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Integration of BIM and GIS on Building Energy Consumption and Transportation Energy Intensity

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ABSTRACT :

Building Information Modelling (BIM) and Geographic Information System (GIS) integration started in the early 2000s to connect detailed building models with large-scale maps. Building sector and Transportation sector are main sources of GHG and CO_2 emissions. Current trends in BIM and GIS integration focus on cloud-based platforms, AI, and machine learning to enhance real-time energy modeling, optimize urban planning, and predict future energy demand. The aim of this study is to assess the Building Operational Energy (BOE) of an educational building and Transportation CO2 Emissions (TCE) commuting from various locations to the source. This integration helps in evaluating energy efficiency and environmental impact for sustainable urban planning. BOE is calculated using three different software's such as Autodesk's Green Building Studio (GBS), Autodesk Insight 360 (I360) and eQUEST (V3-64) (developed by James J. Hirsch & Associates (JJH) and Lawrence Berkeley National Laboratory (LBNL)) and TCE is calculated with QGIS (V3.40.3). The results indicate the BOE of an existing educational building is 3603 MJ/m²/year using Autodesk's Green Building Studio, 3525.2 MJ/m²/year using Autodesk Insight, and 3467.52 MJ/m²/year using eQUEST software's. Additionally, TCE for conventional vehicles are 5795.26 kg CO_2. The study highlights the crucial role of sustainable design and operational strategies in reducing BOE and TCE in existing educational buildings.

Keywords: BIM (Building Information Modelling); GIS (Geographic Information System); Building Operational Energy (BOE); Transportation CO2 Emissions (TCE); Sustainable planning; Internal combustion Engine (ICE) vehicles; window to wall ratio (WWR)

1. INTRODUCTION

The main sources of Green House Gases (GHG) and Carbon dioxide (CO_2) emissions are building sector and transportation sector. Table-1 shows the various percentage of GHG and CO_2 emissions from building and transportation in the World and India.

Table-1: Percentage of GHG and CO_2 emissions from building and transportation in the World and India

	TRANSPORTATION		**REFERENCE**	**BUILDING**		**REFERENCE**
	GHG	**CO_2**		**GHG**	**CO_2**	
World	**15%**	**23%**	**1.https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-10**	**6%**	**42%**	**2.https://www.epa.gov/ghgemissions/global-greenhouse-gas**
India	**9.7% (2016)**	**90%**	**3.https://theicct.org/wpcontent/uploads/2022/05**	**17%**	**20%**	**4.https://rmi.org/indias-buildings-sector-moonshot-corporate-climate-commitments-can-forge-the-path**

Building Information Modelling (BIM) is a digital representation of the physical and functional characteristics of a building or infrastructure. Geographic Information System (GIS) is a spatial technology that captures, analyses, and visualizes geographic data to support decision-making and planning. Building Operational Energy (BOE) is the energy used for operating electrical systems (Electrical appliances, HVAC system) in a building during its lifetime. Efficient management of this energy is crucial for reducing overall energy demand and environmental impact. Similarly, transportation intensity, measured in terms of CO_2 emissions (TCE), represents the carbon footprint of fuel consumption in transportation activities. BIM enables detailed simulation of building energy performance, considering factors like insulation, HVAC efficiency, and lighting systems. By integrating energy modelling software's, BIM helps assess different design scenarios to optimize operational energy use and reduce emissions. GIS provides spatial analysis for transportation-related emissions by mapping travel patterns, identifying high-emission zones, and optimizing routes for sustainable mobility solutions such as electric vehicle charging infrastructure and public transport planning. Combining BIM and GIS enables a holistic approach that supports sustainable planning and development.

The advantage of this study is improved energy efficiency, helping building owners and city planners reduce energy consumption by optimizing building operations and transportation networks for sustainable urban development. Additionally, it supports informed decision-making by combining energy performance data with geographic analysis, allowing for more accurate and effective sustainability planning and implementation.

However, advancements now allow seamless integration of BIM and GIS for real-time data sharing, dynamic simulations, and predictive modelling. This enables more accurate assessments of energy consumption, emissions, and optimization strategies. Current applications include smart city planning, energy-efficient building design, sustainable transportation networks, and disaster management.

- Current Trends and Technological Advancements (2020s - Present):

I. Cloud-based BIM and GIS: Cloud platforms facilitate real-time data sharing and advanced simulations for accurate and dynamic energy modelling across geographic locations. (“ASCE”)

II. Building Energy Performance and Transportation Intensity: Integrating BIM and GIS enables deeper insights into combined energy use of buildings and transportation, optimizing urban planning to minimize energy consumption. (“ASCE”)

III. Artificial Intelligence and Machine Learning: AI and machine learning are used within BIM+GIS platforms to predict energy consumption patterns, optimize energy systems, and forecast future demand. (“Science Direct”)

2. Literature Review

- Ebrahim Karan Et al (2015), Reports that the building and transportation sectors consume significant energy and CO_2emissions, it requires an integrated analysis. By combining BIM for buildings and GIS for transportation, it maps energy use and highlights how occupant travel behavior impacts total energy demand, suggesting solutions like electric vehicles and solar panels to reduce emissions. The methodology in the paper involves three main steps: data collection, model development, and scenario analysis. First, building and transportation data are gathered using BIM, GIS, and Origin-Destination (O&D) surveys. Then, an integrated BIM-GIS model is developed to analyse energy consumption, followed by simulation and scenario testing to evaluate energy-saving strategies like solar panels and electric vehicles.
- T. Park Et al (2014), reports that Project Cost Estimation of National Road in Preliminary Feasibility Stage Using BIM/GIS Platform. The study highlights how Integrating BIM and GIS improves cost estimation for national road projects. It enhances project management, provides clear 3D visualizations for better understanding, and ensures consistent cost estimates. The system allows flexible route selection, improves resource efficiency, and offers a detailed cost analysis of construction, land acquisition, and maintenance. Overall, it helps stakeholders make better decisions and streamline the feasibility process. This study integrates BIM and GIS to improve cost estimation for national road projects during the feasibility stage. A BIM/GIS-based system was developed to estimate construction, land acquisition, and operation & maintenance costs. Users input GIS data, and the system processes details like bridge and tunnel properties, earthwork quantities, and land boundaries. Running on AutoCAD, it provides 2D/3D visualizations for better route analysis and decision-making. The methodology ensures flexibility in modifying routes while maintaining consistent and reliable cost estimates.
- Hyunjoo Kim Et al (2015), Experimentally reports that the Importance of Integrating BIM and GIS for highway earthwork balancing. Cut and fill earthwork is crucial for reducing costs and environmental impact. Using a semantic web approach simplifies data exchange, overcoming traditional challenges. A prototype system effectively simulates earthwork processes, optimizing construction plans. Accurate elevation data is essential, as it significantly affects earthwork volumes. They integrate BIM and GIS to balance highway cut and fill earthwork. BIM data (road shape, elevation) and GIS data (terrain, soil types) are combined using semantic web technologies for smooth data exchange. Spatial analysis calculates earthwork quantities, and a prototype system simulates the process. The method is tested on a highway project in South Korea, improving accuracy and efficiency in road construction.
- R. Liu and R. R. A. Issa (2012) focused on the feasibility of Integrating GIS and BIM for subsurface pipeline management, validated through a campus building case study. It improves field workers' understanding, reducing risks during excavation, and provides accurate 3D visualizations of pipe systems. However, challenges in data integration, especially regarding pipeline details, remain. Future research should expand to various infrastructure types, optimizing maintenance routes and enhancing operational efficiency. They used the methodology that Integrates GIS and BIM to improve the visualization and management of subsurface pipelines. They use ArcGIS for mapping, Revit for modeling buildings and utilities, and AutoCAD Civil 3D for integrating and modifying the data. The process follows a structured workflow, combining 2D GIS and 3D BIM data for a comprehensive understanding of underground infrastructure. This Integration enhances maintenance efficiency and reduces the risk of accidental damage during excavation or repairs.
- Mingzhu Wang Et al (2019) States that the effectiveness of Integrating BIM and GIS for underground utility management, addressing challenges like lack of unified models. It proposes a comprehensive data model and an integrated framework using IFC and CityGML. Feedback shows strong support for the platform, with future work focusing on enhancing it with more data. The study integrates BIM and GIS to improve underground utility management. It starts with gathering feedback from stakeholders and identifying challenges, like the lack of a unified digital model. The research proposes a common utility data model with five categories: network, component, geometry, condition, and miscellaneous information. An integrated framework is developed, using IFC and CityGML for better representation.
- Jaeheo Et al (2021) presents that identifying the optimal sites for photovoltaic (PV) plant installations near highway networks in South Korea using a BIM-GIS integrated approach. The four-stage methodology includes data collection, geo-spatial analysis, energy output evaluation, and BIM-based visualization. Results showed a combined potential output of 8,227 MWh, proving the method’s efficiency. The integration of BIM and GIS enhances site selection and supports sustainable infrastructure planning.
- Linlin zhao Et al (2019) presents a novel approach that combines BIM and GIS to enhance the planning of water distribution systems (WDS). The methodology involves integrating BIM project data into a GIS framework through semantic mapping, facilitating comprehensive geo-

spatial analysis. This integration enables the creation of a 3D visualization model of the proposed WDS and its surroundings, allowing for the identification of potential conflicts and optimization of pipeline layouts. The study demonstrates that this BIM-GIS integration streamlines the planning process, improves decision-making, and supports sustainable development by providing a more accurate representation of the physical and functional characteristics of the WDS within its environmental context.

- Shingi Yamamura Et al (2017) reports that GIS and BIM based urban energy planning system aimed at optimizing technical and policy solutions for urban infrastructure redevelopment. The methodology encompasses constructing and analysing a database using GIS, designing an optimal energy system with BIM assistance, and providing 3D visualizations through a user-friendly interface. A case study demonstrates the system's potential to identify effective strategies for urban energy performance enhancement. The integration of GIS and BIM facilitates comprehensive analysis and visualization, thereby supporting sustainable smart city development.
- Bei wu, rui zhou Et al (2021) research that the integration of BIM and GIS to enhance building life cycle management. The methodology involves creating a unified platform that combines BIM's detailed building data with GIS's spatial analysis capabilities, facilitating comprehensive management from design to demolition. This integration allows for improved decision-making, efficient resource utilization, and enhanced sustainability throughout the building's life cycle. The study concludes that the BIM-GIS approach significantly contributes to more effective and sustainable building life cycle management.
- Sanyuan Niu Et al (2015) introduces a novel approach that combines BIM and GIS within a web-based platform to enhance low-energy building design. The methodology involves integrating detailed building information from BIM with spatial data from GIS, enabling real-time energy performance evaluation and visualization through a user-friendly web interface. This system allows stakeholders to assess and optimize building designs for energy efficiency interactively. The study demonstrates that such integration facilitates informed decision-making, improves collaboration among project participants, and supports the development of sustainable, energy-efficient buildings.

3. METHODOLOGY:

The methodology in this study broadly divided into 4 stages. The stages are Data Collection, Modelling of Building, Energy Analysis, Interpret results

Data Collection:

It includes collection of architectural plan of existing/actual educational building and travel details of dwellers of the building. The building is a three-story (G+2) educational building with a total plinth area of 1148 sqm. It comprises multiple classrooms designed for academic instruction, along with well-equipped laboratories to support practical learning. A seminar hall is included to host academic events and presentations. Additionally, staff rooms are provided to accommodate faculty and administrative personnel. The travel data contains latitude and longitude of origin location, travelling mode, travelling time, purpose, fuel type.

Modelling of Building:

The building frame work is modelled in software - Revit Architecture (2024) based on actual plan. During the modelling process, all essential components such as doors, windows, HVAC systems, and ventilators were incorporated. Electrical appliances including fans and lighting fixtures were also added to ensure accurate representation of the building's energy performance.

Energy Analysis:

Existing/Actual Building is modelled for BOE estimation using following software’s

i. Autodesk Green Building Studio
ii. Autodesk Insight 360
iii. eQUEST

For BOE analysis, each software requires specific input parameters to simulate energy performance accurately. Key inputs include the building's operation schedule, type of building, geographic location, and the HVAC system used. These factors collectively influence the estimation of annual energy consumption.

TCE is estimated based on Conventional Vehicles - Internal combustion vehicles (ICE) using QGIS software (3.40.3). During the calculation of TCE for conventional vehicles, emission factors were considered based on standardized values. These emission factors were sourced from the Intergovernmental Panel on Climate Change (IPCC) guidelines.

Interpret Results:

The results reveal the BOE for the existing educational building varies slightly across different simulation software’s. Based on key input parameters such as lighting systems, occupancy and usage patterns, heating and cooling loads, HVAC configurations, and operation schedules, the BOE was estimated using three different simulation software’s. Autodesk Green Building Studio yielded a value of 3603 MJ/m²/year, Autodesk Insight reported 3525.2 MJ/m²/year, and eQUEST provided 3467.52 MJ/m²/year. The TCE resulting from conventional vehicle usage were calculated to be 5795.26 kg CO_2. This value was derived based on travel distance, fuel type, and emission factors in accordance with IPCC guidelines.

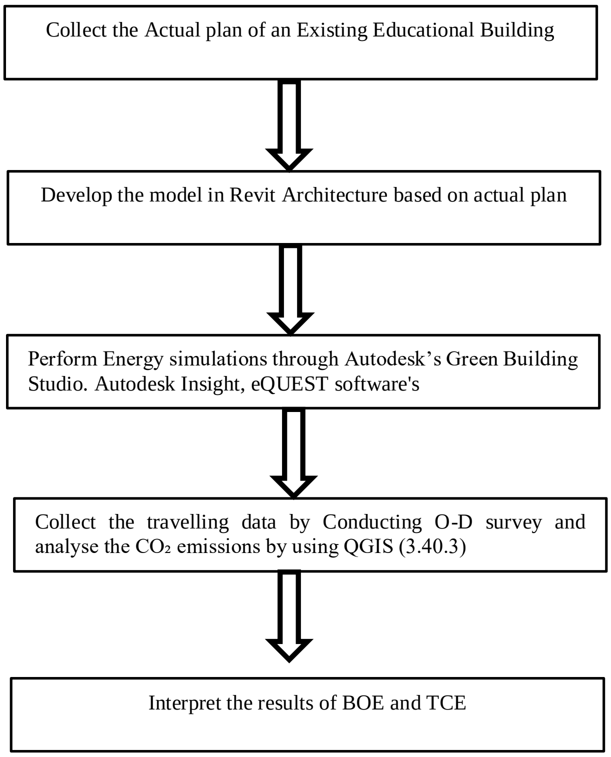

Fig-1 Project Execution Plan

4. CONCLUSIONS:

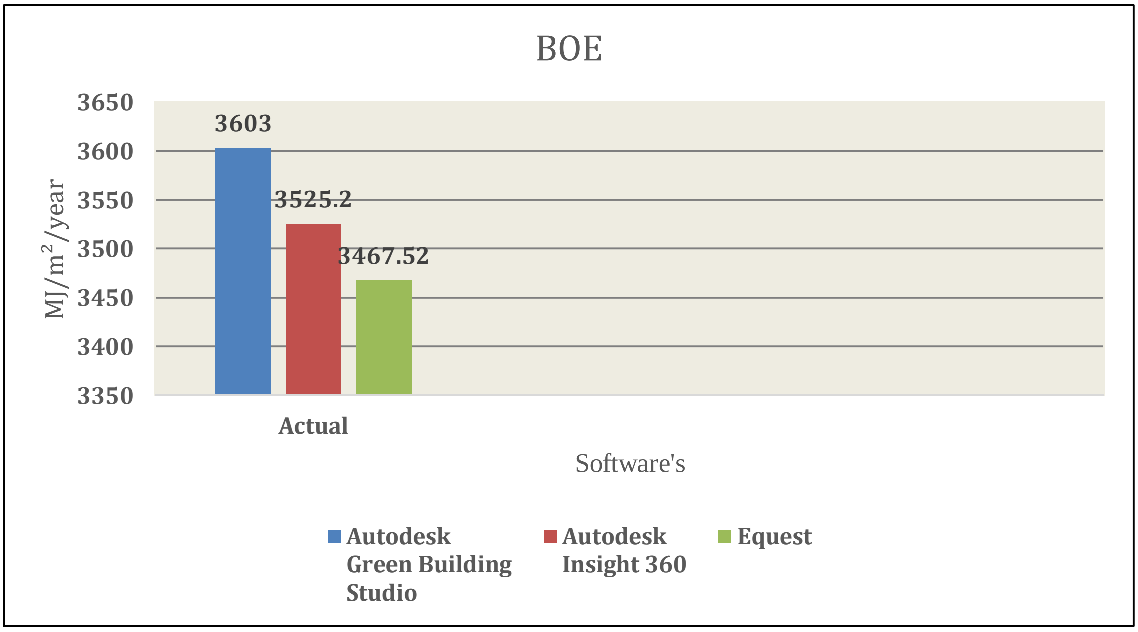

Fig-2Comparison of BOE

The Average Energy analysis (EA) of BOE for actual is 3531 MJ/m²/year and TCE is 5795.26 kg CO_2. Increasing the Window-to-Wall Ratio (WWR), strategically adding windows and ventilators, and incorporating solar panels for daylight harvesting can significantly reduce BOE, promoting energy efficiency and sustainability. Implementing electric vehicles further decreases TCE, minimizing environmental impact. These combined measures enhance both building and transport sector performance. The key benefit of this research is its ability to support data-driven decision-making for designing energy-efficient buildings and low-emission transportation systems.

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