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A Review on Energy Analysis of Building Using Building Information Modelling

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Abstract: Building Information Modeling (BIM) has emerged as a crucial tool for energy analysis in building design, enabling precise simulations and predictive analytics to optimize energy efficiency throughout a structure's lifecycle. This literature review explores the importance of energy efficiency in buildings and the role of BIM in modern architecture. It discusses theoretical frameworks for energy analysis, including an overview of techniques and the integration of BIM with energy simulation tools. The review also examines methodological approaches in the literature, such as case studies and comparative analyses of different BIM tools for energy analysis. Recent advances in energy analysis of buildings are highlighted, including innovations in BIM technology and advances in energy simulation algorithms. The review identifies challenges and limitations, such as technical barriers in BIM adoption for energy analysis and gaps in current research and practice. Future directions in energy analysis using BIM are discussed, including emerging trends and technologies, as well as recommendations for future research. The review concludes by emphasizing the importance of integrating BIM with energy-efficient retrofitting strategies, community engagement, and smart energy management systems to drive the transition towards net-zero energy buildings that align with ecological imperatives and social values.

Keywords: BIM adoption, Energy Consumption, Energy simulation

I. INTRODUCTION

A. Introduction to Energy Analysis in Building Design

Energy analysis in building design involves assessing the energy performance of a structure through various stages of its lifecycle, ensuring that efficiency and sustainability are prioritized. To effectively implement energy analysis in building design, the integration of Building Information Modelling (BIM) is crucial as it enhances collaboration and data management throughout a project's lifecycle. BIM allows for precise simulations that can predict energy consumption patterns and identify inefficiencies before construction begins, enabling stakeholders to make informed decisions that align with sustainability goals. Moreover, employing advanced methodologies such as life cycle energy analysis not only quantifies the energy performance of buildings but also highlights areas where improvements can be made, ultimately reducing the environmental impact associated with the built environment. As the industry moves towards more comprehensive frameworks, leveraging these technologies will become essential in achieving higher standards of energy efficiency and meeting climate objectives.

B. Importance of Energy Efficiency in Buildings

As energy efficiency becomes increasingly critical in building design, the role of predictive analytics powered by AI emerges as a transformative approach to enhance sustainability outcomes. By analysing historical data on energy consumption and identifying trends, AI can assist architects and engineers in creating designs that not only meet current standards but also anticipate future demands for energy-efficient solutions (Thomas, 2023). For instance, companies like Unilever have successfully utilized such technologies to innovate eco-friendly products tailored to consumer preferences, demonstrating the potential for similar applications within the construction sector (Young, 2021). Moreover, the integration of tools like Building Information Modelling (BIM) with advanced AI algorithms can optimize energy usage throughout the project lifecycle, ensuring that buildings are designed with minimal environmental impact while maximizing operational efficiency. This synergistic approach underscores the necessity of adopting comprehensive strategies that encompass both technological advancements and sustainable practices in the pursuit of high-performance buildings.

C. *Role of Building Information Modelling (BIM) in Modern Architecture*

In addition to the benefits of energy analysis and BIM integration, it is imperative to consider how emerging technologies such as predictive analytics can further enhance building efficiency. By harnessing AI-driven insights, architects and engineers can anticipate future energy demands and optimize design choices, accordingly, thus aligning with sustainability initiatives more effectively (Thomas, 2023). For instance, companies like Unilever have successfully employed these strategies to innovate eco-friendly products based on consumer behaviour, showcasing a model that could be adapted for the construction sector (Young, 2021). Such proactive measures not only promote energy conservation but also pave the way for smarter urban planning, where buildings are designed to adapt dynamically to changing environmental conditions, ultimately contributing to climate resilience in the built environment.

D. *Theoretical Frameworks for Energy Analysis*

1) *Overview of Energy Analysis Techniques*

In addition to enhancing energy performance, the integration of BIM fosters innovative design approaches that prioritize sustainability through real-time data analysis and collaboration among multidisciplinary teams. For instance, utilizing predictive analytics powered by AI within BIM frameworks allows architects and engineers to anticipate future energy demands and adapt designs, accordingly, thus promoting the development of eco-friendly structures that align with consumer trends for sustainability (Thomas, 2023). This synergy not only streamlines the design process but also significantly reduces operational costs associated with energy consumption over a building's lifecycle, as evidenced by projects like the Masdar Headquarters, which achieved remarkable energy efficiency through such methodologies (Young, 2021). As these technologies evolve, they are likely to redefine industry standards, encouraging a shift towards more resilient and environmentally conscious architectural practices.

2) *Integration of BIM with Energy Simulation Tools*

Furthermore, the integration of Building Information Modelling (BIM) with advanced energy simulation tools not only enhances predictive capabilities but also facilitates real-time adjustments during the design phase. For example, utilizing Energy Analysis Models in conjunction with BIM can lead to significant reductions in carbon emissions by optimizing building orientation and material choices based on environmental data. This proactive approach allows architects to create designs that are not only aesthetically pleasing but also functionally efficient, aligning with global sustainability targets. Moreover, as stakeholders increasingly recognize the financial benefits associated with energy-efficient buildings—such as lower operational costs and improved marketability—the adoption of these technologies is likely to accelerate, further embedding sustainability into architectural practice. Ultimately, this evolution underscores a critical shift towards an industry standard where energy performance is paramount, driving innovation and fostering a culture of responsibility within the built environment.

II. LITERATURE REVIEW

The difference between BIM and 3D computer-aided design (3D CAD) lies in the latter's ability to allow for the creation of bright contextualised semantic electronic representations of building components and systems, such as spaces, walls, columns, beams, and MEP systems, rather than just graphical people like lines, arcs, alongside circles. With the use of the BIM (building information modelling) tool, it is also feasible to generate a model that incorporates information about the building's physical attributes, procurement, and functioning. Examples of information that could be included in a building information model (BIM) for an air handling unit include its location, supplier, shape, flow rates, operation and maintenance schedule, and clearance requirements (CRC Construction Innovation, 2007). The MSC's seismic response and provide a method for conducting more accurate seismic analyses using a stiffness coupling spring matrix. Their study finds MSC1 and MSC2 vulnerable to displacement, while MSC3 exhibits superior integrity, emphasizing the need for improved external inter-module connection stiffness (Khaled Elsayed et al. 2024) and Mehrdad Arashpour et al. (2017) uncertainties in hybrid infrastructure projects combining on-site and off-site modular construction. By analysing seven projects, they identify risks such as cost overruns and quality deficiencies. Their research advocates a triadic risk analysis approach to enhance coordination and mitigate project deviations, ultimately improving overall efficiency in modular construction. Sriskanthan Srisangeerthan et al. (2020) inter-module connection systems in multi-story modular buildings, addressing challenges in structural integrity and lateral load transfer. They highlight the need for high-performance connections to ensure stress dissipation and load distribution, concluding that optimized connection strategies significantly enhance seismic resilience and durability.

A growing number of construction companies are embracing BIM, prefabrication, and modular building technologies to greatly enhance their output and efficiency. Focussing on the benefits, challenges, and possible uses of building information modelling (BIM) for prefabrication and modular construction, this literature review examines key studies and research on the topic.

III.METHODOLOGY

The research methodology outlines the framework for carrying out the investigation. It describes the methods for collecting, analysing, and interpreting data to address the research questions and achieve the study's objectives. The kind of research, the methodology, and the many tools and methods that will be used to gather and analyse the data are all described in this section.

Type of Research: Descriptive and Comparative Research

This study uses a descriptive and comparative research approach to examine the integration of Building Information Modelling (BIM) in modular construction, with a focus on comparing it with conventional building methods.

Primary Data: This study collects primary data through industry surveys, expert interviews, and BIM model creation. Surveys gather quantitative insights from professionals on BIM integration, cost savings, and coordination issues. Expert interviews provide qualitative perspectives on implementation challenges and productivity impacts. Additionally, BIM models in Revit and Navisworks facilitate cost, time, and performance analysis.

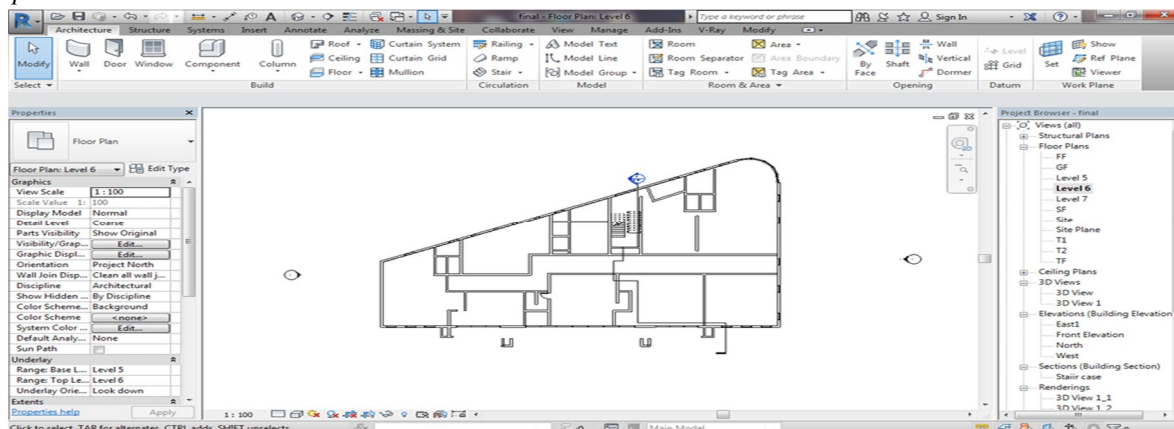
Secondary Data: Secondary data is obtained from literature reviews and historical project records. Scholarly articles and reports offer context on BIM adoption, benefits, and challenges in modular construction. Historical project data is analysed to compare traditional and modular methods, highlighting BIM-driven improvements and identifying areas for further optimization in construction practices. A stratified random sampling approach ensures a diverse representation of construction professionals, including architects, project managers, engineers, BIM consultants, and contractors. The target population includes individuals experienced in BIM and modular construction. A sample size of 100-150 survey participants and 10-12 expert interviews ensures statistical significance and qualitative depth. Inclusion criteria focus on professionals with hands-on BIM experience, while those lacking BIM knowledge are excluded. Stratified sampling guarantees key industry subgroup representation.

IV. CASE STUDY

About 19 years ago, we set out on an endeavour to redefine the premium and luxury housing experience for Pune. With a drive to build and provide ultramodern projects to Pune, we focused on delivering living spaces that are at par with upcoming trends and standards. While we were at it, we also kept devising new ways to integrate a sense of holistic community living amongst Pride Purple residents. With a strong foundation in the world of apartments, row houses, bungalows, commercial plazas, convention centres and hotels, today, we are synonymous with luxury and premium living. Pride Purple Square is a commercial development by Pride Purple Group. It is in Wakad, Pune. It offers spacious and skill-fully designed Shops, Showrooms and Offices. The project is well equipped with all the amenities to facilitate the needs of the business owners.

V. EXPERIMENTAL ANALYSIS

A. Develop Model in REVIT



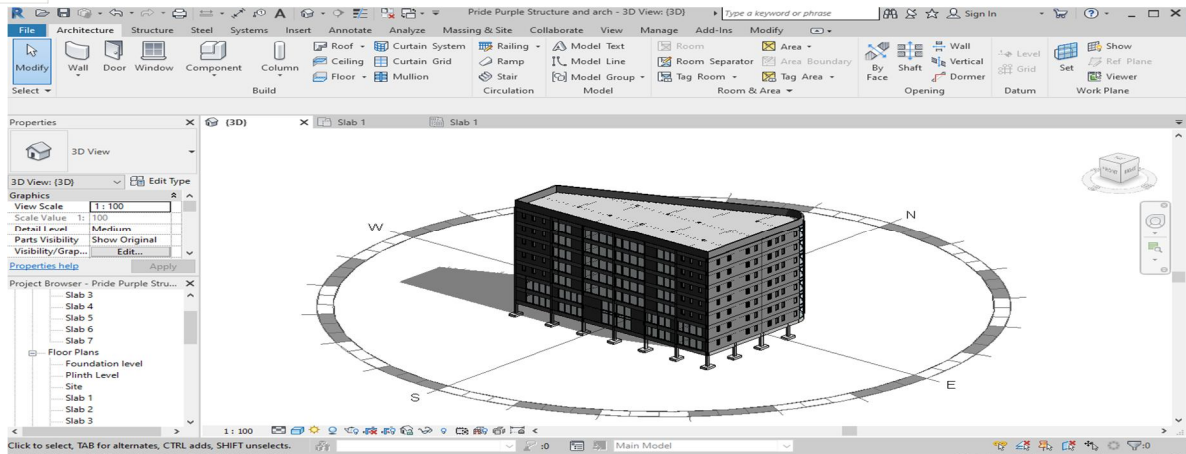


Fig.3. the plan is created in Revit Architecture at level 2, showcasing the column layout in the 3D view.

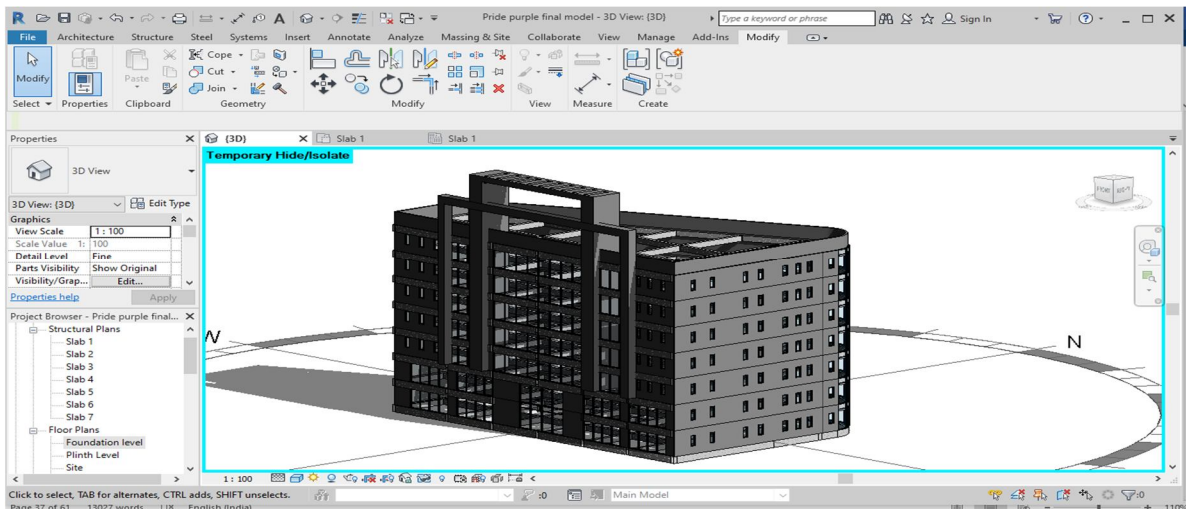


Fig. 4. Final Elevation

B. Method for 5D Modeling in Navisworks

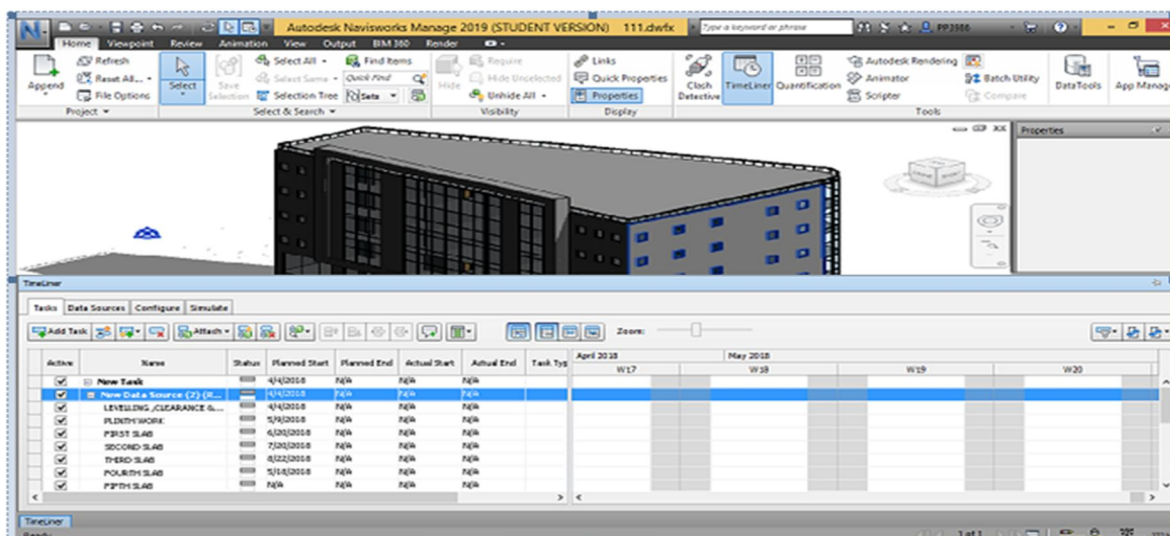


Fig.5. Naviswork Time liner

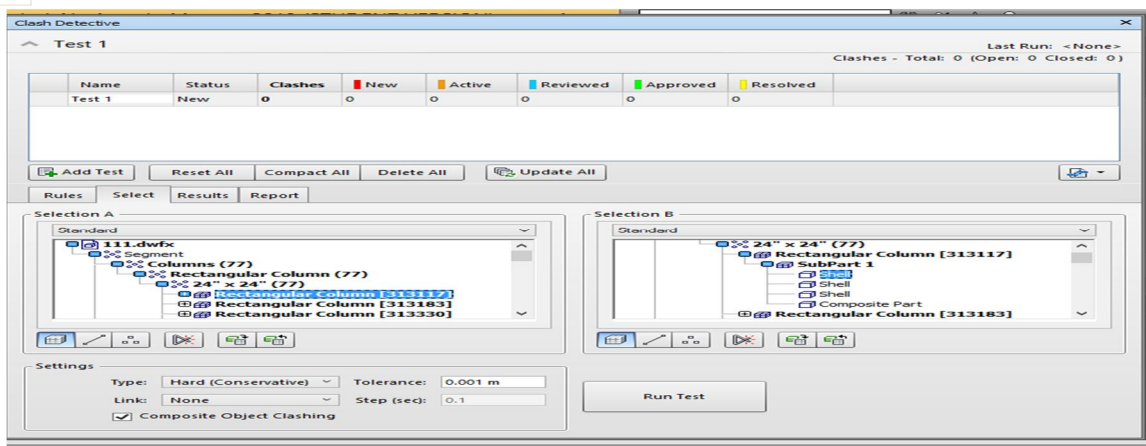


Fig.6. Navisworks clash detection

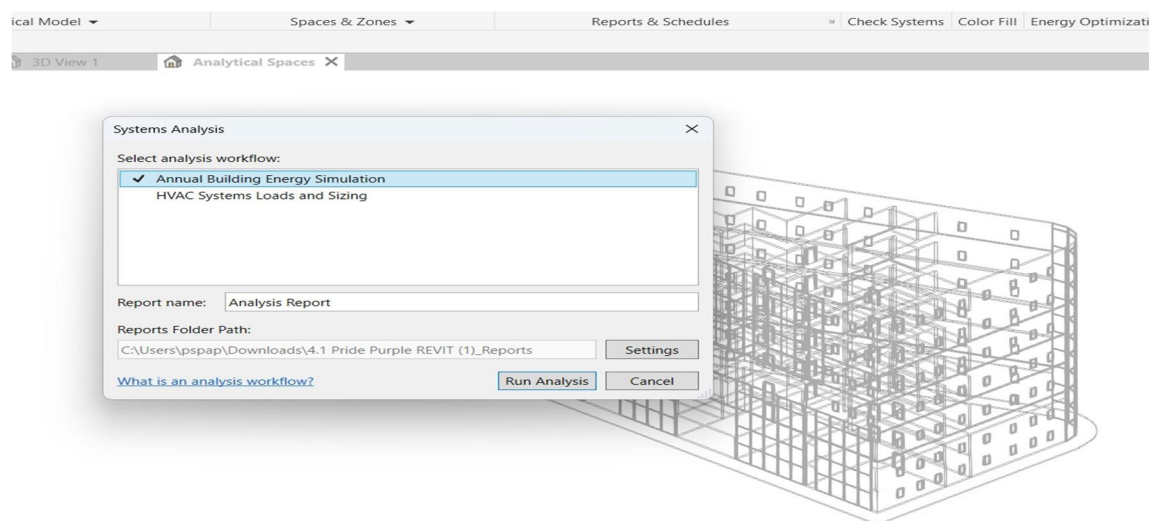


Fig.7. Annual Building Energy Simulation

| Parameter | Value | Unit | Description |
|----------------------|-------|---------------------|--|
| Building Area | 5000 | m ² | Total floor area of the building |
| Building Height | 15 | meters | Height of the building |
| Window to Wall Ratio | 30% | - | Percentage of wall area covered by windows |
| U-Value (Walls) | 0.35 | W/m ² .K | Heat transfer coefficient of walls |
| U-Value (Windows) | 2.8 | W/m ² .K | Heat transfer coefficient of windows |
| Indoor Temperature | 22 | °C | Average maintained indoor temperature |
| Outdoor Temperature | 35 | °C | Average outdoor temperature during peak conditions |

Table 1: Building Energy Parameters

| Construction Type | Energy Consumption (kWh/m ² /year) | Total Energy Consumption (kWh/year) |
|---------------------------|---|-------------------------------------|
| Modular Construction | 90 | 450,000 |
| Conventional Construction | 120 | 600,000 |

Table 2: Consumption Comparison between Modular and Conventional Construction

| Parameter | Modular Construction | Conventional Construction |
|---------------------------------------|----------------------|---------------------------|
| Embodied Energy (kWh/m ²) | 500 | 700 |
| Building Lifespan (Years) | 50 | 50 |

Table 3: Embodied Energy and Building Lifespan Comparison between Modular and Conventional Construction

| Parameter | Value | Unit |
|-----------------------------|-------|------------------|
| Solar Heat Gain Coefficient | 0.5 | - |
| Solar Radiation | 800 | W/m ² |
| Lighting Power Density | 10 | W/m ² |
| Lighting Hours per Day | 12 | Hours |
| Lighting Days per Year | 365 | Days |

Table 4: Solar Heat Gain and Lighting Parameters for Building Design

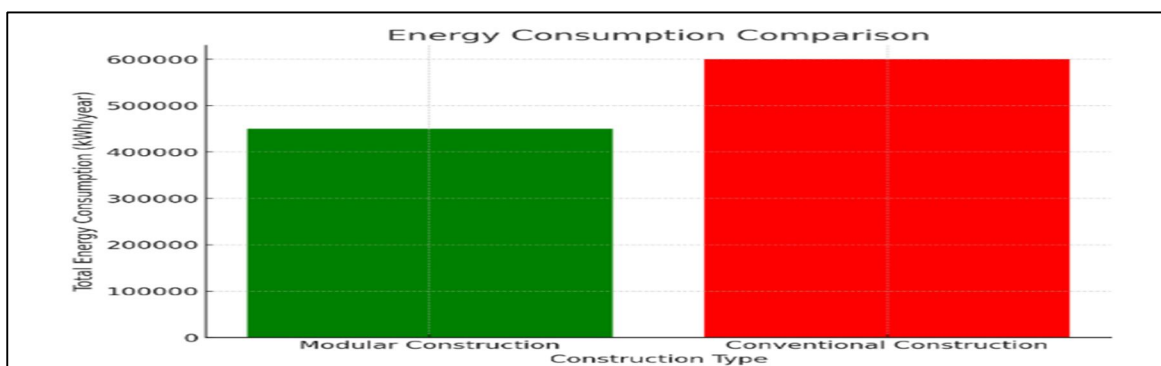


Fig. 8. Energy Consumption Comparison

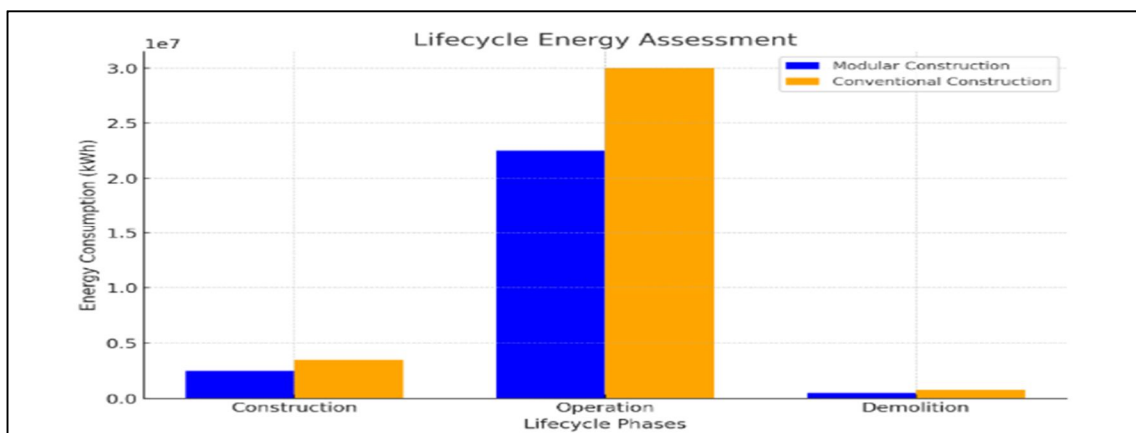


Fig. 9. Lifecycle Energy Assessment

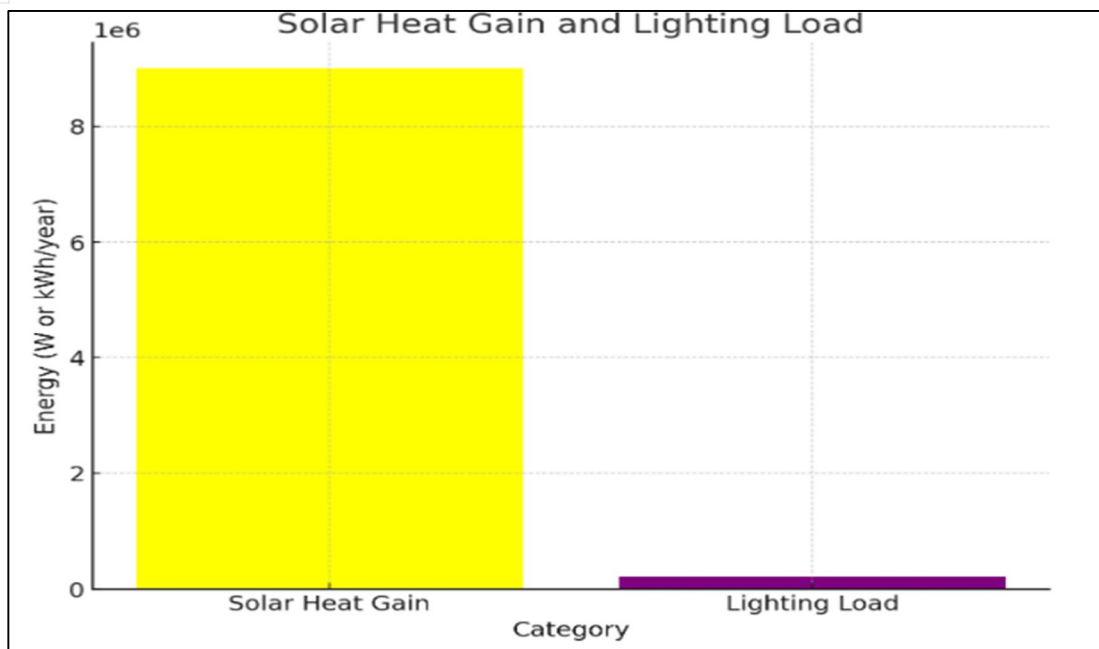


Fig. 10.Solar Heat Gain and Lighting Load

| Energy calculations | | | |
|---------------------|--------------------|----------|---------------|
| Sr. No. | | Units | Cost |
| 1 | Total Consumption | 32867.5 | ₹ 1,68,838.17 |
| 2 | Public Use | 3806.12 | ₹ 19,601.52 |
| 3 | Remaining | 29061.38 | ₹ 1,49,236.65 |
| 4 | Per Flat | 3632.67 | ₹ 18,654.58 |
| 5 | Per Flat Per Month | 302.72 | ₹ 1554.55 |

Table 5: Different use Energy

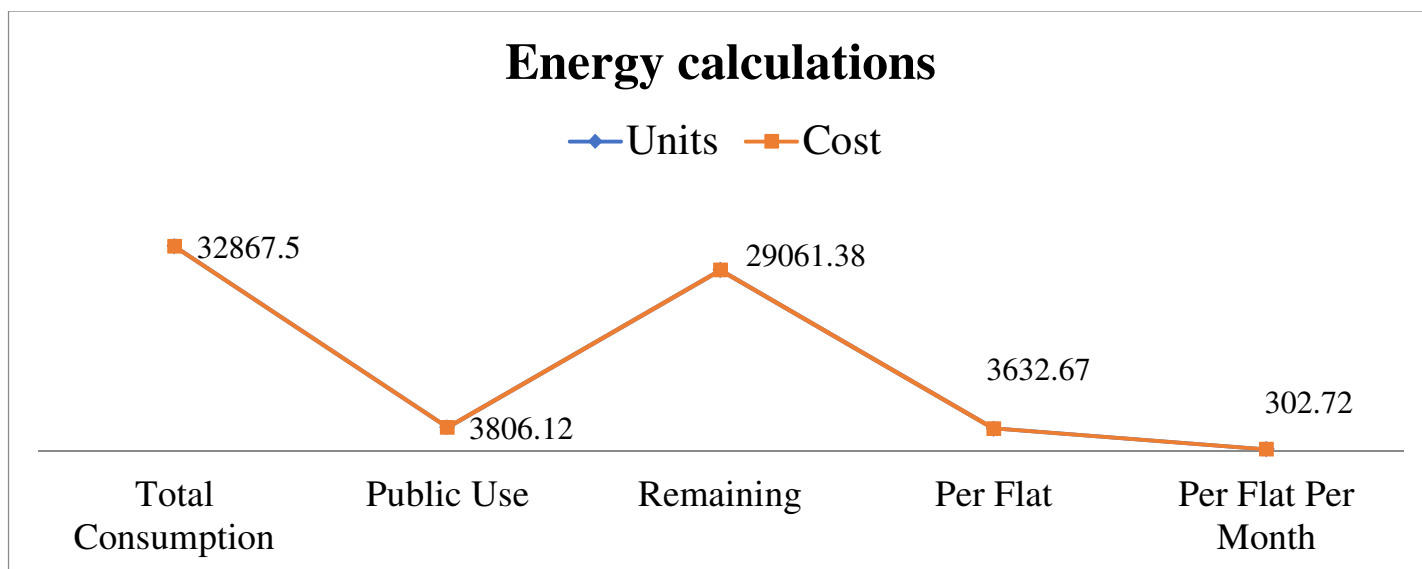


Fig.11. Energy Calculations

| Energy Used | Avg. no of Applications/Device's used per flat | Avg. Uses per day (Hours) | Energy Used Per year (KWh) by a flat | Cost per Month (5.43 X usage) | Cost Per Year |
|------------------|--|---------------------------|--------------------------------------|-------------------------------|---------------|
| Electricity | Lighting | 24 hours | 2900 | 15747 | 188964 |
| Electricity | Water heating + refrigerators + dryers + miscellaneous areas including electronics | 4-6 hours | 187.3 | 1017.039 | 12204.47 |
| Natural gas | Cooking gas | 4.5 hours | 1200 | 6516 | 78192 |
| Heating | Geysers | 2.5 hours | 216 | 1172.88 | 14074.56 |
| Ventilation | Exhaust Fans | 12 hours | 302.4 | 1642.032 | 19704.38 |
| Air conditioning | Air conditioners | 12-14 hours | 2000 | 10860 | 130320 |
| TOTAL | | | 6805.7 | 36954.95 | 443459.4 |

Table 6: Energy Calculation for convectional building

| SR NO | GREEN BUILDING | | | | CONVENTIONAL BUILDING | | | |
|-------|--------------------|-----------------------------------|----------------------|---------|-----------------------|--------------------------------|-----------|---------|
| | QUANTITY | GREEN BUILDING MATERIAL | RATE | COST | QUANTITY | CONVENTIONAL BUILDING MATERIAL | RATE | COST |
| 1 | 4457 bags | FLY ASH CEMENT criteria 15 (4) | 250 | 1114151 | 4457 bags | CEMENT | 350 | 1559950 |
| 2 | 91 brass | SAND | 3008 | 273783 | 91 brass | SAND | 3008 | 273782 |
| 3 | 169 brass | AGGREGATE | 1500 | 252786 | 169 brass | AGGREGATE | 1500 | 252786 |
| 4 | NA | WATER | NA | NA | NA | WATER | NA | NA |
| 5 | 1000 ltr | ADMIXTURE criteria 4,14,17 (5) | 150 / LIT | 150000 | NA | NA | NA | NA |
| 6 | 125 m ³ | AAC BRICKS criteria 15(6) | 3200/ M ³ | 1600204 | 125 M ³ | RED BRICKS | 8 | 500000 |
| 7 | 231 sqmt | SOLAR PANEL criteria 18,19,14(10) | 1780/U MIT | 410769 | NA | NA | NA | NA |
| 8 | 2 pit | R.W.H criteria 11,21(7) | 35000 | 70000 | NA | NA | NA | NA |
| 9 | 88 unit | U.V COATING criteria 13,14(9) | 550/U NIT | 48400 | NA | NA | NA | NA |
| 10 | 12000 sqft | P.V.C FLOORS criteria 17,26,14(7) | 200/SQ FT | 2400000 | NA | FLOORING | 130/SQ FT | 1500000 |
| TOTAL | | | | 6320092 | | | | 4086518 |

Table 7: Cost Comparative Analysis for Green/Sustainable Building and Convectional Building

VI. CONCLUSIONS

As the integration of community engagement and sustainable practices evolves, it is crucial to consider the role of technological advancements such as Smart Energy Management Systems (SEMS) in facilitating these efforts. By employing SEMS alongside Building Information Modeling (BIM), stakeholders can harness real-time data analytics not only to improve energy efficiency but also to involve communities in monitoring their environmental impact actively. For instance, when residents have access to energy consumption data through user-friendly interfaces, they are more likely to engage in energy-saving behaviors, thereby fostering a culture of sustainability at the grassroots level. This collaborative approach, which combines technology with local insights, can lead to innovative solutions tailored to specific community needs while ensuring compliance with increasingly stringent regulations aimed at reducing overall carbon footprints in urban settings. Ultimately, this synergy between advanced technologies and community involvement will be pivotal in driving the transition towards net-zero energy buildings that resonate with both ecological imperatives and social values.

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