Using BIM to Simulate the Energy Consumption and Reduce Its Cost

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Abstract—**Building Information Modeling is a powerful tool for many aspects of construction; most of them are related to 3D modeling to find incompatibilities in the different disciplines that affect the construction. Its application for measuring or analyzing the energy consumption of a building is rarely used.**

This paper intends to explain how Building Information Modeling software is useful to simulate the energy consumption, assessing various combinations of characteristics of the buildings for its analysis. In this case, Revit 2017 from AutoDesk is the software employed to model the building, due to its common use in the construction industry. Green Building Studio 2017 is the software for the energy consumption analysis, because it is also from AutoDesk.

Using Green Building Studio software is a practical tool which can generate different energy analysis simulation considering diverse factors such as location, the number of stories, the material of the envelope, the shape of the building. The comparison parameter of each model is the energy consumed in a year, and the cost related.

Index Terms—**BIM, energy consumption, 3D modeling, green building.**

I. Introduction

Building Information Building (BIM) is a useful tool for virtual design and construction in 3D that captures all the construction phases anticipating and solving pre-existing problems that occur during the integration of diverse disciplines.

In the literature review, it is shown that there are more studies to make in this integration between the 3D modeling and the energy simulations and analysis.

This paper aims to show the possibility to reduce energy consumption during the design phase using the Building Information Modeling software in order to choose the best options for materials, size, shape, number of stories of a building and reduce its energy consumption.

A. *Establishing the Problem*

Hwang [1], [2] and Pramen [3] explains why the green buildings have characteristics that qualify them with higher costs initially, it says that the expenses are higher because of the special environmental sound materials, tools and design. This statement establishes the reason why is so important to identify the proper design in order to reduce energy consumption and life cycle cost and recover the initial major investment.

It is common that architects and engineers must meet the owners' demands for energy consumption savings. Many countries have established political liabilities, with goals to achieve in the future years.

B. *Identify the Deficiencies*

There are international actions made for on climate change, where developed countries have ratified their commitment to reduce CO2 emissions. The building and construction sectors have been identified as one of the major contributors to global environmental impact due to their high consumption of energy [4]. In the mix of both subjects, is where technology in construction has been improved in order to help in accomplishing the energy reduction goals and attend the countries' commitments.

BIM has been considered a powerful tool for 3D modeling, especially from the beginnings of the 1980's [4]. It has been proved also in the architects, designers, engineers and construction industries. One of most used software for 3D modeling is Autodesk Revit, which belongs to the AutoCAD software family and is one of the most popular drawing software.

BIM has being used in the construction industry prioritizing building design, assembly, and operation. Its main application starts with the 3D modeling, but now it can be useful and an empowering tool for energy analysis.

With the advances in the technology and software, it is easier to calculate energy consumption in the design phase of a project and 3D modeling is part of this more precisely tools using nowadays in the construction industry.

II. Literature Review

Ahn and colleagues [5] mentioned BIM-based energy simulation tool can reduce costs and time required for building energy simulation work, and no practical interface between CAD tools for and dynamic energy analysis tools has been developed so far.

Costa and colleagues [6] mentioned how BIM-based energy simulation tool can reduce costs and time required for building energy simulation work

Conclusions from this paper show the results using Green Building Studio (GBS) to surpass these issues, reducing costs and generating savings for the occupants.

The research aims to demonstrate how a 3D model is useful to evaluate possible designs in order to reduce the future energy consumption and before investing in the construction of a building.

Royapoor & Roskilly [7] through a comparison between an existing building energy consumption versus a 3D model, they concluded that simulations with 3D models are very helpful tools in order to have accurate analysis results of the energy consumption and energy cost for its life cycle, calculated in 30 years approximately. So this tool helps owners and designers to choose the best design before its construction.

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III. Research Methodology

An office building was simulated using Revit Architecture 2017, which operational energy consumption was calculated using Green Building Studio.

Using different materials in the modeling, the case study building was examined to make the energy consumption comparison.

The components of a building that impacts more in the energy dissipation have been recognized and investigated, such as wall, windows, door, floor and ceiling. Heat loss is up to 35% trough un-insulated walls and 25% through the roof, the rest is lower than 15% [4].

The changing of materials was evaluated to determine its effects on reducing the building's annual operational energy use, and the results came from integrating between Revit and Green Building Studio. The walls materials changed from brick, concrete to the window wall, a number of windows in all the sides of the structure, and the material of the ceiling.

IV. Case-Study Building

The building is an office commercial construction with a 48,711 s.f. of floor area in five stories, as it is shown in Figs. 1, 2 and 3, located in the city of Boston, Massachusetts (Latitude = 42.4509 , Longitude = -71.0785). This location was selected as an important city of the east coast and it has an important change of temperature trough a year. The temperatures vary from 97 ℉ and -11 ℉.

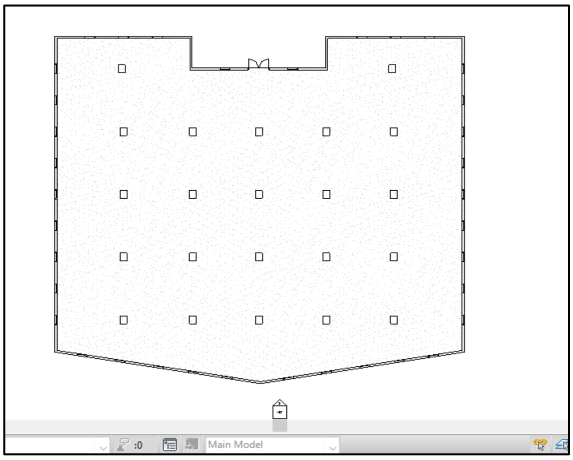

Fig. 1. Simulation model with interior.

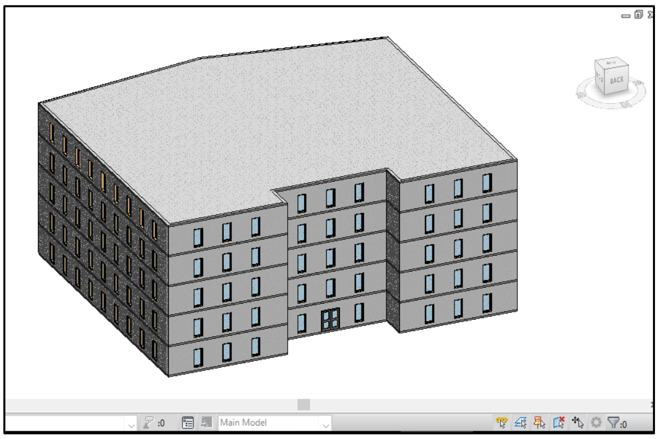

Fig. 2. 3D view AutoDesk revit.

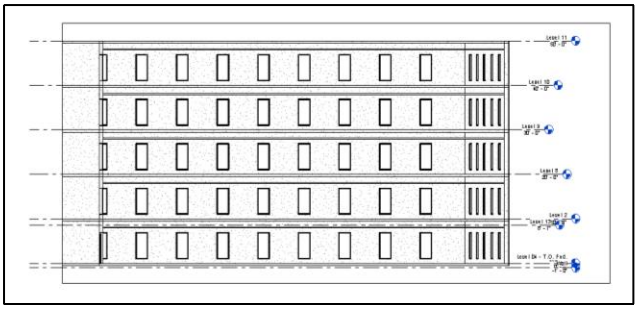

Fig. 3. Section drawing of the case study building.

The variables considered for the energy analysis was the Electric Cost of 14 cents of US dollar per kWh, and the Fuel Cost of 1.16 dollars per 100 kBTU.

For the selected location, the weather summary is shown in the following figures, from the Green Building Studio software:

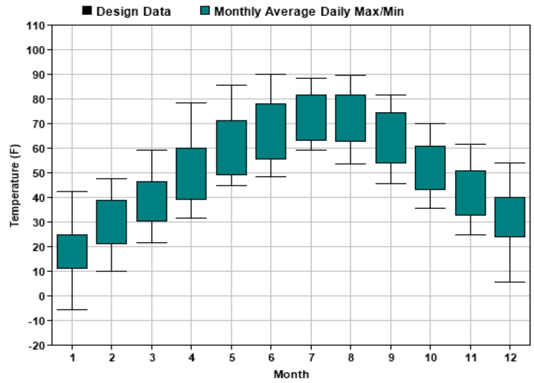

Fig. 4. Monthly design data.

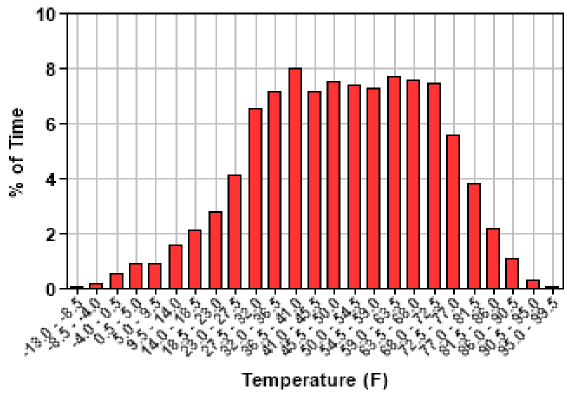

Fig. 5. Dry bulb frequency distribution (annual).

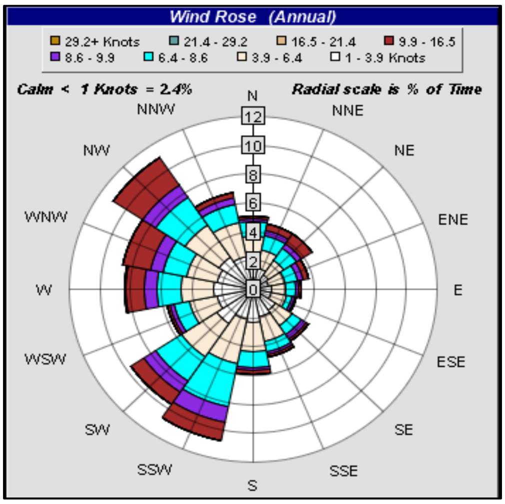

Fig. 6. Wind rose annual.

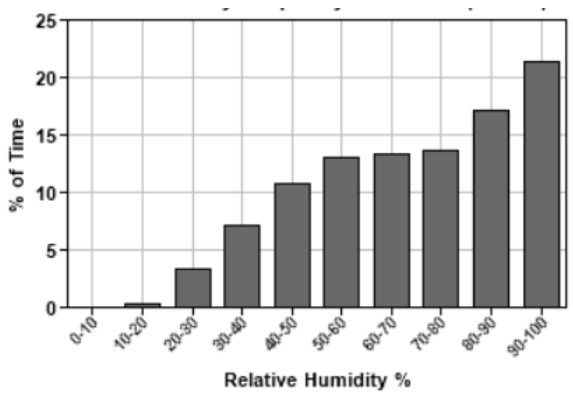

Fig. 7. Relative humidity frequency distribution (annual).

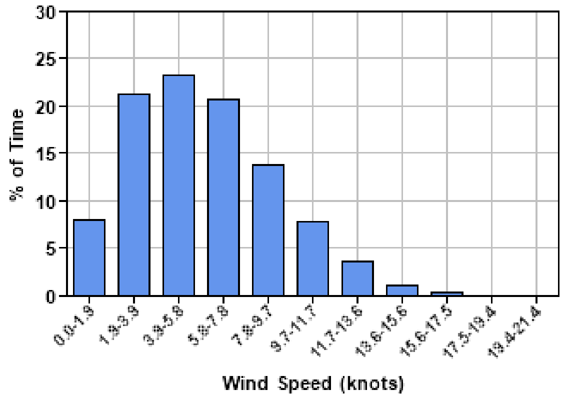

Fig. 8. Wind speed frequency distribution (annual).

V. Sustainability: LEED Points

In regards to obtaining LEED points in order to achieve a certification, it is required to accomplish some standard in one part of the construction process. The area related to this study is Materials and Resources, which considers a part specialized in Building Life Cycle Impact Reduction. It contains 5 available punctuations and especially suggests the optimization of the environmental performance of products and materials: Whole-Building Life Cycle Assessment which indicates that the project's structure or enclosure that demonstrates a minimum of 10% reduction, compared with a baseline building.

The right-sizing of the materials also affects the embodied energy of materials. There can be as much as a 20-30 percent positive impact on the life cycle of the building by looking at structure sizing and slab depth (USGBC).

VI. Findings

Exists several types of software in the industry to make a 3D model, some of them are more precise and complex from others, such as Revit, Sketch Up, and ArchiCAD. In regards to architectural drawings, AutoCAD is commonly used in every architectural design.

The principal benefits of using BIM are [8]:

- 3D simulation, BIM allows 3D simulation of the building and its components. It can predict collisions, show environmental variables on different building designs, and calculate material and time quantities.
- Accuracy vs estimation. Being able to virtually construct the building before physical construction begins on site, BIM adds a level of accuracy to both building quantities and quality that supersedes historic processes of design and documentation. Building materials and environmental variables in real time rather than manually estimated.
- Efficiency vs. redundancy. By simple drawing building elements only once in a project in lieu of a drawing plan, then projecting elevations, then section, we can begin to capture time and focus that additional time on other design issues.

In regards to the energy simulations, this report shows how replacing alternative types of materials impact in comparison with the baseline. In conducting the analysis, the location and zones of the building maintain the same. It is assumed that 5 companies will co-work there, one in each floor. The HVAC system of the building is a single room cooling system. The set of higher-performance materials will be recommended in order to reduce the energy consumption of the building, so it will be less harmful to the environment.

A. Baseline Design

The baseline construction of the case-study office building involves concrete for the walls, double glazed glass for windows in all the 4 facades of the building, no ceiling treatment, and concrete floors. With these characteristics of the building, the highest amount of energy use intensity of 62 kBTu/ sf/ yr.

Fig. 9 and Fig. 10 show the heating and cooling requirement for the baseline model of the building for each month of the year. The higher months with heating load are January, December and February in a high to low order, in regards the cooling load the months are August, July and June.

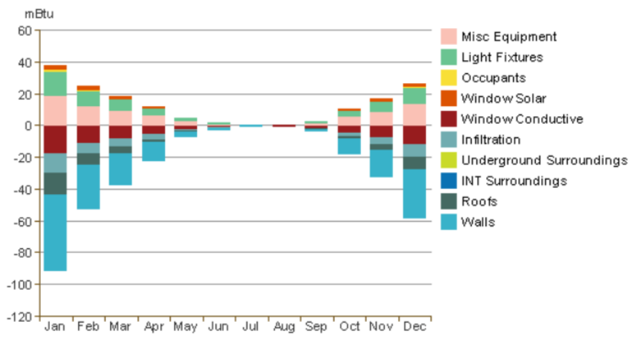

Fig. 9. Monthly heating load

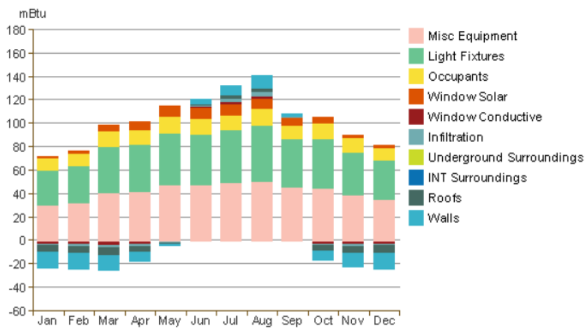

Fig. 10. Monthly cooling load

The monthly fuel and electricity consumption are shown in Fig. 11 and Fig. 12, where the fuel is mostly consumed in January, February and December, and the electricity in August, July and June.

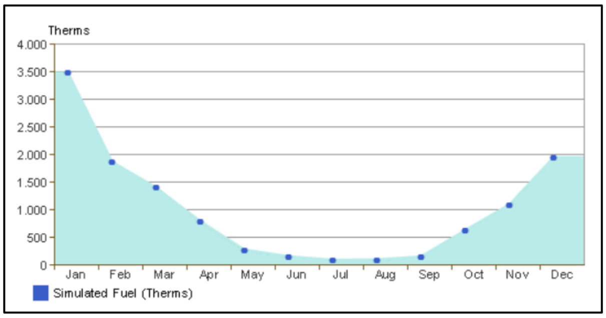

Fig. 11. Monthly fuel consumption

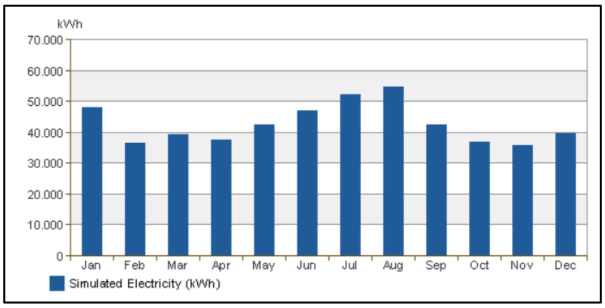

Fig. 12. Monthly electricity consumption

B. *Wall Modification*

The concrete wall was replaced by brick masonry and a window wall, in each change the energy consumption has been increased in different percentages. The results can be seen and compared in Tables I and II. Tables I and II indicate that the window-wall will provide the major annual operational energy consumption in 577,562 kWh/yr and consequently $ 45,713 annual electricity cost. The masonry wall shows an energy consumption increase in 537,824 kWh/yr and $ 41,633. Both options consume higher energy than the baseline concrete material which 511,007 kWh/year with $39,582 annual electricity cost. The Fig. 13 shows the 3D model using masonry brick in walls for this research.

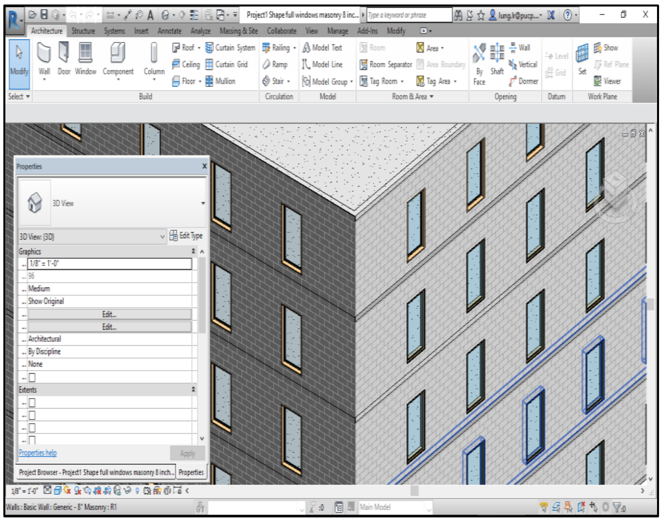

Fig. 13. Brick walls of the case study building.

C. *Modification of the Windows*

The based model of the windows is a double glazed glass in standard timber frames, and in this point the materials compared are double glazed glass in aluminum frames, and single glazed glass timber frames. Tables I and II demonstrate how the energy consumption is affected by the windows components and properties.

TABLE I. IMPACT OF ALTERNATIVE TYPES OF MATERIALS ON OPERATIONAL ENERGY CONSUMPTION, FROM THE BASELINE MODEL

Material		Life cycle operational energy consumption (kWh)	Annual operational energy consumption (kWh)	Percentage	Difference
Element	WALL				
Baseline	Concrete Wall	15,330,198	511,006.60		
Alternatives	Brick	16,134,708	537,823.60	5.25%	804,510
	Window Wall	17,326,851	577,561.70	13.02%	1,996,653
Element	WINDOW				
Baseline	Total Double glazed timber	15,330,198	511,006.60		
Alternatives	Double glazed with aluminum frames	15,901,341	530,044.70	3.73%	571,143
	Simple glazed with timber frames	16,422,076	547,402.54	7.12%	1,091,878
	Half of Windows	15,704,094	523,469.80	2.44%	373,896
Element	FLOORS				
Baseline	Concrete floors	15,330,198	511,006.60		
Alternative	Timber floors	15,535,452	517,848.40	1.34%	205,254
Element	CEILING				
Baseline	No ceiling	15,330,198	511,006.60		
Alternatives	Acoustinc Ceiling Tile	12,344,130	411,471.00	-19.48%	-2,986,068
	Gypsum Wall Board Tile	12,343,467	411,448.90	-19.48%	-2,986,731

TABLE II. IMPACT OF ALTERNATIVE TYPES OF MATERIALS ON OPERATIONAL ENERGY CONSUMPTION, FROM THE BASELINE MODEL

Material		Life cycle electricity price (US$)	Annual electricity price (US$)	Percentage
Element	WALL			
Baseline	Concrete Wall	1,187,448	39,581.60	
Alternatives	Brick	1,248,991	41,633.03	5.18%
	Window Wall	1,371,402	45,713.40	15.49%
Element	WINDOW			
Baseline	Total Double glazed timber	1,187,448	39,581.60	
Alternatives	Double glazed with aluminum frames	1,224,957	40,831.90	3.16%
	Simple glazed with timber frames	1,236,424	41,214.13	4.12%
	Half of Windows	1,213,250	40,441.67	2.17%
Element	FLOORS			
Baseline	Concrete floors	1,187,448	39,581.60	
Alternative	Timber floors	1,192,481	39,749.37	0.42%
Element	CEILING			
Baseline	No ceiling	1,187,448	39,581.60	
Alternatives	Acoustinc Ceiling Tile	963,507	32,116.90	-18.86%
	Gypsum Wall Board Tile	963,544	32,118.13	-18.86%

It is shown that using double glazed windows with aluminum frames increases energy consumption by 3.73% from the baseline design in 530,045 kWh/ yr and $40,832. Both models are lower than using single glazed windows which consume 547,403 kWh/yr and its annual cost is $ 41,214.13 in timber frames.

In parallel, this research compared the reduction of the amount of windows in the building in 50 percent. The presence of windows helps the building ventilation and allows light to enter. This reduction in windows quantity reflects in 2.44% higher energy consumption and 2.17% higher annual electricity cost.

D. Modification of the Floor

In the study, two types of floors are compared, concrete floor and timber floor and it is shown in Tables I and II. The results demonstrate that concrete material is more energy efficient using it on the floors of the building, the energy consumption increases in 1.34%.

E. Modification of the Ceiling

The modification of the ceiling is another variable of this study which recognizes the impact of the high light reflectance improves space illumination, allowing fewer light fixtures, a reduced electrical light output. Electrical lighting is significant energy consumer in a building. Ceiling tiles incorporate also microencapsulated phase change material which absorbs, stores and releases excess external heat gains, to provide thermal comfort trough passive cooling, so reduces energy demands of the existing HVAC system.

Due to these benefits, the case-study building presents an important enhancement on energy consumption when it uses ceilings. Using ACT (Acoustic Ceiling Tile), the annual energy consumption is 411,471 kWh/yr and represents 19% which originates an important impact also in the annual electricity cost of $ 32,117. The results shown are quite similar when GWB (Gypsum Wall Board) is used for ceiling, 411,449 kWh/ yr.

F. Sustainable Solution for the Case-Study Building

Tables I and II show that the most efficient combination of all the materials choices analyzed in the previous elements results in 411,449 kWh/ yr which consider the baseline case-study building adding the GWB ceiling. This result means that the materials of the analyzed elements for this building can be enhanced, so its energy consumption will be reduced.

VII. Conclusions

BIM tools are very useful for owners and designers to select the best energy efficient design for a project, in the design phase and investing the lower part of the project budget is optimal, before continue with more intensive investments. Comparing different designs and materials before constructing a building, is an effort to reduce environmental impacts and reduce the life-cycle cost of a building.

BIM models also include detailed specifications of the materials for an accurate analysis of the energy consumption of a building, so BIM must be considered in determining the best beneficial design in pre- construction stages.

There are some building elements more effective in the reduction of energy consumption, and it can be identified with a comparison chart like the one used for this case-study building.

The results show that the impact in the energy reduction is higher when the ceiling tiles are added to the building and the reduction is close to 20%, the type of wall is the next in the incidence in more than 10%, and the third is the type of windows, the single glazed glass affects in 7% in the energy consumption.

VIII. Recommendations for Future Research

One of the clues to solving problems in 3D modeling and energy analysis is the usage of software with different complexity, major uniformity and integrability is required.

Integration with the construction cost in this analysis will be helpful, because each design and material selection is related with a construction cost differential. So a construction cost estimation added to the life cycle cost gives a complete picture for the owners and investors, to make decisions. Using alternative materials or systems can increase the construction cost and generate a contrary result for a project.

Further studies have to be made comparing the energy model results versus the real consumption after the buildings were constructed, in order to improve or refine this connection and make it more realistic and take better decisions during their design process. These energy measurements can be extended for long period of times to make sure the life cycle energy consumption is still accurate.

Generate a process or flow chart to identify which element of a building has more impact on reducing the energy consumption, based on the type of construction and locations.

Include more elements or parts of a building in the analysis to increase the variables, incorporating HVAC systems, renewable systems such as solar panels, and structural elements wood made.

References

[1] B. G. Hwang and W. J. Ng, "Project management knowledge and skills for green construction: Overcoming challenges," *International Journal of Project Management*, vol. 31, pp. 272-284, 2013.

[2] B. G. Hwang and J. S. Tan, "Green building project management: Obstacles and solutions for sustainable development," *Journal of Sustainable Development*, vol. 20, pp. 335-349, 2012.

[3] P. Pramen and N. Pushpala, "Green and non-green school buildings: An empirical comparison of construction cost and schedule," *Construction Research Congress of the American Society of Civil Engineers*, 2012.

[4] M. Shoubi, M. J. Shoubi, A. Bagchi, and A. Barough, "Reducing the operational energy demand in buildings using building information modeling tools and sustainability approaches," *Ain Shams Engineering Journal*, 2014.

[5] K. U. Ahn, Y. J. Kim, S. C. Park, I. Kim, and K. Lee, "BIM interface for full vs. semi-automated building energy simulation," *Journal of Energy Buildings*, 2013.

[6] A. Costa, M. Keane, J. Torrens, and E. Corry, "Building operation and energy performance: Monitoring, analysis, and optimization toolkit," *Journal of Applied Energy*, 2011.

[7] M. Royapoor and T. Roskilly, "Building model calibration using energy and environmental data," *Journal of Energy and Buildings*, 2015.

[8] E. Krygiel and B. Nies, *Green BIM: Successful Sustainable, Design with Building, Information Modeling*, 2008.

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