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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 Srisangeerthanan 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.

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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

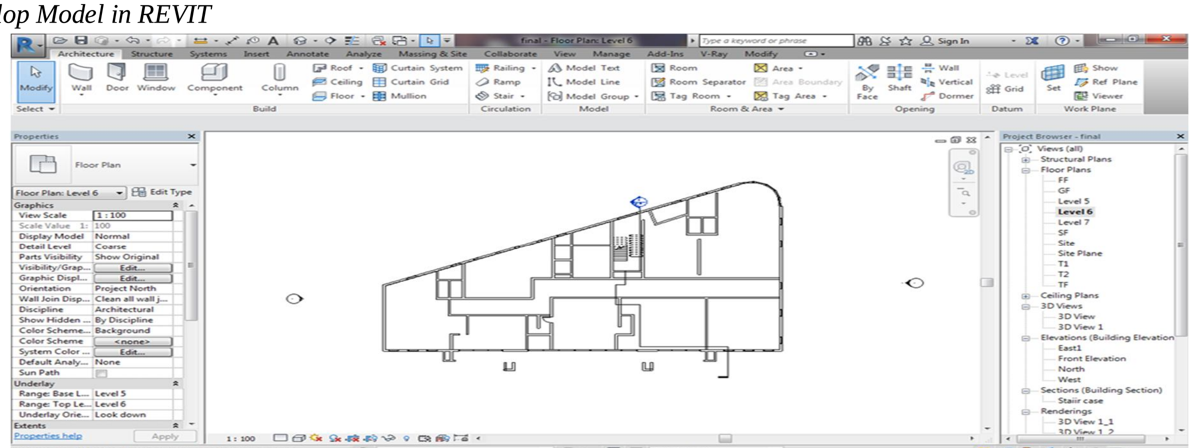

Fig.2. Architectural floor plan created in Revit for Level 1

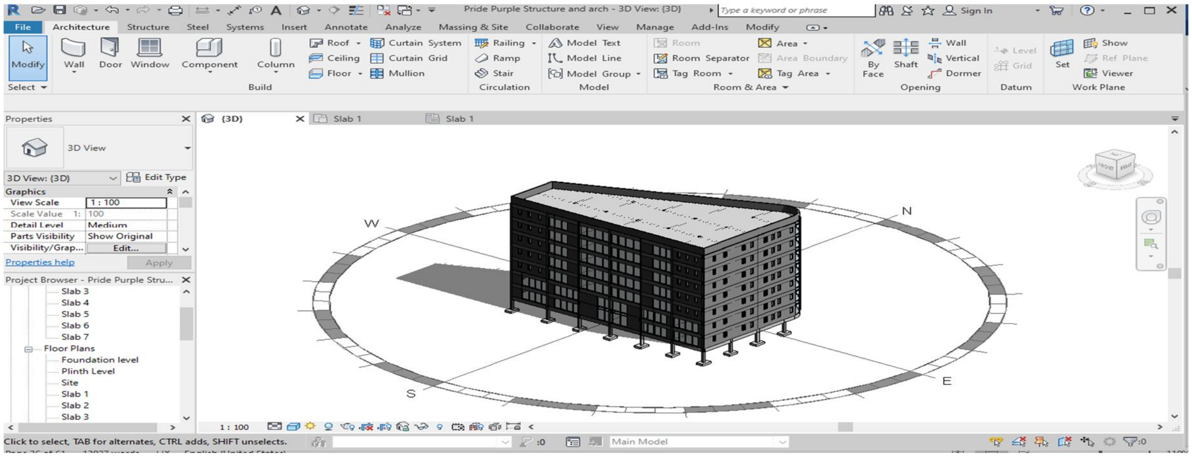

Fig.3. the plan is created in Revit Architecture at level 2, showcasing the column layout in the 3D view.

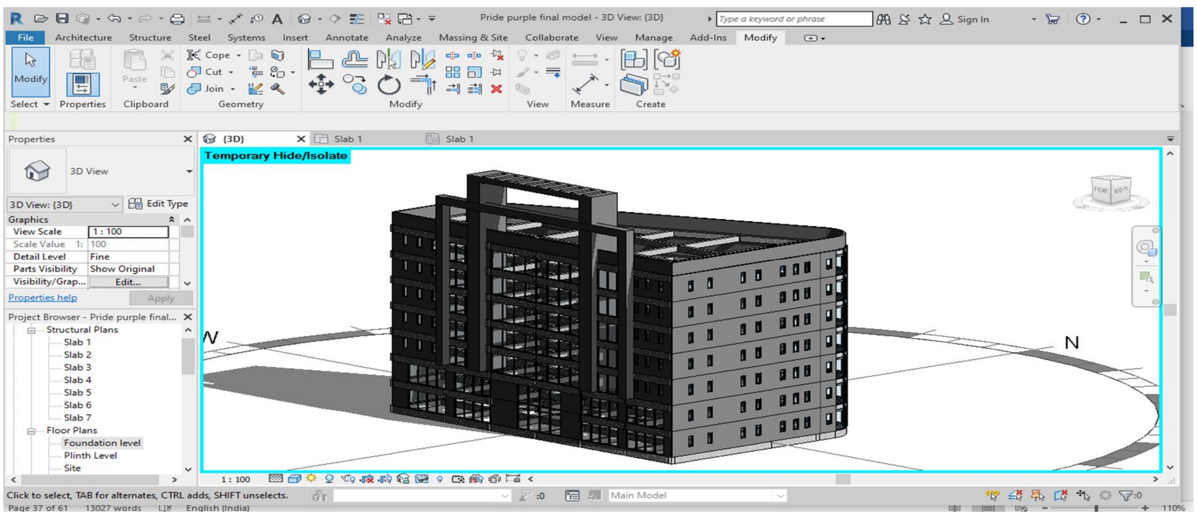

Fig. 4. Final Elevation

B. Method for 5D Modeling in Navisworks

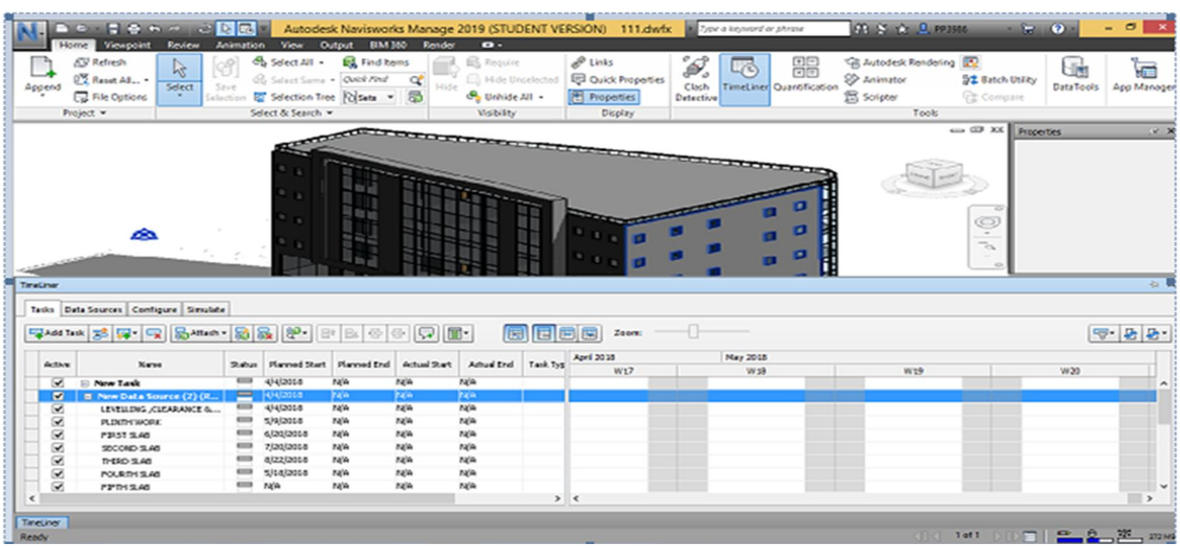

Fig.5. Naviswork Time liner

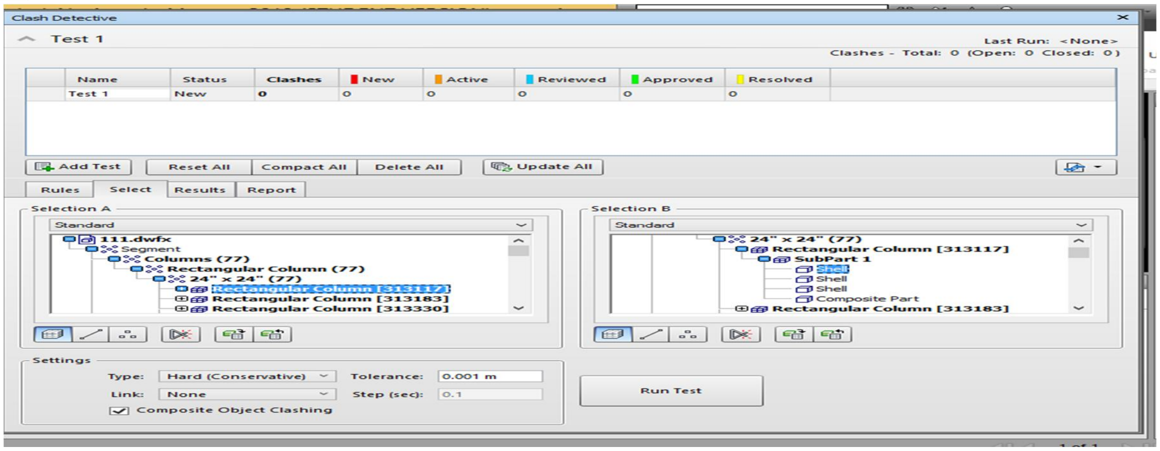

Fig.6. Navisworks clash detection

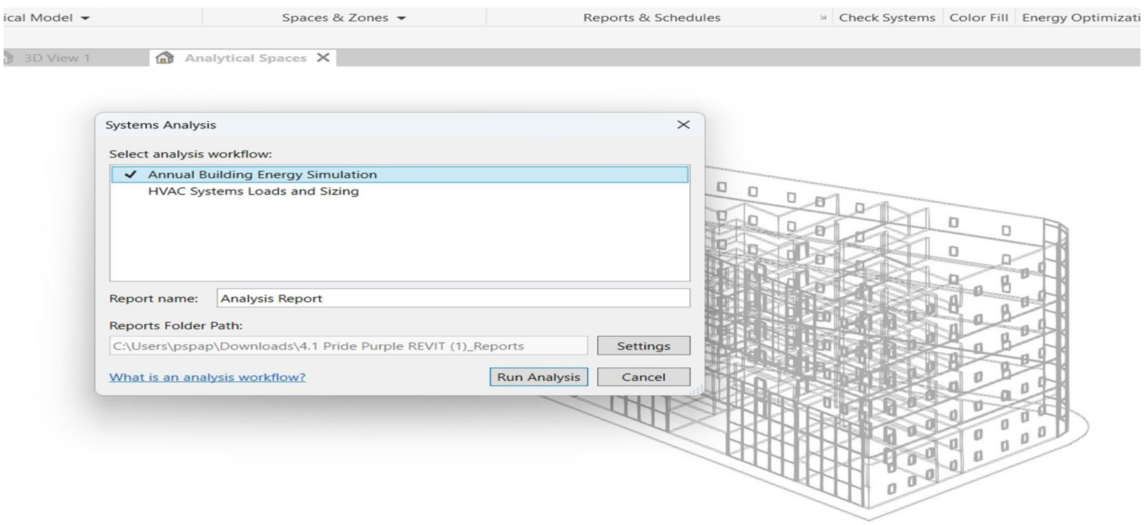

Fig.7. Annual Building Energy Simulation

Parameter	Value	Unit	Description
Building Area	5000	m²	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/m²·K	Heat transfer coefficient of walls
U-Value (Windows)	2.8	W/m²·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

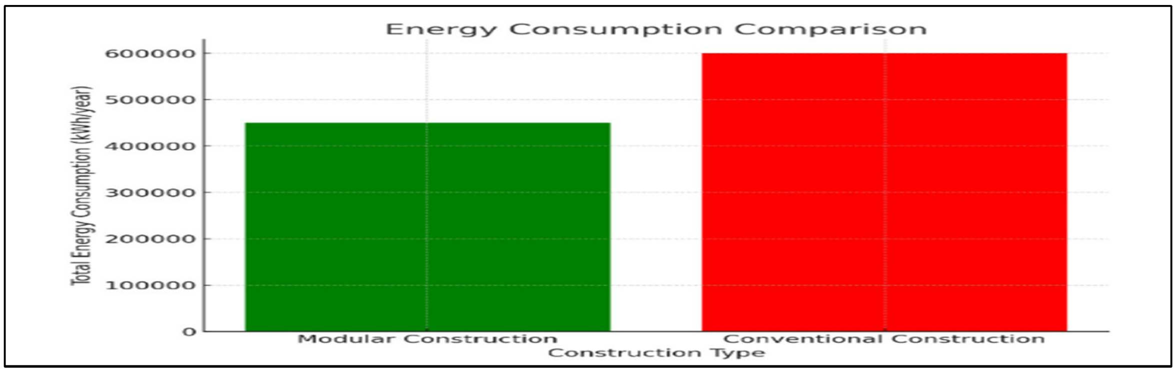

Fig. 8.Energy Consumption Comparison

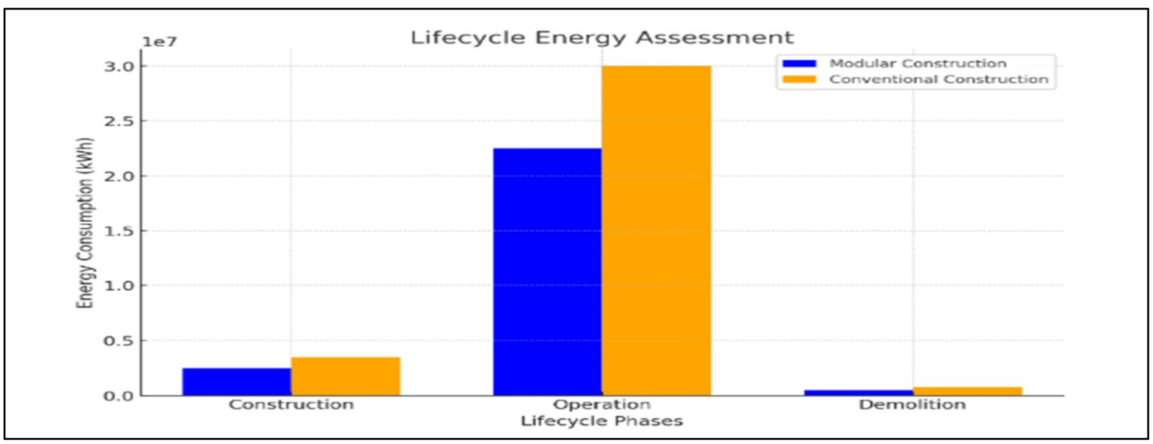

Fig. 9.Lifecycle Energy Assessment

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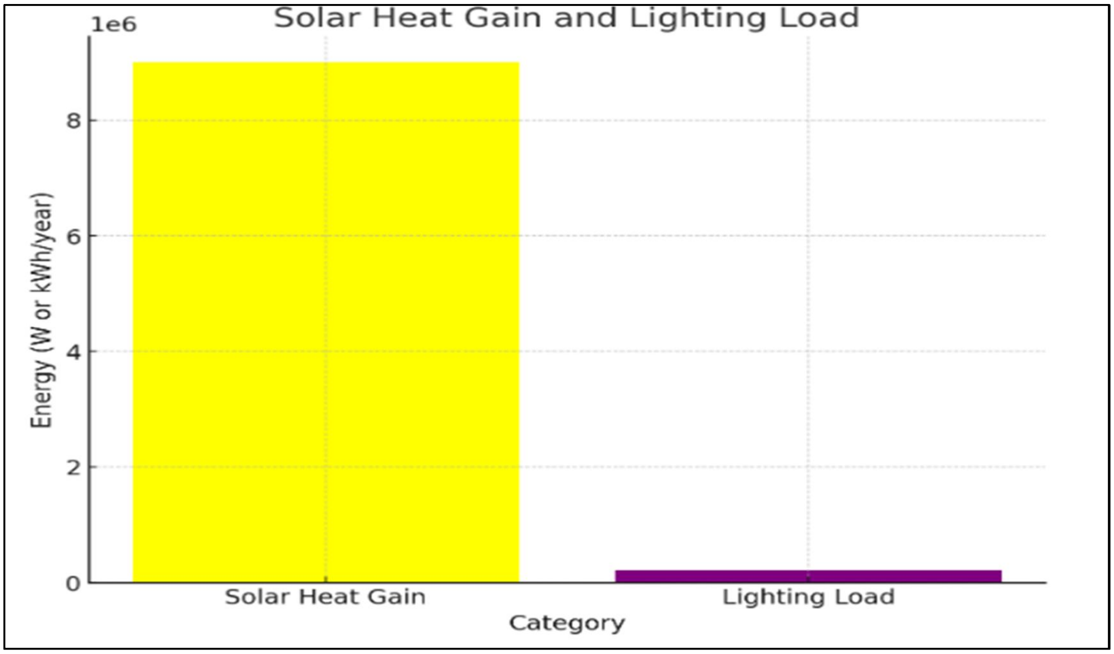

Fig. 10.Solar Heat Gain and Lighting Load

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

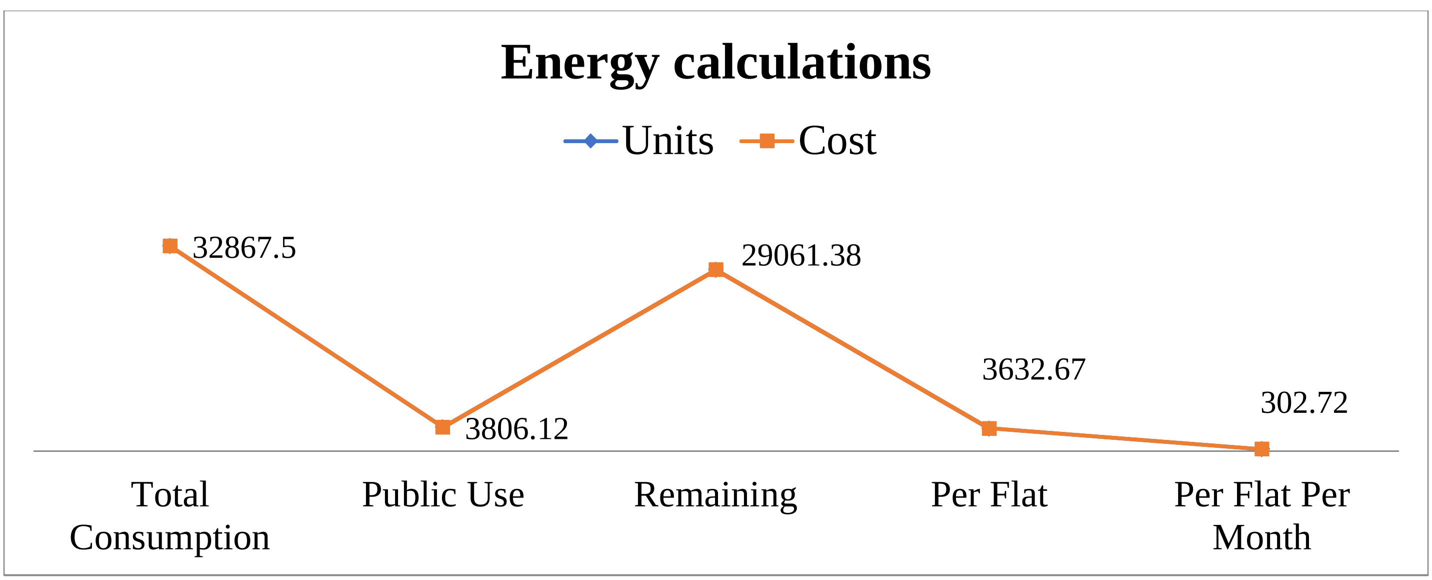

Fig.11. Energy Calculations

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

	GREEN BUILDING				CONVENTIONAL BUILDING			
SR NO	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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