TO DEVELOP A NEARLY ZERO ENERGY BUILDING USING BIM AND AR

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Abstract:

A Net Zero-Energy Building (NZEB) is a building with net zero energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site. There are only a limited number of buildings that use the concept of NZEB at present. The construction of NZEBs is becoming more and more feasible owing to advancements in building technology, renewable energy systems, and academic research. The current project aims to conceptualize a residential building that uses the concept of NZEB. With the combination of BIM and AR technology, the concept of NZEB can be achieved in the maximum reasonable way. As we visualize the building, the energy optimization of the building can be done in a better manner in the present and future than in the past due to the advancements in technology like Building Information Modeling (BIM) and Augmented Reality (AR). Together BIM and AR can be used as tools to help in designing, constructing, and operating the NZEB. By providing detailed visualization, energy analysis, and real-time data, BIM and AR help in optimizing the building performance and achieving the NZEB goals.

Keywords: Building Information Modeling, Augmented Reality, Net Zero Energy Building

1. INTRODUCTION

The pursuit of sustainable building practices has catalyzed the emergence of Net Zero-Energy Buildings (NZEBs), representing a paradigm shift in the construction industry. These buildings aspire to achieve a delicate equilibrium between energy consumption and renewable energy generation on-site, thereby significantly reducing their environmental footprint [1]. Despite

ISBN-978-81-19905-39-3

their potential to mitigate climate change and resource depletion, NZEBs remain relatively rare in today's construction landscape. However, recent advancements in building technology, renewable energy systems, and academic research are steadily making NZEB construction more attainable. This report is dedicated to the conceptualization of a residential building that not only embraces but exemplifies the principles of NZEBs. At its core, the project seeks to harmonize the innovative potential of Building Information Modelling (BIM) and Augmented Reality (AR) technologies to revolutionize the design, construction, and operation of NZEBs [2]. By seamlessly integrating BIM and AR into the project workflow, the aim is to empower stakeholders with comprehensive insights and tools for informed decision-making. The utilization of BIM offers a sophisticated platform for collaborative design and data-driven decision-making, enabling stakeholders to visualize the building's performance parameters, simulate energy consumption scenarios, and optimize design elements for maximum efficiency. Augmented Reality, on the other hand, enhances the design process by overlaying digital information onto the physical environment, facilitating real-time visualization and immersive experiences. Together, BIM and AR represent transformative tools that can revolutionize the traditional approach to building design and construction. However, despite the promise of NZEBs and the potential of BIM and AR technologies, several challenges persist [3]. These include limited adoption and integration of NZEB principles and technologies, as well as barriers related to education, training, and policy incentives. Addressing these challenges requires a concerted effort from industry stakeholders, policymakers, educators, and researchers to foster interdisciplinary collaboration, develop robust training programs, and incentivize the adoption of sustainable building practices. In conclusion, this report aims to contribute to the on-going discourse on sustainable building practices by advocating for the widespread adoption of NZEB principles and the utilization of BIM and AR technologies. By embracing innovation and collaboration, we can realize the vision of NZEBs as standard practice in the built environment, paving the way for a more sustainable future for generations to come [4].

Reddy and Jagadish (2001) [1] highlight the significant energy consumption involved in manufacturing and transporting building materials, especially cement and steel. They demonstrate that using energy-efficient or alternative materials, like soil-cement blocks, can reduce energy use in load-bearing masonry buildings by up to 50%. Notably, transportation energy for materials like bricks accounts for 5-10% of manufacturing energy. Ortiz et al. (2015)

ISBN-978-81-19905-39-3

[2] emphasize the importance of life cycle assessment (LCA) in evaluating nearly zero-energy buildings (NZEBs), particularly regarding waste management. They recommend integrating LCA tools with Building Information Modeling (BIM) and Augmented Reality (AR) to optimize waste management. Chastas et al. (2016) [3] review the shift from operational to embodied energy dominance in residential buildings as they become more energy-efficient, highlighting the need for standardized protocols and further research. Chel and Kaushik (2017) [4] advocate for designing buildings with nearly zero energy consumption and using low-energy materials. They stress the importance of energy-efficient equipment and renewable energy technologies to minimize environmental impact and CO_2 emissions. Coimbra (2021) [5] demonstrates the environmental and economic benefits of sustainable construction using a case study of a 100-year-old building. The study highlights the use of recycled materials and efficient equipment to reduce energy consumption and operational costs. Wie and Harrison (2021) [6] explore various technologies for Net-Zero Energy Buildings, emphasizing the importance of renewable energy sources and energy-efficiency measures tailored to local climates and building codes. Allouhi et al. (2022) [7] propose a Hybrid Renewable Energy System (HRES) for multi-family buildings, focusing on solar and wind power combined with hydrogen generation and storage to enhance efficiency and cost-competitiveness [8]. Hussain et al. (2022) [9] examine how smart bins connected to the Internet of Things (IoT) can improve waste collection efficiency. Their study in Al Rayyan, Qatar, shows that continuous monitoring through IoT reduces waste collection costs, CO2 emissions, and route completion times. Lin and Chen (2022) [10] introduce a comprehensive framework for designing and validating Net-Zero Energy Buildings, integrating both passive and active solutions. Their case study demonstrates the practicality of NZEBs in reducing energy consumption and provides valuable guidance for future building projects.

Wilberforce et al. (2023) [11] focus on reducing electricity usage and minimizing the environmental impact of homes through zero-energy buildings (ZEBs). They identify barriers to commercialization, such as lack of incentives and limited policies, and suggest technological advancements and government incentives to promote ZEB adoption. Huo et al. (2023) [12] highlight the energy-saving potential of external Venetian blind shading (EVBS) in nearly zero energy buildings (NZEBs), using a model to optimize shading for different climates. Wang et al. (2023) [13] explore microbial-induced calcite precipitation (MICP) for creating bio-cement, emphasizing its low-cost, environmentally friendly nature despite limitations with fine sands

ISBN-978-81-19905-39-3

or soils. Liu et al. (2021) [14] advocate for using domestic organic residues (DOR) to boost soil organic carbon (SOC), enhancing soil health and supporting sustainable agriculture. Li et al. (2023) [15] recommend combining Building Information Modeling (BIM) and Augmented Reality (AR) to visualize and optimize construction sequences, reducing energy use and improving efficiency in NZEB projects. Park et al. (2023) [16] discuss integrating BIM with energy simulation and cost estimation tools to help designers make informed decisions, emphasizing the role of AR in enhancing understanding and collaboration on-site. These studies collectively underscore the importance of innovative technologies and sustainable practices in construction to achieve energy efficiency and environmental benefits.

Agarwal (2015) [17] explores the use of Augmented Reality (AR) in civil engineering to minimize construction errors. AR projects architectural and structural drawings in actual scale on-site, enabling real-time 3D comparisons with ongoing construction, which helps quickly identify and rectify errors. Despite current practical challenges, further research could lead to effective AR tools for construction management, design, and marketing. Hernandez and Brioso (2018) [18] examine the integration of Building Information Modeling (BIM), AR, and Lean Construction, highlighting benefits such as quicker decision-making and improved project monitoring. Their review points to a need for deeper research on these technologies' combined use, particularly in automating workflows and enhancing design, control, and flow processes. Diao and Shih (2019) [19] emphasize the importance of AR in Architectural and Civil Engineering (ACE) education, advocating for careful AR system selection, objective grading standards, and markerless systems. Collaboration between academia and industry is deemed essential for advancing AR deployment in ACE education. Machado and Vilela (2019) [20] focus on the need for real-time data in construction site monitoring. They highlight the potential of integrating BIM and AR for improved visualization and information processing. Their review identifies key technologies like fiducial markers, GIS/GPS, laser scanners, and photogrammetry for automatic data capture, and discusses challenges such as precision, calibration, and occlusion. Future work should validate a comprehensive BIM-AR integrative model and assess AR's impact on work performance.

2. OBJECTIVES AND METHODOLOGY

The objective of the present study is to develop a Nearly Zero Energy Building and an AR Model. The methodology adopted is depicted in Figure 1.

ISBN-978-81-19905-39-3

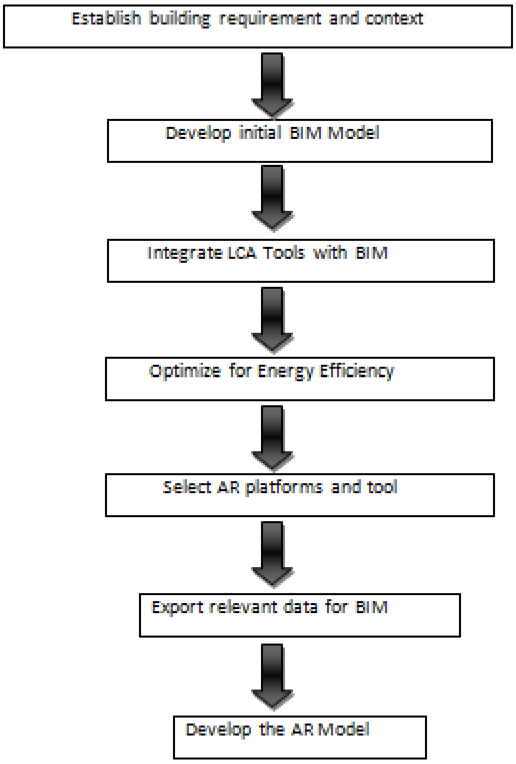

Figure 1: Methodology

3. SUSTAINABLE MATERIAL

Some of the sustainable materials are Reclaimed wood, reclaimed metal, Precast concrete, Bamboo, Cork, Shipping container, Rammed-earth tyres, Earth bag, Recycled steel, Ferrock, Timber Crete, Grass Crete, Paper Crete, Hemp Crete, Plant based Polyurethane Rigid Foam, Straw Cable and Recycled Plastic. Innovative sustainable building materials offer a wide array of options for environmentally conscious construction projects. Reclaimed wood and metal not only lend unique aesthetic appeal but also reduce demand for virgin resources. Precast concrete minimizes on-site waste and energy consumption during production. Bamboo, known for its rapid growth and durability, provides a renewable alternative to traditional building materials. Cork, harvested from the bark of cork oak trees, offers excellent insulation properties while promoting sustainable forestry practices. Shipping containers repurposed into modular structures exemplify adaptive reuse and reduce construction time and costs.

Rammed-earth tires and earth bags utilize natural materials like soil and tires, reducing the carbon footprint and promoting eco-friendly building techniques. Recycled steel finds new life in construction projects, diverting waste from landfills and conserving energy compared to

ISBN-978-81-19905-39-3

virgin steel production. Ferrock, a ground-breaking cement alternative, not only utilizes waste materials but also actively sequesters carbon dioxide, mitigating its environmental impact.

Timber Crete and Glass-Crete showcase innovative approaches to utilizing waste materials and renewable curing methods, further reducing the ecological footprint of construction projects. Additionally, plastics, often vilified for their environmental impact, offer potential as building materials when recycled properly. From PET bottles to polystyrene, advancements in recycling technology enable the reuse of plastics in construction, promoting circular economy principles and reducing reliance on finite resources. These diverse materials collectively demonstrate the potential for sustainable building practices to shape a more environmentally friendly and resilient built environment.

4. SOLAR ENERGY:

Solar energy is hailed as the most abundant natural resource, with the potential to meet many times the current global energy demand. In India, the average intensity of solar radiation received is around 200 MW per square kilometer, translating to a vast capacity potential of 5000 trillion kilowatt-hours per year incident over land area, with most regions receiving 3-5 kilowatt-hours per square meter per day. Leveraging this abundant solar resource and available land, the assessed potential of solar power in the country stands at an impressive 750 gig watts peak (GWp), highlighting the significant opportunity for solar energy to play a pivotal role in meeting energy needs while reducing reliance on fossil fuels and mitigating environmental impacts. The concept of adopting the solar in the present work is show in Figure 2.

Figure 1: Image of Solar Energy from our model

ISBN-978-81-19905-39-3

5. ROOFTOP RAINWATER HARVESTING:

Rooftop rainwater harvesting involves capturing rainwater from building rooftops, storing it in tanks, or directing it to recharge systems. This method, known for its simplicity, eco-friendliness, and affordability, serves various domestic and commercial needs, including toilet flushing, laundry, gardening, and more. By replenishing groundwater and enhancing its quality, rooftop rainwater harvesting contributes to sustainable water management, mitigating water scarcity challenges and fostering resilience in communities' water supply systems. The concept view of Rainwater Harvesting is shown in Figure 3.

Figure 3: Schematic diagram of Rainwater Harvesting

6. Waste Reduction/Recycling (Biogas Plant)

A green approach to construction not only diverts waste from landfills through the use of sustainable materials but also extends to the operational phase of buildings, where waste reduction measures can significantly impact resource conservation. Waste recycling, including wastewater recycling, presents opportunities for conservation, whether through on-site waste management practices like garbage separation and composting or centralized wastewater treatment systems that reuse water from dishwashing or laundry. While larger-scale solutions may pose cost and energy challenges, smaller steps such as installing low-power showerheads or implementing biogas plants to convert wastewater to fertilizer offer viable alternatives. A biogas plant is a facility that produces biogas through the anaerobic digestion of organic materials such as agricultural waste, food scraps, sewage, or other biomass. Anaerobic digestion is a natural process where microorganisms break down organic matter in the absence of oxygen, producing biogas as a byproduct. Typical concept of biogas plant is show in Figure 4.

ISBN-978-81-19905-39-3

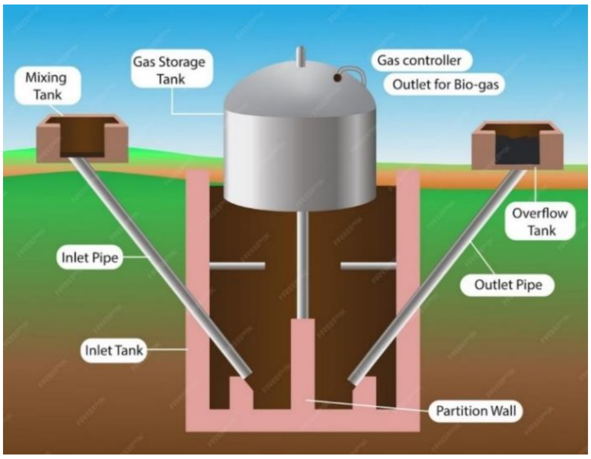

Figure 4 Typical biogas plant (freepik.com)

7. Building Modelling

Considering factors such as the size of the house, number of rooms, layout preferences, and budget constraints, initial plans were worked out.

The final rendered 3D model is shown in Figure 5.

Figure 5 Rendered View of 3D Model

ISBN-978-81-19905-39-3

8. Develop An Augmented Reality (AR) Model

The implementation of Augmented Reality (AR) to convert Revit software design into a real-time model by using "Blender" Blender is a versatile and open-source 3D creation suite used for modeling, animation, rendering, compositing, and more. It offers a comprehensive set of tools for creating high-quality 3D content, making it popular among artists, designers, and animators. The sample of the AR model created in the project is shown in Figure 6. Due to limitations in loading the Revit file into Blender, the complete AR model, as depicted in Figure 5, was not fully captured.

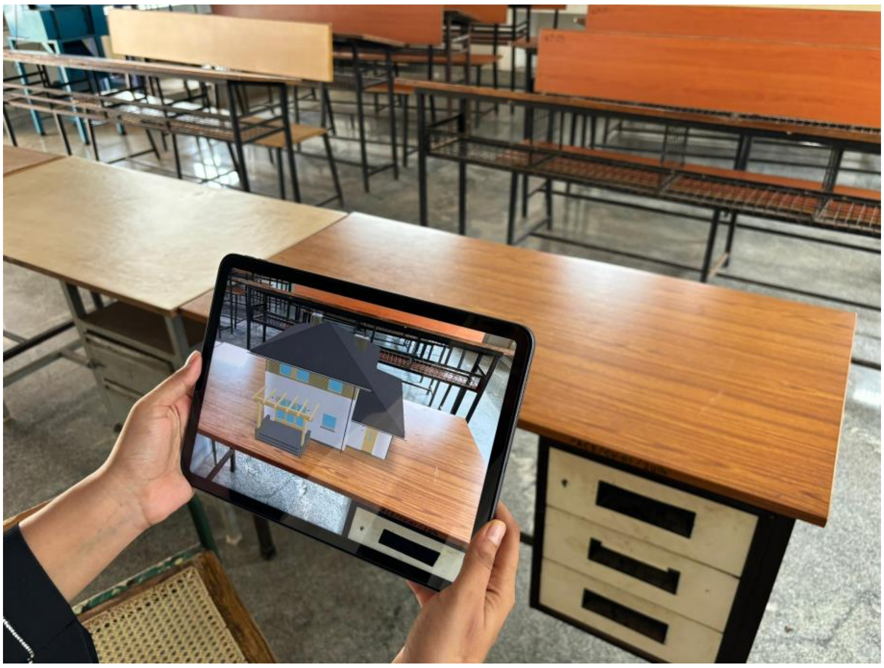

Figure 6 Augmented Reality of a house using Blender

9. Results and Discussion

7.1 Optimizing NZEB Design

Through the integration of Building Information Modeling (BIM) technology, our project successfully optimized the design process of Net-Zero Energy Buildings (NZEBs). By leveraging BIM's capabilities, such as 3D modeling, parametric design, and energy analysis tools, it was able to create more efficient and sustainable building designs. The use of BIM facilitated comprehensive energy simulations, allowing us to assess the energy performance of different design iterations and identify areas for improvement.

7.2 Enhancing Construction Accuracy

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Our project demonstrated the effectiveness of BIM in enhancing construction accuracy for NZEBs. By generating detailed digital models of the building components and incorporating precise construction information, such as dimensions, materials, and sequencing, BIM helped streamline the construction process and minimize errors. This resulted in improved construction efficiency and reduced waste, contributing to the overall sustainability of the project.

7.3 Ensuring Optimal Building Performance

The integration of BIM and AR technologies enabled us to ensure optimal building performance throughout the lifecycle of the NZEB. By visualizing building data and performance metrics in real-time through AR interfaces, stakeholders could monitor energy consumption, indoor environmental quality, and other key parameters. This enhanced visibility empowered decision-making and facilitated proactive maintenance, ultimately maximizing the building's energy efficiency and operational performance.

10. CONCLUSION

In conclusion, our project illuminates the transformative impact of merging Building Information Modeling (BIM) and Augmented Reality (AR) technologies in revolutionizing the construction landscape, particularly in the realm of Net-Zero Energy Buildings (NZEBs). By seamlessly integrating BIM and AR, our research showcases how architects, engineers, and construction professionals can leverage advanced digital tools to streamline design processes, improve construction precision, and ensure the operational efficiency of NZEBs.

Despite encountering hurdles such as technological complexities, our study underscores the pivotal role of ongoing innovation and collaborative endeavors in realizing sustainable building practices. Looking ahead, it is imperative to channel further research and development efforts towards refining existing design tools, expanding access to renewable energy sources, and advocating for regulatory frameworks conducive to NZEB construction. Embracing this holistic approach will not only propel the evolution of sustainable architecture but also contribute significantly to mitigating environmental impact and advancing the global transition towards a carbon-neutral future.

ISBN-978-81-19905-39-3

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ISBN-978-81-19905-39-3