tool used to get the project built.

All of these models were necessary to successfully complete the project as it was designed; however, it became a whole separate set of tasks to simply manage the geometric information changes to the various models.

5. BIM implementation

BIM can be used to combine these separate analyses and design into one model. Although most of these things cannot be done directly in a BIM model, the model can be used as a basis for much of this work, thus eliminating overlap in replicating changes made to the building geometry. BIM can reduce the costs associated with traditional sustainability analysis, while also realizing the benefits associated with the analysis, by making the information required for sustainable design, analysis and certification routinely available simply as a byproduct of the standard design process. Also, linking the building model to analysis tools allows for evaluation of design aspects that affect energy, material and water consumption during the early design phases. This is not possible using traditional 2D tools. This section will discuss BIM application in these strategies as follows:

5.1. BIM in early green design stages

The most effective way to achieve green objectives is to start at the earliest stages. Factors such as orientation of a building, its shape and overall mass, the level of glazing, plus the construction materials used, have the most impact on how a building performs with regards to energy use. The importance of engaging the designer within an integrated design framework at this stage is important, both from the final environmental impact standpoint and from a cost perspective.[16] Many BIM platforms and tools offer integrated massing and orientation exploration and analysis utilities from early design phases. An example of these tools is Autodesk "Vasari". Vasari is focused on conceptual building design using geometric and parametric modeling, integrating energy modeling and analysis features. Using simple settings to input, you can specify project's location and use, then create iterations of the design using different masses using geometric and parametric variables, or by varying geometry semantic options such as occupancy hours,

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[16] *Building Information Modeling for Sustainable Design.* (Autodesk whitepaper, 2005).

glazing percentage, HVAC system and others. It supports an integrated BIM environment through direct file exchange with Autodesk Revit. Figure 5

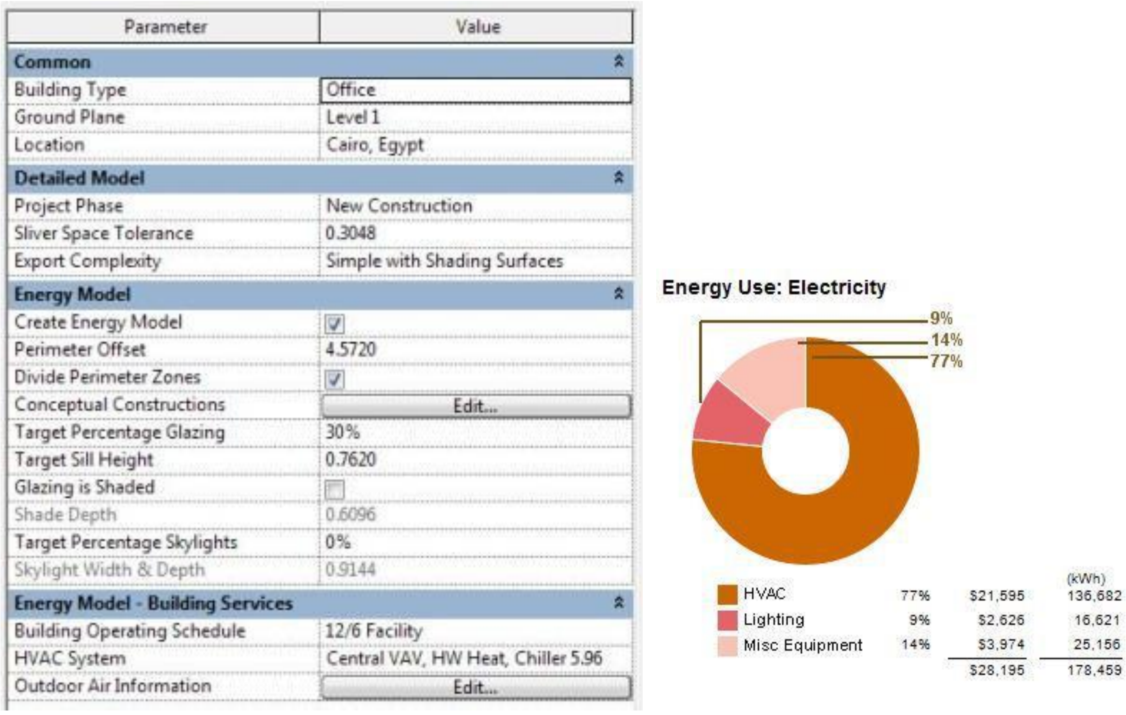

Figure 5 The design options available in Vasari (Left), and a part of the energy analysis report it can create on energy consumption

Another approach is to integrate analysis tools with BIM platforms from early design phases. An example of this approach is "Green building Studio" (GBS) that integrates with Autodesk Revit through gbXML. gbXML facilitates the transfer of building information, enabling integrated interoperability between building design models and many engineering analysis tools available today, including GBS. GBS is a web-based service that allows users to perform fast, whole building energy, water analyses of a Revit-based building design. These analyses can be performed by architects from within their own design environment. Based on the building's size, type, and location, the service determines the appropriate material and equipment defaults by using regional building standards to make intelligent assumptions. Using simple menus, designers can change these settings to define specific aspects of the design; a different orientation or a lower U-value glazing for example. The service then analyzes the model and the user is able to view the output in a web browser, including estimated energy and cost summary. Users can then explore design alternatives by updating the settings used by the service and rerunning the analysis, or by revising the model itself in Revit. The output also summarizes the water usage and electricity and fuel costs, calculates an ENERGY STAR[17] score and calculates points towards LEED daylighting credit.[18] Figure 6

[17] ENERGY STAR is an international standard for energy efficient consumer products originated in the United States of America.

[18] *BIM and the Autodesk Green Building Studio* (Autodesk white paper, 2008).

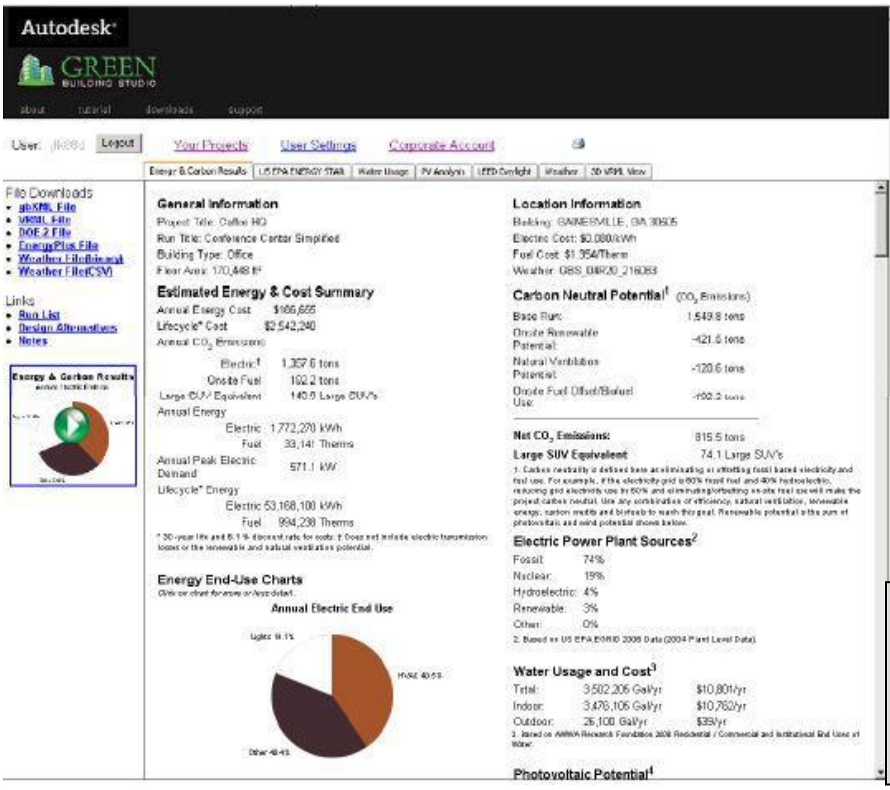

Figure 6 The estimated energy usage summary as the user views them in the browser

5.2. Daylighting

The most common goal related to day lighting design is the ratio of interior to exterior illuminance[19] or daylight factor. This is what the LEED Indoor Environmental Quality (IEQ) Credit 8.1 is based on. In LEED-NC, additional options are available, including demonstrating the availability of 25 foot-candles of daylight in 75% of regularly occupied areas at the work plane level at noon using computer simulation.[20] After goals for natural daylight are established in the design requirements, the designer can begin using the BIM model with a daylighting simulation package. Here the BIM model is used primarily for geometry generation. Geometry reuse can save time based on the complexity of the project. There are a lot of daylight simulation software packages currently available. The most accurate tools developed to date have been based on the Radiance engine. A number of packages use the Radiance engine as a basis and supply a front-end user interface that allows designers to use the engine. A few of these applications are as follows:[21]

- IESVE; can run energy and daylight analysis. It imports model geometry directly from a BIM model through gbXML, also it integrates through Revit BIM platform API to directly import models from it.

- Ecotect; offers a wide range of simulation and building energy analysis functionality, including water usage, energy consumption and daylighting. Supports file import via gbXML, in addition to multiple 3D standard formats.

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[19] Illuminance is the luminous flux per unit area on a surface, expressed in foot-candles, commonly described as the amount of light on a surface.
[20] Krygiel and Nies, p. 157 Op. cit.
[21] Ibid. p. 160

- Daysim is a free application; it is also compatible with files created in Ecotect with no direct connectivity to the BIM model.

- Autodesk's 3ds Max Daylighting; this application has a simple interface for running daylighting applications. It imports files from most of 3D standard formats such as FBX. It also offer direct file import from Revit.[22] Figure 7

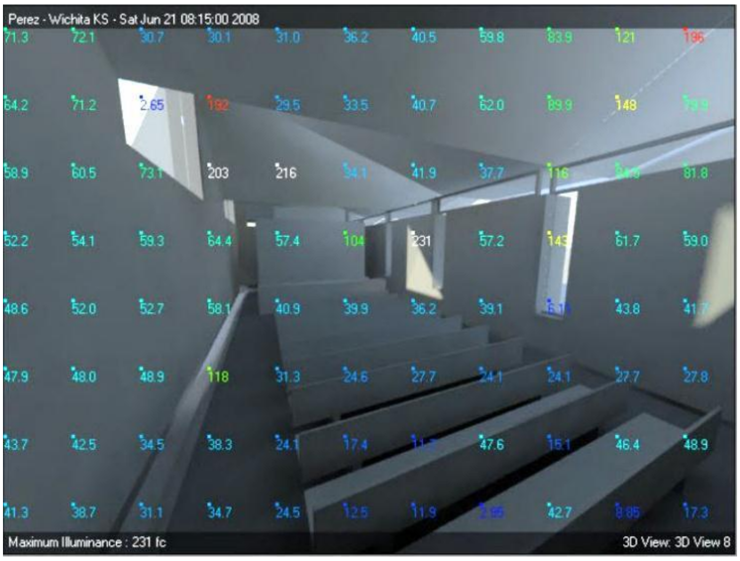

Figure 7 Illuminance levels overlayed as a grid on a rendering , donethrough daylighting analysis in 3DS MAX

5.3. Water efficiency

Designers can collect information from the BIM model to help them calculate how much rainwater can be captured from the available roof areas and expected water demand from sinks, toilets, and other water fixtures. Designers can pull this information and integrate it with a spreadsheet application, or use the internal capabilities of the BIM platform.

- Water harvesting

Roof areas in a BIM model are fairly basic. The plan area of the roof will be the area that is available to collect rain. This might eliminate certain roof types; Entry canopies, occupied spaces such as terraces. Rain fall data can be acquired from databases such as "worldclimate.com" and compiled with areas from the model in a spreadsheet to estimate water harvesting capability.

- Water consumption and reuse

In order to figure out how much water is consumed and how much graywater available in the building to reclaim, designers have to get a count on the number of fixtures in the building and what their uses are. A BIM model can be set to do this counting and sorting of fixtures, by creating a simple plumbing schedule within the model that contains properties such as fixture count and flow rate. These fields will be dynamically updated as fixtures are added or removed from the project as the design continues to progress.

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[22] *Daylight Simulation in 3ds Max Design 2009* (Autodesk, 2008) <http://images.autodesk.com/adsk/files/3dsmax_started.pdf> [accessed 5 December 2012].

Plumbing Schedule			
Fixture Description	Count	Flow Rate	Graywater
Drinking Fountain-2D: Drinking Fountain-2D	6	1.5	☑
Lavatory-Single-2D: 26" x 22"	5	2.5	☑
Sink Kitchen-Double: 42" x 21"	1	2.5	☐
Sink Vanity-Round: 19" x 19"	18	2.5	☑
Sink-Mop-2D: Sink-Mop-2D	3	1	☐
Toliet-Commercial-Wall-3D: 19" Seat Height	25	1.6	☐
Urinal-Wall-3D: Urinal-Wall	4	1	☐

Figure 8 A plumbing schedule generated in Revit, to calculate water comsumption and reuse

5.4. Energy modeling

For energy modeling to be successful, a solid, well-built and properly modeled model is needed. Then the model needs to be transferred from the BIM platform to an energy analysis tool. In some applications, it is currently possible to run a basic analysis out of a BIM model directly in the BIM platform (such as Revit). Here the model is useful for geometry and attribute generation and regeneration as the design progresses. Many analysis tools are available for energy simulation with various capabilities such as:

- IESVE; as previously mentioned, it is a robust energy analysis tool that offers a high degree of accuracy and interoperability with a BIM model, and it can run the whole range of building environmental analysis.
- EnergyPlus; analyzes heating, cooling, lighting, ventilation and other energy flows. There is no direct connectivity between BIM models and EnergyPlus. Models have to be exported via gbXML to intermediate tool such as Ecotect and then exported to EnergyPlus through IDF files.

5.5. Sustainable materials

Using a BIM model, designers can easily query the model for different materials or products and derive the volume of each. Many BIM applications have the ability to create dynamic schedules. These schedules can be created once in the course of the project and will continually maintain up-to-date information in them. The data in these schedules can be used in conjunction with spreadsheet applications to calculate quantities of materials as needed. For example, designers could set the BIM model to dynamically calculate the volume of Fly Ash in concrete as shown in Figure 9

Concrete		
Material: Name	Material: Volume	Volume of Fly Ash
Concrete — Cast-in-Place Concrete	258.04 CF	13.93 CF
Concrete — Cast-in-Place Concrete	210.28 CF	11.35 CF
Concrete — Cast-in-Place Concrete	239.44 CF	12.93 CF
Concrete — Cast-in-Place Concrete	66.89 CF	3.61 CF
Concrete — Cast-in-Place Concrete	805.50 CF	43.50 CF
Concrete — Cast-in-Place Concrete	230.04 CF	12.42 CF
Concrete — Cast-in-Place Concrete	700.39 CF	37.82 CF
Concrete — Cast-in-Place Concrete	86.00 CF	4.64 CF
Concrete — Cast-in-Place Concrete	272.33 CF	14.71 CF
Concrete — Cast-in-Place Concrete	4286.46 CF	231.47 CF
Concrete — Cast-in-Place Concrete	477.20 CF	25.77 CF
Concrete — Cast-in-Place Concrete	230.29 CF	12.44 CF
Concrete — Cast-in-Place Concrete	191.17 CF	10.32 CF
Concrete — Cast-in-Place Concrete	258.04 CF	13.93 CF
Concrete — Cast-in-Place Concrete	5102.40 CF	275.53 CF
Concrete — Cast-in-Place Concrete	18527.22 CF	1000.47 CF
Grand Total: 31	32843.34 CF	1773.54 CF

Figure 9 Analysis of usage of Fly Ash in Revit

6. Conclusion

This research indicates that BIM can facilitate the very complex processes of sustainable design and the related activities and analyses, as well as automate a multitude of activities like material takeoffs, while capturing and coordinating information into a single integrated model. Thus greatly saving time and effort associated with such complex design tasks, and more importantly, provide design model data and geometry that is up to date to all project participants. A summary of BIM applications in sustainable building design can be found in Figure 10.

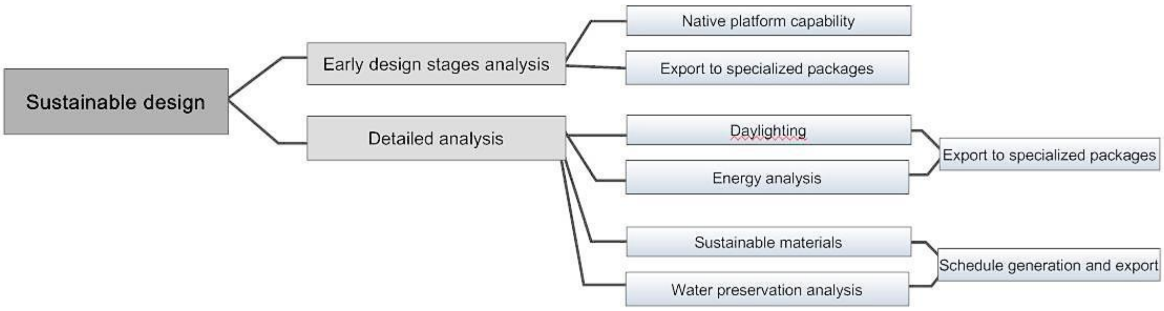

Figure 10 Summary of BIM applications in sustainable building design

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