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IMPLEMENTING BIM FOR SUSTAINABLE CONSTRUCTION IN DEVELOPING COUNTRIES: EMPHASIZING ECONOMIC, ENVIRONMENTAL, AND SOCIAL ASPECTS

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Graphical abstract

Abstract

Sustainable construction seeks to integrate social, economic, and environmental objectives throughout a project's lifecycle. In developing countries, this process is hindered by limited technology, inefficient manpower, and resource mismanagement within the architecture, engineering, and construction (AEC) industry. This study investigates the potential of Building Information Modeling (BIM) to address these challenges and promote sustainable construction practices. A mixed-method research approach was adopted, combining an extensive literature review with a case study on sustainable building practices in Bangladesh. BIM-based tools such as ArchiCAD, Tekla, Solibri Model Checker, and Revit were utilized to evaluate building performance, energy efficiency, and cost optimization. The findings reveal that BIM integration can reduce construction waste, improve collaboration across project phases, and enhance energy efficiency through better material selection and lifecycle planning. Cost-benefit analysis demonstrated a potential reduction in construction and maintenance costs by 15–40%, with a high return on investment and shorter payback period compared to traditional methods. The study concludes that BIM offers a viable pathway to achieving economic, environmental, and social sustainability in the construction industry of developing countries, provided that adequate training, policy support, and technological infrastructure are implemented.
Keywords: Sustainable construction, BIM, collaboration and integration, BIM performance, benefit and acceptance.

1.0 INTRODUCTION

Developing countries are increasingly engaging in sustainable construction practices. The globalization trend has provided them with opportunities to take initiative in a competitive global arena. Organizations such as (Building Research Establishment Environmental Assessment Method) BREEAM and (Leadership in Energy and Environmental Design) LEED are lending a helping hand in this endeavor. However, the sustainable construction industry in developing countries still lacks adequate technology and site management systems. Additionally, sustainable construction practices differ from one country to another, and political conditions and social inequities also influence their implementation [1].

Implementing Building Information Modeling (BIM) could be a key solution for advancing the construction industry, particularly in developing countries. BIM has the strength to address project complexities not only in pre-construction phases but also during project operations. Specifically, BIM enables real-time coordination between multidisciplinary teams, reducing design errors and rework during both design and construction phases. It provides accurate quantity take-offs and cost estimation, improving budget control and resource allocation. Additionally, BIM's 3D visualization and data integration support efficient facility management during the operational phase, ensuring better lifecycle performance of the project. Communication and collaboration systems throughout the construction process simulate a virtual reality environment.

Simultaneously, BIM offers an opportunity for quick returns on investment [2]. For developing countries, incorporating BIM technology aligns with profitable and economic thinking. Design for Manufacture and Assembly (DFMA) and lean construction are now enhanced through BIM, making the technology easily transferable between countries. BIM standards and adoption globally support the construction industry as an international investment on a global scale. Currently, BIM is also being embraced by Small and Medium-sized Enterprises (SMEs) to yield better outcomes for their operations. Furthermore, BIM is receiving certification from the International Organization for Standardization (ISO 9001 and ISO 14001) for its quality and management systems.

The construction industry in developing countries is evolving through three stages to enhance their socioeconomic status: I) Incorporating high technology in the early stage; II) Utilizing intermediate technology with effective solutions; and III) Advancing in terms of labor and productivity. All of these stages must be executed within economic budget constraints [3]. For sustainable growth, there's a growing emphasis on integrating technology while optimizing manpower. Through feasibility studies and analyses, there's a shift towards prioritizing high technology in initial planning for sustainable solutions. Moreover, various funding sources such as the Private Export Funding Company (PFEFC), Overseas Private Investment Corporation (OPIC), and Private Investment Company in Asia (PICA) are supporting national development initiatives. Furthermore, there's a strong focus on leveraging computer-added value and enhancing collaboration and communication at all levels of the construction phase. These efforts aim to make their systems more flexible and efficient over time [3]. The construction industry has significantly intensified its technological efforts since recognizing the importance of object-oriented building product modeling from the 1990s to the present. The widespread adoption of Computer-Aided Design (CAD) marked the initial phase of project simulation. Subsequently, in response to the demand for more extensive information and complex project solutions, policymakers and financiers have embraced Building Information Modeling (BIM) as the cornerstone of construction innovation. BIM is poised to further evolve into a more sophisticated and logical method, offering computerized solutions for the construction industry [4].

In developed countries, a significant portion of construction projects now focus on renovation and reconstruction, with a growing emphasis on achieving Net-Zero building energy efficiency through participation in various case studies. Coordinating with smart design, such as Building Information Modeling (BIM), is a priority to enhance occupant comfort and update economy [5]. Top construction companies globally are now deeply concerned about construction strategies in developing countries, particularly regarding construction waste management and energy crises, due to their widespread impact on the global biological and environmental ecosystems. Addressing issues such as construction waste, inefficient resource management, and the energy crisis can contribute to reducing global conflicts by prioritizing development challenges in developing or impoverished countries, thereby aligning with the construction industry's role in advancing global socioeconomic development [6]. The United Nations' classification of developing countries in 1971 highlighted their lower per capita GDP, lower living standards, and reliance on technology for infrastructure development with limited material resources [7]. However, developing countries are now shifting their approach to meet unique challenges such as rapid urbanization, inadequate infrastructure capacity, scarcity of sustainable building materials, limited technical expertise, and the urgent need to balance economic growth with environmental sustainability.

The construction industry in developing countries faces significant challenges, including limited resources and investment, and despite beneficial regulations proposed by policymakers to encourage initiatives, issues persist. These include a shortage of specialized training in construction management, deficiencies in communication and information exchange between design and construction teams, inadequate utilization of resources without proper investigation, limited participation between import and export industries, underutilization of high technology, lack of accurate data, varied environmental impacts, mismanagement of resources, the influence of political and technical issues, and limited interest in sustainable construction. Given these challenges, there are no easy alternatives. It's imperative for developing countries to take immediate action, employing labor-intensive, machinery, and technology-intensive solutions on a global scale [3, 7, 8]. This research paper aims to explore the role of BIM in sustainable construction in developing countries, specifically identifying the challenges and potential approaches for sustainable construction using BIM. The study will examine existing methods in the sustainable construction industry and suggest modifications that may aid in implementation or provide solutions. The goal is to demonstrate that the joint venture of BIM and sustainable tools can enhance sustainable construction. Finally, the paper will elaborate on the sustainability aspects of the country, addressing better construction methods to benefit developing countries.

Beyond economic and environmental benefits, BIM also supports social sustainability by improving stakeholder communication, ensuring safer construction practices, and enhancing the comfort and well-being of occupants. In developing countries, these social factors are critical for creating inclusive and resilient infrastructure.

2.0 RESEARCH METHODOLOGY

According to research principles, data were gathered from various sources, including articles, journals, books, and reports. Several case studies were examined to establish clear goals for solutions. An extensive literature review was conducted to categorize sustainable construction through the adoption of BIM in developing countries. This literature highlighted the importance of measuring sustainable construction and the necessity of BIM within its framework. The overall data and analysis helped uncover aspects of sustainability in developing countries. Key online portals accessed for data included Science Direct, IEEE Xplore, EBSCOhost, Safari, Springer Link, Academia.edu, and Emerald. Important books and leading international articles were also analyzed. The research for this thesis is divided into three parts: sustainable construction analysis, BIM measurement, and BIM for sustainable solutions. The research methodology utilizes both qualitative and quantitative measures to investigate the significance of sustainable construction in developing countries, the benefits of BIM integration, crucial factors for its implementation, and its future impact.

2.1 Case study –A focus of Sustainable Construction on Bangladesh

Figure 1 outlines the methodology of the case study on sustainable construction in Bangladesh. Situated in South Asia, Bangladesh covers an area of 147,570 sq. km and has one of the highest population densities in the region, with approximately 916 people per sq. km. The landscape is predominantly low and flat, while natural resources such as natural gas, stone, and timber play an important role in the construction sector. Dhaka and Chittagong are the primary economic hubs, driving national development through urbanization and industrial growth. However, rapid population increase and limited land resources create pressure on infrastructure and housing, making sustainable construction practices essential. Recent initiatives in urban planning and design improvements reflect a growing focus on integrating environmental considerations and resource efficiency into the country’s development strategy.

The country's GDP growth remains steady at a constant rate of 5.33%. Presently, the construction and real estate sectors significantly contribute to the GDP growth through their involvement in aesthetic design and urbanization initiatives. Furthermore, the IT sector and sustainable guidelines are evolving on a daily basis, indicating a growing awareness among the younger generation regarding environmental concerns and climate change [9, 10, 11].

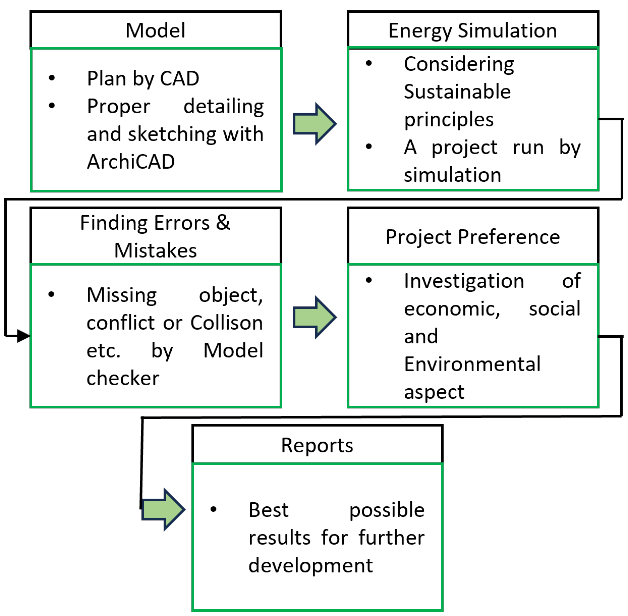


Figure 1 The overall methodology of the case study

A survey conducted by the World Bank in 1994 illustrated that a 1% increase in infrastructure stock correlates with a 1% increase in the total GDP (per capita) for all countries [7]. For example, the 12% annual construction growth in Dhaka City has influenced the total GDP by approximately 3.7%. Currently, the building industry and real estate sectors are investing in or undertaking projects contributing around 14.50 billion BDT or US $231 million [12].

The energy status, along with the adoption of energy-efficient materials and technologies, is as crucial in developing countries, especially in the Indian region, as it is in developed countries. In Bangladesh, population growth and CO2 emissions have been influenced by environmental changes over the past two decades. The construction industry is striving to analyze and address pollution prevention issues, advocating for sustainable solutions and calculations [13]. However, construction industries are encountering technical and functional difficulties, facing challenges in establishing organizational setup programs to meet their demands. Consequently, construction waste remains a barrier to environmental sustainability and development [14]. In response to customer demand and supply, the industry evaluates project quality and emphasizes safety and health comfort features, leading to increased demand for sustainable market pricing [15]. Some companies are taking initiatives to construct sustainable infrastructure following Leadership in Energy and Environmental Design (LEED) guidelines, primarily focusing on the use of sustainable materials for building solutions. However, reliance on conventional design tools like AutoCAD and STAAD Pro design persists in some design sections. Despite these challenges, there is optimism as some companies are recognizing the importance of design perfection, such as balancing time versus speed. Notably, certain companies are embracing Building Information Modeling (BIM) for structural design [16].

Until today, the construction industry in many developing countries has often relied on outdated methods and inadequate guidelines, such as limited use of modern design tools, lack of standardized building codes, insufficient quality control, and minimal consideration for sustainability. According to a UN report, 94% of the world's population growth occurs in developing countries, causing demand for infrastructure to outpace structural development. As a result, these conventional and under-regulated practices continue to dominate construction activities [16, 17]. In Bangladesh, superstructures have undergone significant modernization over the last few decades. The construction industry is contemplating swift technological advancements and enhancing productive facilities. Particularly, cities like Dhaka and Chittagong are competing to embrace further sustainable or green development through the adoption of modern technologies [18].

2.2 Multi-Story R.C.C Building in Chittagong

Table 1 depicts the architectural details of the seven storied R.C.C building in Chittagong with a gross floor area of 143 m2. In pursuit of sustainable construction, additional sustainable materials were integrated with ArchiCAD 18 software in Bangladesh, with emphasis placed on three key phases: initial building sketches, design iterations, and construction documentation. The transition from Building Information Modeling (BIM) to Building Energy Modeling (BEM) is encompassed by this approach, utilizing software tools such as ArchiCAD, Tekla, and Solibri Model Checker to ensure efficiency and sustainability. Despite the absence of some sustainable components in ArchiCAD 18, sustainable design principles are prioritized in the process, supported by various software solutions available in the engineering market, such as Virtual EnvironmentTM and EcotechTM. This comprehensive approach not only streamlines project delivery but also enhances environmental comfort and occupant satisfaction throughout the building's lifecycle, aligning with a commitment to sustainability and quality in construction practices. Figure 2 illustrates the general view of the project and helps to visually comprehend its overall arrangement and components.

Table 1 Architectural details of the project considering sustainability.

Project Name	Ali Vila
No. of stories	Seven (existing six single apartments)
Gross floor area (m^2)	143
Total covered area (m^2)	180
Building volume (m^3)	721.548
Scale size	1:100
Ground Floor height (ft.)	11
Typical Height or level (ft.)	10
Staircase	02 (landing and entrance)
Lift	Capacity- 10 persons Projection- west side
Windows	Sliding glazed doors on most of the south and west faces
Doors	Exterior: Sliding doors facing south Interior: Flush and panel doors
Water Catchment Area	Utilizes most of the common roof space to capture maximum rainfall
Solar Panel	02 (depends on maximum solar energy preservation)

Figure 2 General view of the project

Before commencing the implementation of sustainable building design and construction, careful consideration must be given to materials selection. On-site construction endeavors aim to minimize material wastage and prioritize recyclable waste. The preference lies with non-toxic, noncombustible, or slowly combustible materials to be employed, thereby reducing environmental impact and long-term costs. Moreover, the chosen materials prioritize human health and align with sustainability goals. Sustainable design principles are adhered to in the material selection, drawing upon resources available in Bangladesh [12, 19]. Portland Cement with 25-50% fly ash, wooden frames for doors and windows, brick walls, marble tiles for flooring, low volatile organic compounds (VOC) paint for interior painting, double silver low-E Pilkington glass (USA), and wooden panels for exterior wall cladding were primarily considered. Table 2 shows the details of building components along with materials for each component.

Table 2. Building components showing materials, dimensions and locations.

Feature	Material / Type	Dimensions	Location / Description
Slab	Concrete Structural	T5"	All floor areas
Beam	Generic-Prefabricated	W1'	Load bearing, all locations
Column	Concrete Structural	W2' × D1'	Load bearing, all locations
Wall (Exterior and Interior)	Brick plaster on both sides	T10"	Load bearing, all locations
		T5"	Around the building periphery and room dividing per floor
Door	Pine Wood frame, double glazed glass	W3'3" × H6'11"	
		W10' × H8'	Room-based in different locations
Window	Pine Wood frame, single- and double-glazed glass	W8' × H7', W6' × H4'11"	Room-based in different locations
Balcony	Aluminum	L7'	Exterior, all sliding door positions
Solar collector plate	Aluminum	L6'7" × W3'5"	On the rooftop
Water tank	Plastic or Steel	L7'4" × W2'10"	On the rooftop
Extra recovery tank	Normal brick with plaster	H5'	On the rooftop

T: Thickness; W: Width; H: Height; L: Length.

2.2.1 Room Allocation using Auto CAD and ArchiCAD

Beginning with AutoCAD, initial design concepts were developed within a company setting (Figure 3a). These were later refined and enhanced using ArchiCAD (Figure 3b), incorporating detailed structural elements and facilitating a more realistic floor plan representation, thus eliminating the need for extensive room allocation descriptions. This streamlined visualization process is easily comprehensible for clients and supervising engineers, facilitating construction procedures. ArchiCAD was instrumental in assessing energy efficiency for sustainability [20], following a structured five-stage process involving space orientation under various climate conditions, assignment of building materials' physical properties, environmental calibration, project execution, and result analysis. Preceding zoning, project preferences are established within ArchiCAD's menu, followed by 3D sun positioning. Zoning, crucial for energy simulation, is executed in either 2D or 3D views, ensuring structural integration with elements like slabs, columns, and beams, while maintaining proper height categorization to accurately evaluate energy efficiency strategies.

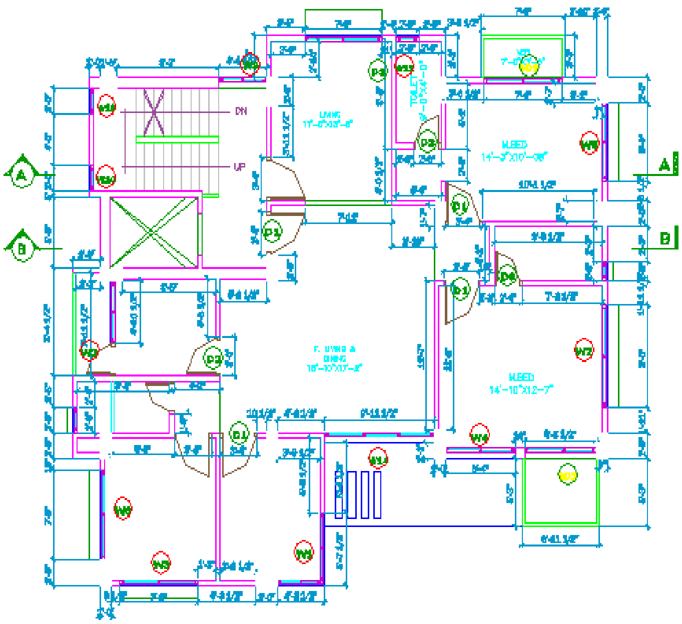


Figure 3(a) Typical floor plan in AutoCAD.

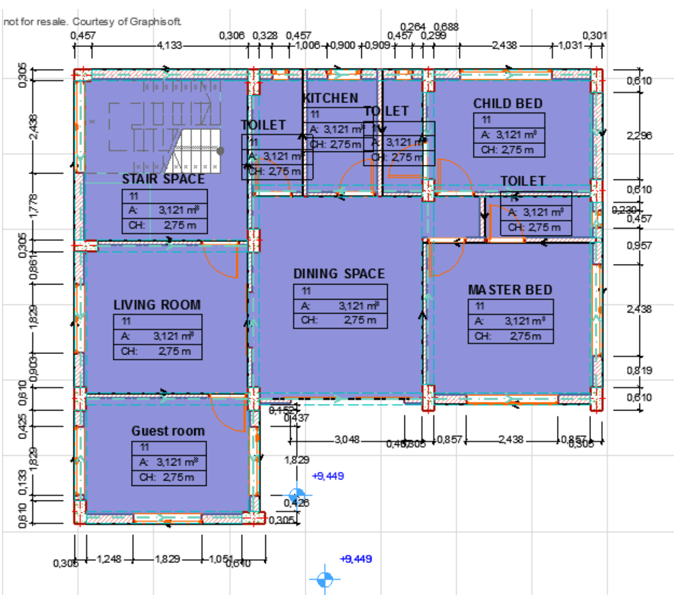


Figure 3(b) Typical floor plan in ArchiCAD.

2.2.2 Zoning orders, energy model review structure and opening panel

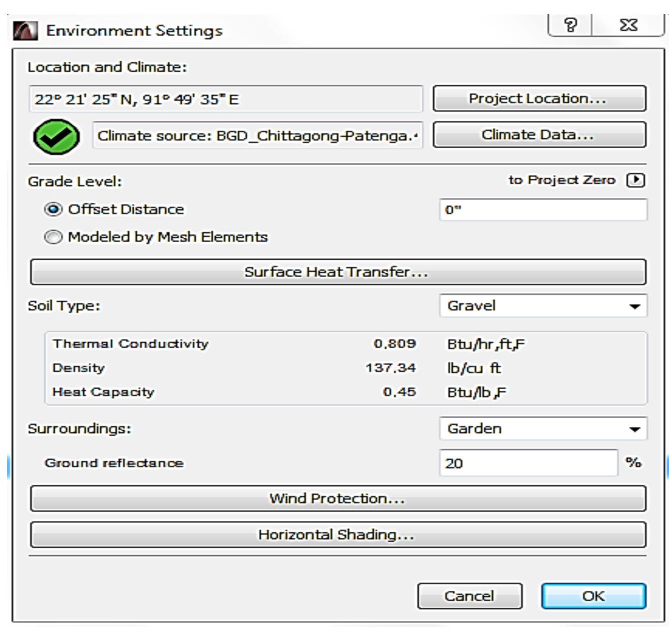
New zone categories in ArchiCAD 18 were defined by accessing the toolbar or navigating through the options menu to locate the zone category settings. Careful integration with existing structural elements such as columns, beams, and walls was ensured to accurately represent the energy review model structure. Individual zone names, numbers, and colors were customized based on specific requirements. The energy evaluation review section under the design menu was transitioned to. Within the thermal block properties, properties were assessed and adjusted accordingly, considering the 3D visualization options for better understanding. The total building system, including heating, ventilation, and cooling details, along with solar thermal collector settings, was configured. Alignment with Bangladesh's building scenario was verified. Structure details, focusing on U values reflecting the project's materials and location, were reviewed. A U-value indicates how well a building element, such as a wall, floor, or roof, resists heat transfer from inside to outside. Lower U-values signify better insulation and reduced heat loss. Opening reviews for elements like windows and doors, considering the analysis requirements for solar energy, were conducted.

2.2.3. Environmental setting, climate data and energy cost simulation

In the next step, the environmental data was set using climate data (Figure 4), obtained through a specialized tool or software. The ASHRAE file format was utilized for climate data location to enhance sophistication. During the environmental setting phase, efforts were made to enhance accuracy by editing wind and shading option data.

Electricity and natural gas costs per kWh were considered according to Bangladesh standards. The addition of solar panels for sustainability was also considered to reduce electricity expenses. Electricity costs for one year were calculated at 1200 BDT/kWh or 10.54 GBP/kWh. Solar panels were utilized in the model to save on electricity bills, with an assumed cost reduction of 8.54 GBP/kWh. Natural gas usage costs were calculated at 781.2 BDT or 6.85 GBP per year, which is lower compared to other countries due to available resources [21].

This procedure was performed within the Additional Energy Simulation Inputs under the Energy Costs section.



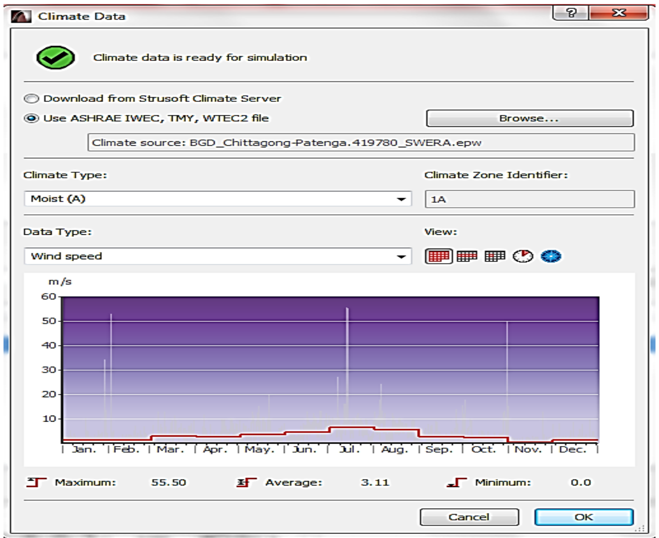


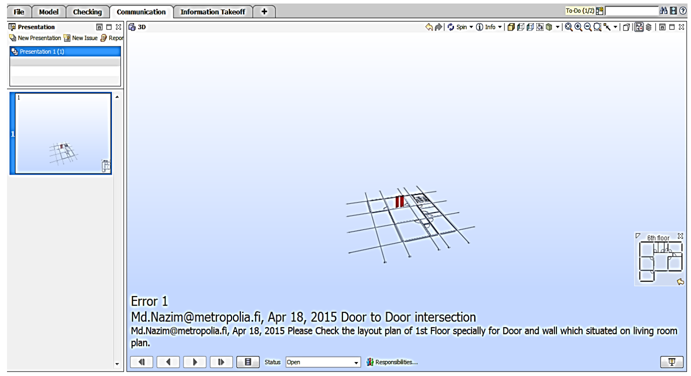
Figure 4 Environmental Settings with the edition of location and climate data.

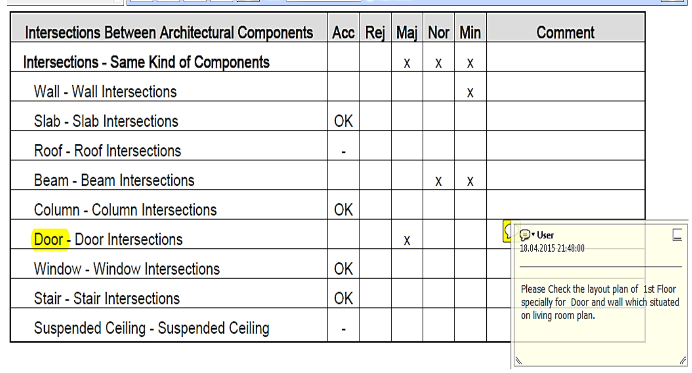
2.2.4 Final simulation

After completing all settings in accordance with Bangladesh's scenario standards as closely as possible, efforts were made to precisely use sustainable materials, ensuring elements with lower U-values and higher heating system efficiency for the building. Once all settings and model checks were finalized, preparations were made to begin the energy simulation process. This simulation was conducted both with and without the inclusion of solar panels in the model. Subsequently, the final report on energy performance evaluation was obtained, providing insights into the building's efficiency under the different scenarios.

The Solibri model checker (SMC) was used to communicate or combine different BIM models imported in IFC (Industry Foundation Classes) format, providing actual visualization of building and geometry data. It possessed intelligence for checking building models and identifying quantity takeoff. Subsequently, it was possible to address construction errors on the construction site through error reporting. After creating an ArchiCAD model with detailing, the IFC file could be opened in Solibri at a specified file or directory location. The short name of the SMC model was selected, and the discipline model type was indicated. Then, files were selected to combine using the added button to load the model. Finally, the model evaluation process was carried out.

The main purpose of the Solibri model checker was pursued in checking for clashes. Before the preconstruction phase, some error issues could be eliminated by establishing rulesets (Figure 5). Image details with comments could be provided, saving time and cost for architects and different team members in transferring and sending files or reports, such as IFC or BCF (BIM Collaboration Format) coordination systems, through quick decision-making. Initially, Solibri checks were performed by clicking on "check" to identify errors. Then, the error point was selected, and tools in the result section were utilized to visualize the actual error occurrence in 3D. Finally, specific error details could be accessed from the results details view. Comments could be made, which were then accepted or rejected by the management community through PDF reports or picture formats, as well as IFC files.

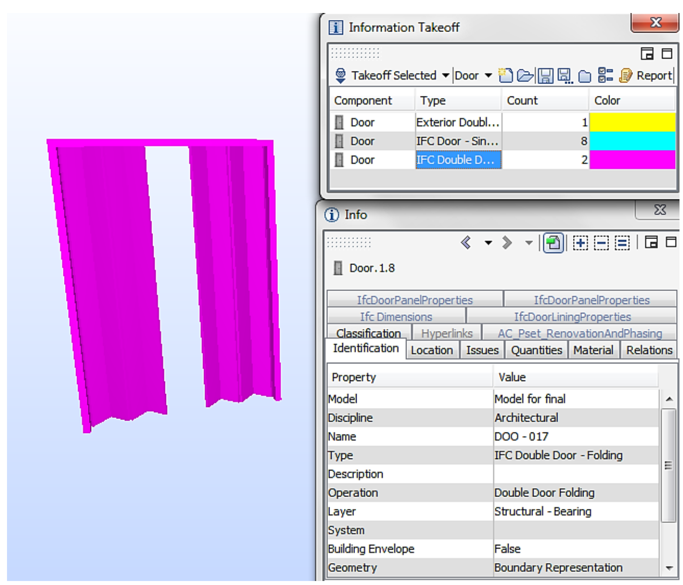




Intersections Between Architectural Components	Acc	Rej	Maj	Nor	Min	Comment
Intersections - Same Kind of Components			x	x	x	
Wall - Wall Intersections					x	
Slab - Slab Intersections	OK					
Roof - Roof Intersections	-					
Beam - Beam Intersections				x	x	
Column - Column Intersections	OK					
Door - Door Intersections			x			User 18.04.2015 21:48:00 Please Check the layout plan of 1st Floor specially for Door and wall which situated on living room plan.
Window - Window Intersections	OK					
Stair - Stair Intersections	OK					
Suspended Ceiling - Suspended Ceiling	-					

Figure 5 Inspection of Error in report and pdf.

Finally, for information takeoff, the building element's properties could be found before and after model checking according to user needs. The button for individual elements or floors could be selected, with detection facilitated by different color codes. Various model disciplines could be analyzed according to specific company requirements. However, in Figure 6, only the architectural discipline was utilized for quantity takeoff. Altogether, a fundamental solution of BIM or BIM-Sustainable based projects was provided by Solibri. It met designer and stakeholder feedback by collecting information and finding errors. Consequently, construction waste was reduced in real-time before proper error detection.



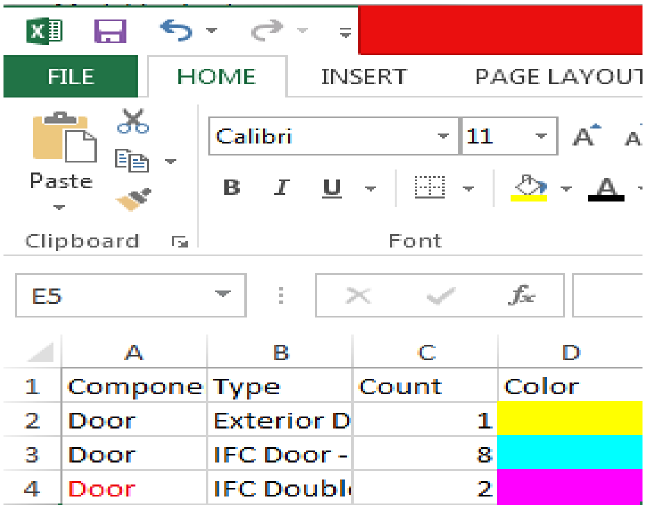


Figure 6 An error object with quantity takeoff detailing.

2.5 Tekla Structural Analysis

From the perspective of Bangladesh, structural detailing was traditionally carried out through hand calculations, with some tasks performed using software such as STAAD-pro or ETABS for seismic and load-bearing designs. However, proper positioning of reinforcement with detailed specifications can also be achieved using BIM software [22]. In figure 7 below, the structural views were organized at their appropriate levels using Tekla BIM software. Additionally, detailed reports on beam, column, and footing reinforcements could be generated using Tekla. Furthermore, the structural and building models can be analyzed by combining both the ArchiCAD model and the Tekla structure into an IFC format file, which can then be checked using Solibri Model Checker. This approach helps in identifying and resolving mistakes or errors throughout the building before the construction phase, ensuring better coordination between the structural and architectural engineers or the design team.

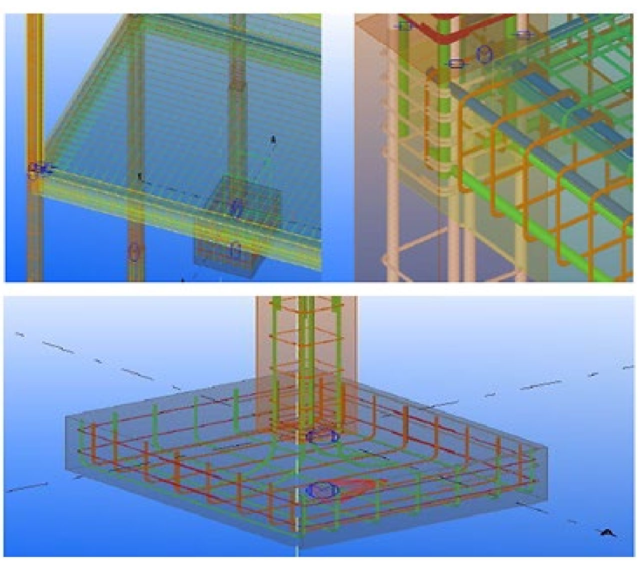
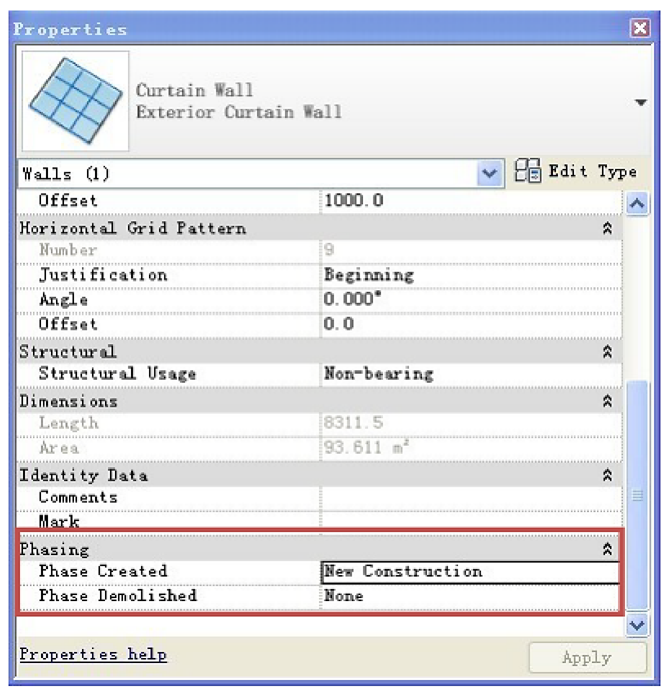


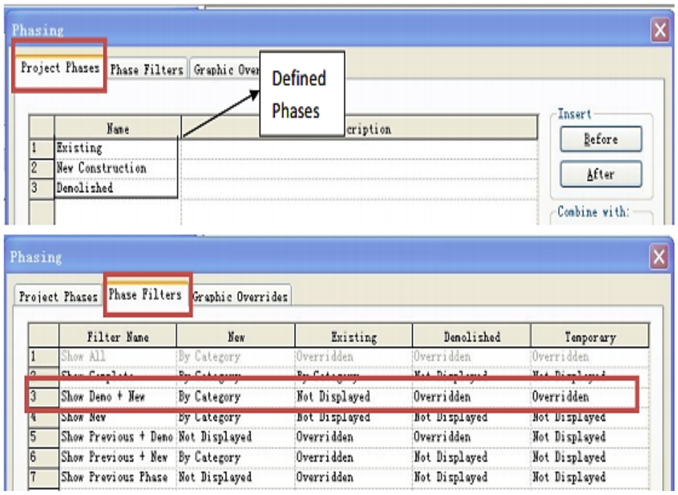
Figure 7 Types of Reinforcement Connections: Beam-Slab, Column-Beam, and Column-Footing.

2.6 Scheduling and Cost Estimation Using Revit Architecture

For further advancement, construction scheduling can be integrated with the connection between design and project schedule (Figure 8). This is achieved using the 4D modeling tool during the object phase. The object phase encompasses properties for assigning new structures or construction stages, based on 3D/BIM features and imported schedules. In Revit Structure, new structures can be defined in the properties dialog box, where phasing categories are displayed by default. Before specifying the structure, objects such as walls, doors, or windows must be selected. Alternatively, the new structure can be removed using phase filters based on user or project needs. The primary advantage is the ability to provide a virtual representation or physical status in relation to time variations, which allows the contractor and construction progress team to easily visualize the project's status. Additionally, to improve professionalism, scheduling realism, and efficiency, tools like Primavera™ are used. This approach ultimately facilitates a virtual construction scheduling process.
Additionally, for detailed cost estimation, a quantity takeoff of materials from the BIM tool is required. This can be achieved by exporting the building model to estimating software like Autodesk QTO. This necessity arises because cost analysis at lower levels of detail (LOD) has limitations. The model is then directly linked with estimating software such as Autodesk QTO, Vico Takeoff Manager, Exactal, OnCenter, and others. Once linked, the model can be processed to generate results, such as a QTO list. These results can subsequently be converted into an MS Excel file to create a comprehensive estimate [23].



(a)



(b)

Figure 8 Use of Revit Architecture for (a) defining phases with linked object and (b) phasing action on assigned object.

2.7 Investment in BIM for Project Development

Project profit can be determined using various cost analysis criteria, such as the following: the Payback Period, which indicates when a company starts generating profit; net present value (NPV) > 0, which shows when the project returns a profit; and internal rate of return (IRR) > cost of investment, where a higher (IRR) represents higher profitability than the investment. For the project, the NPV and IRR values were considered for a logical explanation. Additionally, sensitivity analysis, illustrated as a graphical method, was conducted by some companies to determine the project's energy-saving potential. There are various calculations or methods for NPV or IRR to obtain cost analysis results. Research has shown that most BIM-aided companies verify the net present value, return on investment (ROI), and Payback Period before BIM optimization [24, 25, 26]. The initial investment in BIM can be recovered relatively quickly, demonstrating its effectiveness in saving both time and construction costs due to its ability to improve design scenarios and ensure quality. Similarly, sustainable construction requires a greater initial investment compared to standard projects, but it yields results over the building's lifecycle that are more than ten times better [27, 28, 29].

Therefore, this study on BIM and sustainable design required a higher initial investment compared to normal projects. Consequently, an evaluation of the cost system was undertaken to determine the future investment benefits of BIM within a company focused on sustainable design. Certain expenses were assumed to support the construction scenario in Bangladesh.

3.0 RESULT AND DISCUSSION

3.1 Evaluating Building Performance and Energy Efficiency

The building's performance over one year, including specific energy data, was provided by the ArchiCAD energy results. The evaluation covered energy performance, energy consumption, and energy balance. Key values delivered the most critical project data, such as the specific average U-value and a detailed narrative of total heating energy progress. Additionally, realistic results for total heating and cooling operations were obtained, based on the fixed location in Bangladesh. The project details with EPE Data are shown in Figure 9.

Key Values

General Project Data			**Heat Transfer Coefficients**	U value	[Btu/sq ft,F,hr]
Project Name:	Ali Villa		Building Shell Average:	0,61	
City Location:			Floors:	--	
Latitude:	22° 21' 25" N		External:	0,30 - 0,89	
Longitude:	91° 49' 35" E		Underground:	--	
Altitude:	0,00	m	Openings:	0,37 - 0,60	
Climate Data Source:	BGD_Chitt..._SWERA.epw				
Evaluation Date:	17.04.2015 22:02:43		**Specific Annual Values**		
			Net Heating Energy:	0,00	kWh/m²a
Building Geometry Data			Net Cooling Energy:	10,25	kWh/m²a
Gross Floor Area:	808,09	m²	Total Net Energy:	10,25	kWh/m²a
Treated Floor Area:	746,06	m²	Energy Consumption:	80,01	kWh/m²a
External Envelope Area:	1586,43	m²	Fuel Consumption:	70,07	kWh/m²a
Ventilated Volume:	2088,27	m³	Primary Energy:	111,67	kWh/m²a
Glazing Ratio:	12	%	Fuel Cost:	497,15	GBP/m²a
			CO_2 Emission:	15,13	lb/sq fta
Building Shell Performance Data					
Infiltration at 50Pa:	4,06	ACH	**Degree Days**		
Outer Heat Capacity:	36.83*10^-4	Btu/sq ft,F	Heating (HDD):	164,92	
			Cooling (CDD):	5022,05	

Figure 9 Project details with EPE Data.

The energy consumption sources were presented in tables. Solar energy factors, rainfall catchment areas, and sustainable materials were utilized in the sustainable project details before energy simulation. As a result, energy consumption for heating and cooling systems, as well as costs and CO^2 emissions, were reduced. ArchiCAD energy evaluation properly utilized materials or renewable energy tools, as demonstrated in its final result. In the model, only solar cells were verified through comparative analysis with a normal building (Figure 10). Material factors in normal building considerations were not revised. It was understood that materials and other factors, such as electricity, made a significant difference in sustainable buildings versus normal buildings over a lifetime.

To enhance clarity prior to construction, predefined results were incorporated into ArchiCAD (Table 3). This facilitated the display of the monthly energy balance, illustrating emit and supply energy bars with equilibrium along the horizontal axis representing the 12 months of the year (Figure 11). Such visualizations proved highly beneficial for the project and company stakeholders in evaluating building performance. ArchiCAD's preliminary methodology not only advanced model visualization during the construction phase but also provided critical insights into energy evaluation. These insights included the potential for reducing energy costs and CO^2 emissions through the implementation of solar cells and other sustainable systems. Therefore, a comprehensive life cycle assessment of the building could yield more accurate results by improving energy efficiency and ensuring precise data input into ArchiCAD. Although the process exhibited some limitations, such as the need for modifiers for specific tools, ArchiCAD provided valuable feedback within the building system, contributing to the project's overall sustainability goals.

Energy Consumption by Sources

Source Type	Source Name	Energy Quantity kWh/a	Primary kWh/a	Cost GBP/a	CO_2 Emission lb/a
Renewable	Solar (Thermal & PV)	1604	1924	NA	0
	External Air	9479	9479		0
Fossil	Natural Gas	44693	49162	306149	21282
Secondary	Electricity	7581	22745	64749	3610
	Total:	63358	83312	370898	24893

Segment 1

Energy Consumption by Sources

Source Type	Source Name	Energy Quantity kWh/a	Primary kWh/a	Cost GBP/a	CO_2 Emission lb/a
Renewable	External Air	9512	9512	NA	0
Fossil	Natural Gas	44693	49162	306149	21282
Secondary	Electricity	7559	30238	79678	3869
	Total:	61765	88913	385828	25152

Segment 2

Figure 10 Energy Consumption Sources (Comparative Analysis: Segment I - With Solar Cells, Segment II - Without Solar Cells).

Table 3 Preliminary Prediction for Building

Building Types	Energy Consumption	Cost	Carbon Footprint	Environment Impact	Total Impact over Lifecycle
Ordinary	More	More	More	More	Complexity
Sustainable	Less	Less	Less	Less	Beneficiary

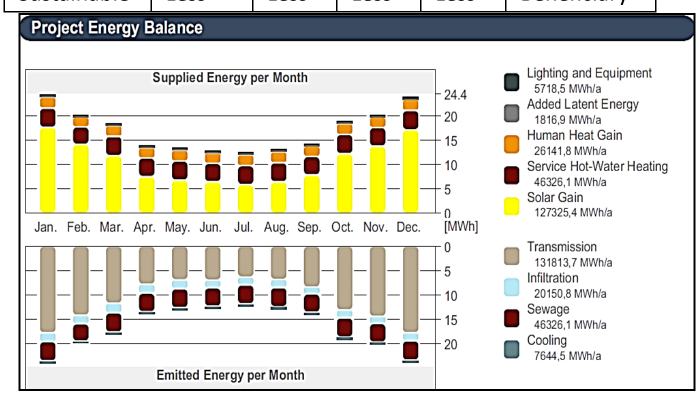


Figure 11 Monthly energy balance

3.2 Investment in BIM for Small and Mid-Sized Companies

In Bangladesh, following the perspective provided by ArchiCAD software and Solibri: All cost interpretations are expressed in terms of Bangladeshi Taka (1 BDT = 0.71 INR = 0.008€). The cost of ArchiCAD software for a single user, one-year license is 17000 INR, or approximately 252 Euros. Solibri Model Checker is assumed to cost 6000 Euros. Detailed initial investment costs in BDT are shown in Table 4.

Table 4 Annual Expenses for BIM software within a company

Software	Quantity*BDT	value
ArchiCAD	6 licenses * 24286	145716
Solibri Model Checker	6 licenses * 750000	4500000
Hardware	6 Computer * 50000	300000
Total cost		**4945716 BDT/year**

For sustainable construction, the initial investment is higher than that of standard construction. However, the long-term benefits are greater compared to other projects. BIM can be integrated BIM for maintenance and allocate staff towards sustainable design and construction. These factors are considered standard values, as shown in Table 5 below. Around 15-40% of construction and maintenance costs could be saved by using BIM through its increased productivity [27]. Conversely, sustainable practices could save 15% of costs [30]. Considering both factors, approximately 20% of the yearly cash inflow or savings from the total annual expense could be accounted for. While sustainable practices have minimal impact during construction, they significantly influence client demand during renting periods. This can be illustrated by the calculation: (12700000* 0.20) = 2540000 BDT/year.

Table 5 Total expense cost of whole operation or maintenance system.

Details	Quantity	Expenses (BDT/Year)
Architect	2	2,000,000
Structural Engineer	1	1,000,000
Draftsman	2	700,000
Project manager	1	900,000
Site Engineer	2	800,000
Safety Engineer	1	400,000
BIM application maintenance	Nil	100,000
Machineries, Structure and operation cost	Nil	6,000,000
Additional Costs for Sustainable Construction	Nil	600,000
Miscellaneous	Nil	200,000
Total		**12,700,000 BDT/year**

The payback period is calculated by dividing the initial investment by the cash flow generated per period, which results in a payback period of about 10 years. For the Net Present Value (NPV) calculation, the required bank interest rate was taken as 7.25% and the net investment was considered for 5 years. Table 6 and Figure 12 show the values of NPV along with the cash inflow and investment.

Table 6 NPV value in periodic year

	Cash inflow	Investment	NPV
1st year	2,368,298	4,945,716	-2,577,418
2nd year	4,576,502	4,945,716	-369,214
3rd year	6,635,433	4,945,716	1,689,717
4th year	8,555,182	4,945,716	3,609,466
5th year	10,345,158	4,945,716	5,399,442

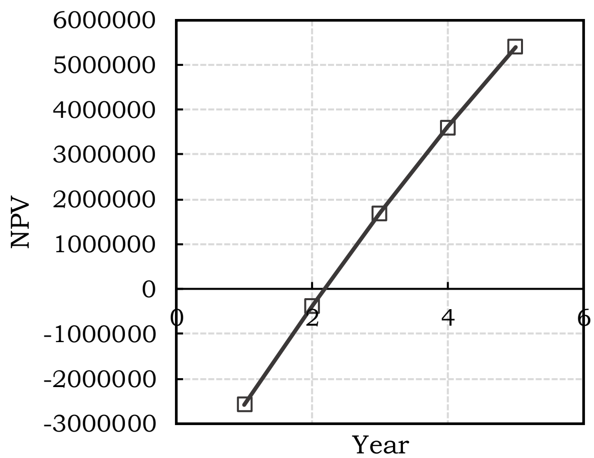


Figure 12 Investment progress of BIM.

The computation of the first year of return on investment (ROI) using the given formula [31, 32] can be detailed with the provided variables. The ROI, calculated to be over 35%, indicates significant benefits by demonstrating that the returns on investment far exceed the initial costs. This high ROI supports informed financial decision-making by providing a clear, quantifiable prediction of value, thereby making a compelling case for the adoption of BIM in sustainable construction projects in developing countries.

$$\text{First Year of ROI} = \frac{\left(B-\left(\frac{B}{1+E}\right)\right)\times(12-C)}{A+(B\times C\times D)} \quad (1)$$

Cost of hardware and software, A =4945716 BDT = 42038.586 Dollars (Present currency)

Monthly labor Cost, B = 1500000 BDT = 12750 dollars (Assumed according to Bangladesh perspective)

Training time, C =3 months

Productivity lost during training, D =50%

Productivity gain during training, E =25%

In a cost analysis conducted through a company-based or project-based approach, realistic results were provided by ROI and NPV. It was evident that the benefits brought by variables such as BIM technology led to successful outcomes for the project or company. The high ROI demonstrated a complex project solution with the potential to yield substantial returns across the project or construction industry. Additionally, these benefits not only reduced overrun costs but also minimized project delays during the construction phase. Therefore, it could be concluded that comparing costs across different projects (Figure 13) substantiates these findings.

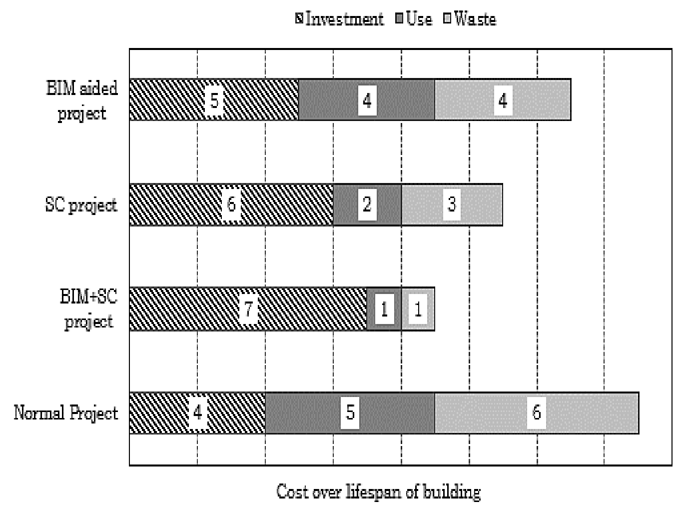


Figure 13 Comparison of different types of projects.

4.0 CONCLUSION

It may be concluded from the study that

- Integrating Building Information Modeling (BIM) into sustainable construction provides measurable economic, environmental, and social benefits for developing countries.
- The study, based on a mixed-method approach and a case study in Bangladesh, found that BIM can reduce construction and maintenance costs by 15–40%, improve energy efficiency, and minimize construction waste through better material selection and lifecycle planning.
- Energy simulations indicated that BIM-enabled sustainable designs, including solar panels and efficient building envelopes, significantly lower energy consumption and CO_2 emissions compared to conventional construction methods.
- BIM offers a practical pathway for developing countries to tackle challenges such as rapid urbanization, limited resources, and environmental sustainability.
- Its adoption can redefine key performance indicators for the construction industry, leading to better infrastructure, economic growth, and improved living conditions for future generations.

Recommendations

- Adopt BIM widely in both public and private sector projects to enhance cost efficiency and sustainability performance.
- Invest in capacity building and technological infrastructure to overcome the shortage of skilled manpower and technical resources.
- Update national policies and building codes to align with BIM-based sustainable construction practices and standardize quality.

- Promote stakeholder collaboration through BIM platforms to reduce design errors, improve coordination, and optimize project outcomes.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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