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Assessment of the Integration of Artificial Intelligence (AI) into Building Information Modeling (BIM) for Smart Construction Management and Decision-Making

Nada S. Al-Muntaser, Eastern Michigan University
Dr. Suleiman A. Ashur, Eastern Michigan University

Suleiman Ashur is a Professor of Civil Engineering and Construction Management and the Program Coordinator at Eastern Michigan University. Dr. Ashur is the Former Director of the School of Visual and Built Environments and Former Interim Director of the Information Security and Applied Computing.

The Integration of Artificial intelligence into Building Information Modeling for Smart Construction Management and Decision-Making

Nada S. Al-Muntaser
School of Visual and Built Environments
Eastern Michigan University
Ypsilanti, MI 48197
Email: nalmunta@emich.edu

Dr. Suleiman Ashur, P.E.
School of Visual and Built Environments
Eastern Michigan University
Ypsilanti, MI 48197
Email: sashur@emich.edu

Abstract

This paper explores the integration of Artificial Intelligence (AI) with Building Information Modeling (BIM), emphasizing potential benefits and addressing associated challenges. Utilizing a web-based AI-BIM tool on a single house model, the case study focuses on design indicators like radiation, sun hours, shadow study, LEED views credits, and energy and water usage. Although additional analyses, such as daylight and glare analysis, COVID-19 occupancy, and façade prototype, are available, they are not covered in this paper. A key highlight is the positive outcome of the energy consumption comparison between AI and commercial software, affirming AI's accurate simulation capabilities. The user-friendly nature of the AI-BIM tool supports swift model creation and analyses, emphasizing the ongoing exploration of AI integration for enhanced construction management efficiency and productivity.

1. Introduction

The construction industry is experiencing a profound shift through technological advancements. The recent incorporation of Artificial Intelligence (AI) into Building Information Modeling (BIM) marks a revolutionary step toward progress and innovation in construction. This integration is reshaping construction management processes across all stages, fostering heightened efficiency, precision, productivity, and reduced time consumption in the industry.[1]

BIM, established five decades ago, serves as a digital representation of construction projects. Its platforms streamline the construction process and communication among project stakeholders (e.g., owners) and construction parties (e.g., engineers). BIM has already enhanced how projects are planned, designed, and constructed.

AI, or Artificial Intelligence, denotes the simulation of human intelligence processes by machines, particularly computer systems, first introduced in 1956.[1] It encompasses the development of algorithms and software capable of replicating or executing tasks traditionally carried out by humans, including learning, reasoning, problem-solving, decision-making, and interaction with the environment. AI aims to create systems that can perform tasks typically requiring human intelligence, aiming to achieve them faster, more accurately, or on a larger scale.

Despite its potential, the adoption of AI in the construction industry has been slow compared to other sectors, as highlighted by Blanco in 2018 and Bughin in 2017. [2, 3] They observed that AI technology remains underutilized in construction. This integration allows construction teams to make decisions based on historical data and future predictions. AI algorithms can analyze large databases, identify patterns, and accurately predict project timelines, costs, and risks. Integrating AI and BIM enhances project planning, reduces delays, aids resource allocation, and improves project outcomes. [2, 4]

Design optimization is another area where AI enhances BIM. AI algorithms can rapidly generate numerous design concepts and alternatives based on parameters, verbal descriptions, and design constraints. This led to more efficient layouts and energy-efficient designs, resulting in cost-saving projects and enhanced sustainability.[5]

The integration of AI into BIM has the potential to enhance the construction management processes. By leveraging data analysis, predictions, automation, and optimization facilitated by AI in conjunction with BIM, project outcomes can realize remarkable gains in efficiency, productivity, and success. There are various avenues for integrating AI with BIM, including: 1) automation of repetitive tasks that yield an increase in productivity,[6] 2) design optimization that may lead to more efficient layouts, energy-efficient design, space utilization, and structural optimization. 3) the integration of AI with Virtual and Augmented Reality (VR & AR) technologies provides a magnificent visualization experience throughout the project and experience of the building before construction.[7]

However, there are several challenges that remain when applying this integration in the construction industry field, including the adverse impact on employment in the construction field directly by replacing human labor in routine tasks.[8] In addition, trust and liability are issues since AI is still in its initial stages of development and the issue of liability if an AI system makes a mistake. The skill gap and training are required to prepare many workers on how to reflect AI systems on their jobs.[9] Finally, there are many ethical challenges the construction industry should consider. Workers need to ensure that AI systems are used fairly, without bias, and with due respect for human privacy. [10, 11]

2. Study Objective

This study aims to evaluate the effectiveness of integrating AI into BIM software for innovative construction management and decision-making. The software assesses an existing building designed to meet LEED standards. Furthermore, the study aims to compare the evaluation of energy consumption. This involves predicting consumption using Carrier eDesign Software, Carrier's Hourly Analysis Program (HAP) software, and AI-BIM cove.tool software.

3. Case Study: Assessment of Building Energy Performance and Sustainability using AI Tool

This case study explores the potential of an AI tool seamlessly integrated into Building Information Modeling (BIM) to deliver valuable insights for building optimization. The cove.tool, an AI-driven web-based analytics platform for building performance analysis and optimization, is featured on their website (https://cove.tools). The software offers comprehensive analyses of buildings, encompassing energy modeling, water use assessment, and compliance with Leadership in Energy and Environmental Design (LEED) standards.

To evaluate the tool, we selected a house designed for the Solar Decathlon Competition 2018-2019 by students in a Midwest university, shown in Fig. 1. The house is in a suburban area in Southeast Michigan. The land is about 150 feet by 480 feet, and the house is 1,600 square feet with three bedrooms and two bathrooms. The building's annual energy consumption was calculated to be 12,658 kWh/yr. The building was designed with solar panels to generate electricity around the year, and solar panels cover approximately at least 17,400 kWh/year.[12]

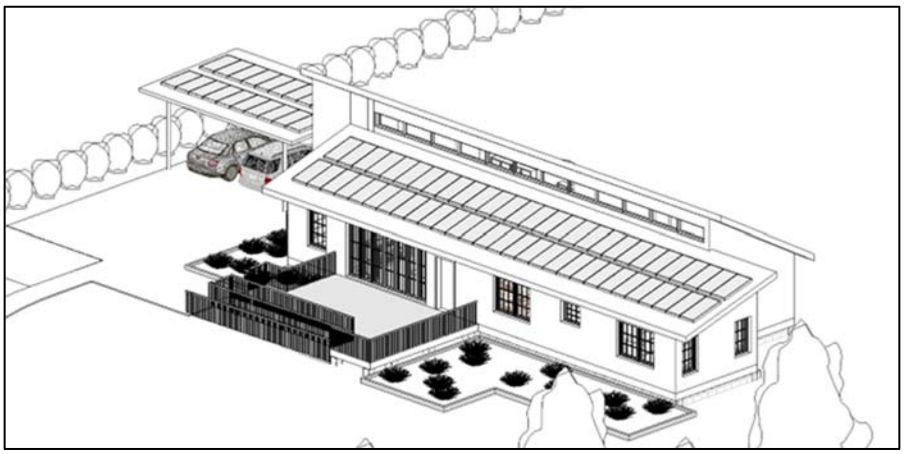

Fig. 1. The Single Net Zero Energy House using Revit.

3.1. Pre-analysis setting

The cove.tool allows users to draw their project directly on the website or upload a file. We initially exported the Revit file using the cove.tool plugin in Revit, and then uploaded it to the web-based cove.tool software. Upon uploading, the software prompts users to select the building type and location. Additionally, the software automatically sets an energy code based on the chosen location, which can be further adjusted according to preferences.

3.2 Project Analysis Indicators and Results

We used cove.tool to evaluate the following indicators:

a. Radiation and Sun Hours

The maximum solar potential represents the highest recorded radiation for our chosen location, derived from daily readings in a weather file. This value signifies the maximum amount of radiation achievable on-site, regardless of the building's geometry. In our model, the software calculates the maximum solar potential to be 282 kWh/m^2, as illustrated in Fig. 2.

The tool also analyzes the sun hours during which the house will be exposed to sunlight, considering any adjacent buildings that may cast shadows on the selected building and potentially affect its exposure to the sun. It calculates sun exposure for the house, revealing a potential maximum of 12 hours, as depicted in Fig. 3.

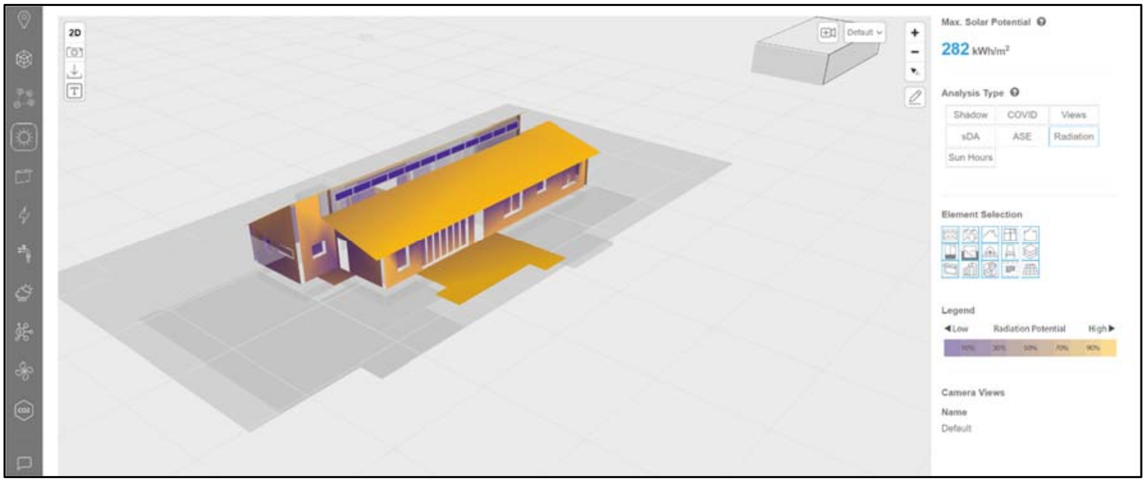

Fig. 2. The Maximum Solar Potential for the Model.

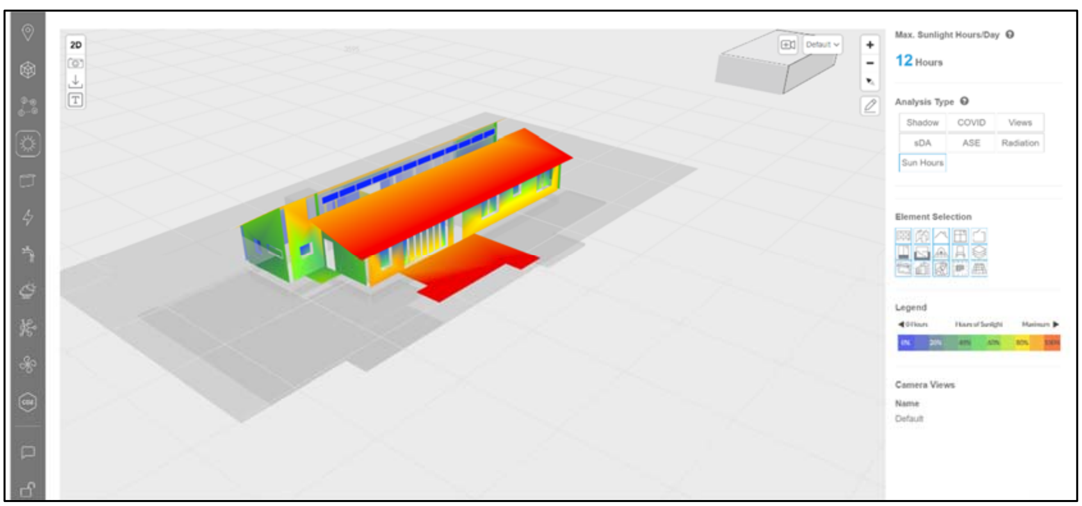

Fig. 3. Maximum Potential Sun Light Hours for the House Model.

b. Shadow Study

Designers can employ shadow analysis to assess solar access on the building at various times throughout the year. This analysis can investigate the influence of surrounding buildings' shadows on the designed building and examine the impact of the landscape, building mass, and self-created shade. Additionally, designers can strategically place shading devices and glare controllers. The tool visually represents the shadows cast on the building, as illustrated in Fig. 4.

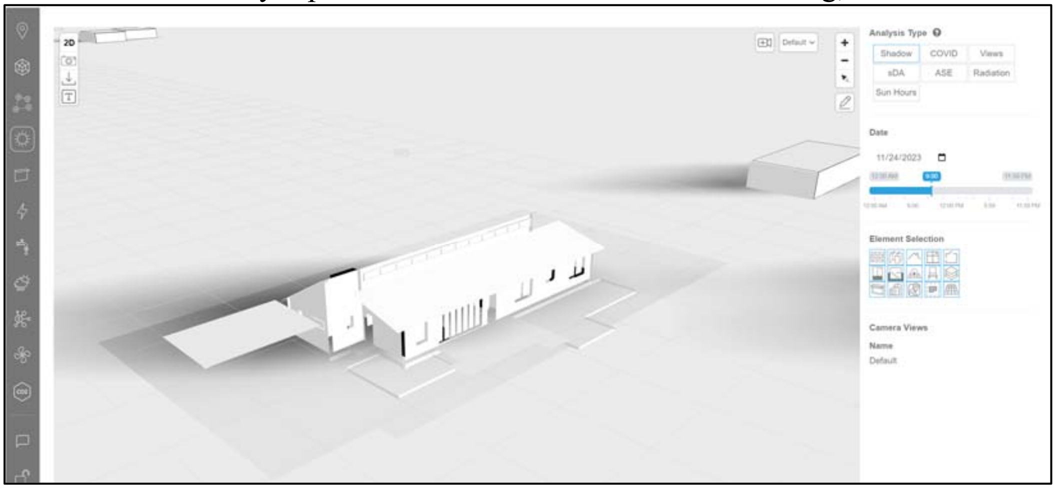

Fig 4. Shadow Analysis for the House Model.

c. LEED Views Credits

The designers can submit the LEED analysis to USGBC, which is responsible for building evaluation, to obtain the LEED certificates. Based on the analysis of the house model, it meets the requirements with a LEED views credit of 86%, as shown in Fig. 5.

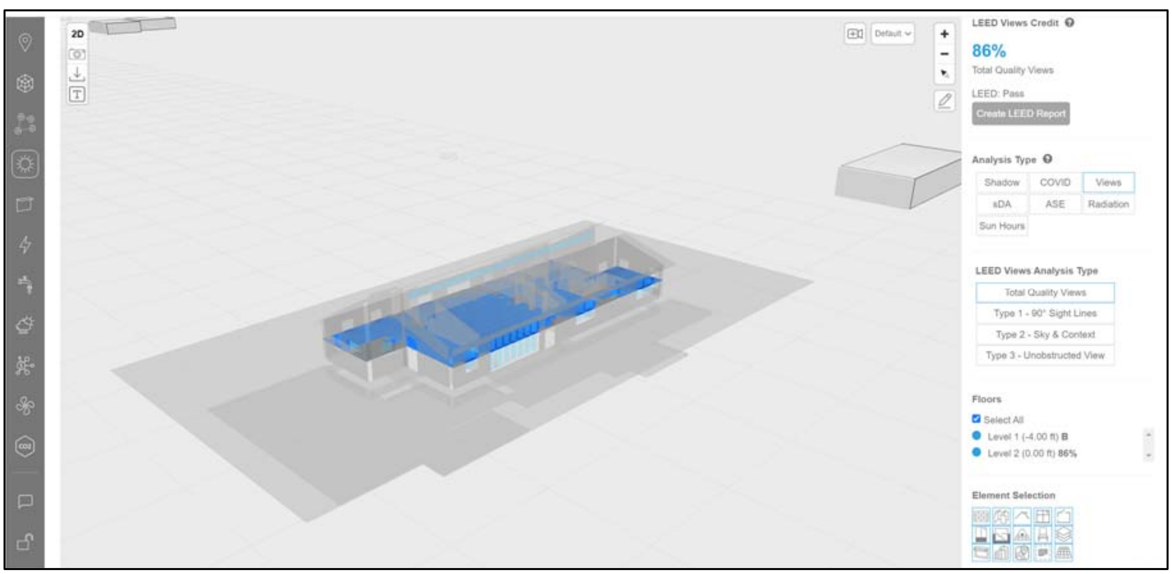

Fig. 5. LEED views credits.

d. Energy Usage Analysis

According to the cove.tool analysis, the single house is projected to consume 27.22 kBtu/ft²/yr., with an electricity cost of $3,136.33/yr, and a gas cost of $229.42/yr, as shown in Fig.

6. Additionally, the tool assesses the building's carbon emissions and the Energy Use Intensity (EUI), which gauges the energy consumption relative to its size, along with a breakdown of usage (e.g., cooling, heating, and lighting).

The total energy consumption for the house using Carrier HAP software was 12,658 kWh/ yr., which is 43,190.9 kBtu/yr using an energy converter calculator. The cove.tool energy consumption is 1,600 sf x 27.22 kBtu/ft²/yr. = 43,552 kBtu/yr. The difference between the two tools is calculated as follows:

$$\% \text{ difference} = \left|\frac{43{,}552 - 43{,}190.9}{43{,}190.9}\right| = 0.8\%$$

Therefore, the cove.tool analysis indicates 0.8% more energy consumption than Carrier HAP, which is deemed insignificant.

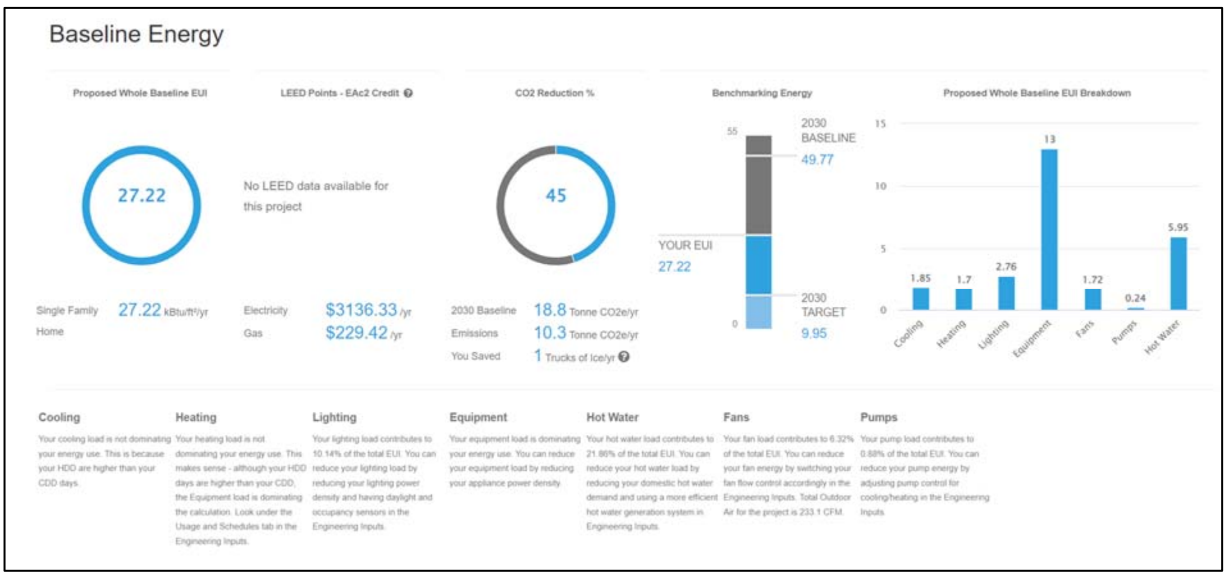

Fig. 6. Model energy baseline.

e. Water Use

As illustrated in Fig. 7, the estimated total water consumption for the single-family house is 208,528 gal/yr. Additionally, the cooling tower, utilized for heat exchange to cool water and dissipate building heat into the air, is projected to consume 1,903 gal/yr. This allows the project to earn 3 LEED points for achieving a 30% indoor water reduction, assuming no irrigation. The indoor usage is indicated to be 57.53 gal/ft²/yr for a single house, resulting in a total water usage of 227,559.23 gal/year for the model.

Fig 7. Water usage.

4. Conclusions and Recommendations:

In this research paper, we implemented and tested AI-BIM technology to explore tools that support various aspects of building design. The results from the case study were surprisingly swift, with the AI-BIM web-based tool generating several analyses and providing critical indicators for designers within a runtime of 10 minutes. The tool offers additional analyses for daylight and glare analysis, COVID-19 occupancy, façade prototype, and many other aspects not covered in this paper.

The accuracy of the tool, particularly in energy consumption calculations, was tested and found to be nearly identical when compared to commercial software used in the field. However, it is recommended to test and compare the tool with other platforms or actual data from existing buildings to ensure reliability.

The AI-BIM web-based tool is user-friendly, allowing users to build models or import them from other software and execute analyses in a remarkably short time. Acknowledging that AI is still under development, its potential benefits are evident, and further exploration of ways to incorporate this technology into construction management processes is crucial for enhancing efficiency and productivity.

Furthermore, it is important for future research papers to explore the potential impact of AI-BIM on workforce diversity and inclusivity. This involves investigating potential biases in AI algorithms and ensuring that everyone has fair access to the technology and its benefits.

By addressing scalability, socio-economic impacts, and workforce considerations, the future of AI-BIM integration can lead to enhanced efficiency, productivity, and inclusivity within the construction industry. Further exploration is crucial to ensure responsible and equitable implementation of this technology, fostering a diverse and thriving construction workforce. This research lays the foundation for such future exploration, paving the way for a more efficient, productive, and inclusive construction sector.

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