Green Retrofitting of Building using BIM-based Sustainability Optimization

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ABSTRACT

The construction industry consumes around 55 percent of Pakistan's annual energy and is the country's most energy-intensive sector. It is, therefore, significant to devise a novel and effective model of green retrofitting of current buildings based on Building Information Modelling (BIM) which aims to reduce building energy consumption to effectively meet diversified climatic concerns and to promote sustainable structures. This research aims to reform the existing building by modifying the design parameters for an inefficient building envelope based on BIM simulation and data optimization results to optimize the overall energy consumption. BIM tools, such as Autodesk Revit and DesignBuilder have been used for the evaluation of the optimized energy-efficient design by comparing different design alternatives. After a detailed analysis, this research has concluded that the existing building is consuming a high amount of annual energy. With the help of BIM tools, which possess advanced algorithms for an effective optimization process, a list of 'green' solutions i.e., optimal designs has been generated, out of which the optimal and cost-effective design saved 46% of energy in total. In this study, the design variables selection has been fulfilled according to the local environmental sustainability.

Keywords: Green Retrofitting; Building Information Modelling (BIM); building energy analysis; data optimization; sustainability

INTRODUCTION

In the era of globalization, Pakistan is Asia's fastesturbanizing country in recent years. The buildings play a vital role and constitute a significant portion of Pakistan's GDP of the construction sector. In comparison to developed countries such as the United States (39%), Canada (27%), and China (20%), Pakistan has the biggest share of energy usage (55%) (Amber K.P. et al. 2021). This sector calls for a sustainable transformation as the country's population continues to expand at increasingly higher rates. Over 40 million people are predicted to reside in Pakistan's cities and towns by 2023 (GoP, *NEECA*, 2016). The high rate of urbanization results in an ever-increasing demand for housing and construction. Consequently, high energy consumption, environmental degradation, and abrupt climatic changes have been faced by the country at considerable levels. Current buildings must be retrofitted to properly address a variety of climate challenges, especially with the emergence of digital building solutions such as Building Information Modelling (BIM).

Pakistan experiences intense cold and heat during peak seasons. As the middle and upper classes' living standards rise, so do their expectations for comfort. Power demand in Pakistan fluctuates between 8000 MW in the winter and 25000 MW in the summer (Ali S.A., *The News*, 2021). Fossil fuels, such as oil and natural gas are the two major elements of Pakistan's present energy balance, accounting for around 62 percent of the country's electrical need (Amber K.P. et al. 2018). Excessive power consumption along with continuous exhaustion of the non-renewable energy sources of the country is not only wasting revenue but also impacting the environment and posing health hazards by increasing carbon footprints and greenhouse gas emissions of the building. The difficulty is exacerbated by the continental climate of most cities of the country, which is typified by substantial daily and seasonal temperature changes. As a result, this harsh environment necessitates enormous energy consumption (Hafeez K. et al. 2017). Energy-efficient buildings are renovated from old buildings to extract the maximum amount of work from the energy supplied by taking steps to minimize energy loss.

Although past studies have attempted several building retrofits via modern methods and solutions for a variety of problems in building systems, greater studies are required on a local level regarding green retrofitting current buildings through BIM. In terms of technical improvements, Pakistan lags in the global construction market. The adoption of BIM in Pakistan is only at 11% (Nawaz A. et al. 2021). This is due to the implementation of conventional management practices, which may be readily reduced with the adoption of innovative technologies such as Building Information Modeling (BIM) (Khan N. et al. 2019). Although some construction firms have adopted the concept of BIM in designing buildings, its actual use is limited due to a lack of skills and expertise in this technology (Nawaz A. et al. 2021). The Architecture, Engineering and Construction (AEC) industry has seen two key developments emerging in the last few years: green building construction and the usage of BIM workflow. An integrated design approach is excellent for green design, and BIM is best known for implementing it. Through its visualization technology and virtual prototyping and because of the advancements made possible by BIM in green buildings, we now have gained access to new tools for assessing construction's energy and environmental impact and managing it (Khahro S.H. et al. 2021). A novel and effective technique is required that addresses the 'green' retrofitting of local buildings through the modification of design parameters of a building envelope considering the regional design parameters in the BIM tools used in this study.

This research aims to modify the design parameters for an effective building envelope based on simulation results to reduce the reliance on active mechanical systems, thereby improving the building's overall energy consumption and transforming it into a green, sustainable structure. The New Extension Building Block-1 of the Industrial Engineering Department from Mehran UET Jamshoro was selected for case study purposes. Design Builder's Data Optimization module employs cutting-edge evolutionary algorithms through a natural selection process based on enhancing building performance. Primarily, the energy performance of the existing building envelope was assessed, various design parameter alternatives were compared using the DesignBuilder Optimization, and finally, a sustainable, green-retrofitted model of the building was proposed with optimum energy efficiency. In this study, the procedure involved in previous studies has been tried to improve in a way to come up with a realistic retrofit solution for the building by proposing green-retrofit alternatives based on locally manufactured building materials as mentioned in the Building Code of Pakistan. It has contributed to the overall well-being of the community by the provision of more accurate energy usage guidelines during the maintenance and renovation of the building.

LITERATURE REVIEW

One of the few contemporary worldwide concerns is the lack of energy and the associated carbon emissions. Construction and operation of buildings made up the majority of all industries' contributions to worldwide final energy consumption (36%) and energy-related carbon emissions (39%) in 2018. Recent proposals and approval of net zero energy buildings or virtually zero energy buildings further show the importance placed on a building's energy efficiency (Zhuang D. et al. 2021).

Since "going green" and "environmental sustainability" have been discussed for a long time in the construction business, official figures show that the AEC sector is still a significant energy user. For instance, the production of construction materials uses around 10% of all the energy consumed worldwide. Energy usage throughout the operating period of a building accounts for 30-40% of total global GHG emissions. Construction and demolition (C&D) trash accounts for approximately 40% of all solid waste in developed nations (Koeppel S. et al. 2007). With decreases in the levels of energy consumption and resource depletion that have been necessary for conventional building life cycles, the idea of environmental sustainability has sparked revolutionary improvements in the built environment. The architecture, engineering, and construction (AEC) sector has come under fire for being a significant source of carbon emissions and a highly uncontrolled field in terms of managing and controlling carbon emissions (Wong J. K. W. et al. 2013; Wong J. K. W. et al. 2015). With limited resources and growing energy prices, reducing energy use and limiting AEC industryrelated GHG emissions have become more serious concerns.

Greening existing structures is receiving more attention as a result of growing worries about climate change and the depletion of limited natural resources. The worldwide building energy intensity per square meter, including the current building, has to be increased on average by 30% by 2030 compared to 2015 to satisfy the global climate aspirations outlined in the Paris Agreement (Liu G. et al. 2019; UNEP, *Glob. Status Rep.* 2017). The conventional design formats and communication patterns of the AEC industry have altered over the last two or three decades as a result of the advancements in CAD software and BIM. Through virtual prototype and visualization technologies, the advancement of building information modeling (BIM) technology offers a new way to forecast, manage, and track the environmental implications of project development and construction (Wong J. K. W. et al. 2015).

The term "life cycle" refers to the period from the time of a building's first conception until its demolition. BIM is a shared knowledge resource for information about a facility, providing a trustworthy basis for choices. Over the last few decades, the range of information about buildings conveyed by BIM has continuously increased as a result of the development of BIM technology and its rising use in the construction sector. Furthermore, BIM has been used in building life-cycle analysis by researchers and practitioners (Ding L. et al. 2014; Soust-Verdaguer B. et al. 2017; Santos R. et al. 2020).

Due to its integrated solutions for assessing and monitoring the environmental sustainability performance of existing buildings, Building Information Modelling (BIM) is now being used for green retrofitting. It may be accomplished by utilizing centralized digital models at various phases of the construction life cycle. The real uses of such technology, however, are currently few and need more research and validation. Even though several green building certifications and ratings, including LEED in the US, BREEAM in the UK, and CASBEE in Japan, have been in place since the 1990s, the world's building energy demand is predicted to rise by almost 50% between 2018 and 2050 if no additional steps are taken to increase building energy efficiency (U. S. E. I. Administration, 2019). Green retrofitting is therefore a crucial step toward a timely decrease in the world's energy consumption for a sustainable built environment.

Especially contrasted to reconstruction, green retrofitting can help reduce life cycle greenhouse gas emissions. However, there are several hurdles to green retrofitting existing buildings, such as selecting appropriate retrofit technologies and efficiently decreasing energy usage, as well as life cycle cost analysis and the return-oninvestment period. To achieve high levels of energy performance in existing buildings through green retrofitting, an ideal mix of multiple solutions must be used. Various building energy modeling tools have been created throughout the design decision-making stage. However, due to the multi-objective optimisation process, decisionmaking during a green retrofit is difficult. The process of picking the best available green retrofit solutions has 181

always clashed with other goals; the ideal answer is frequently a trade-off between numerous elements such as energy, economy, technology, environment, legislation, and social issues. As a result, researchers investigated the use of centralized digital modeling as a decision-support system for prioritizing retrofit measures (Volk R. et al. 2014; Wei Y. et al. 2015; Nielsen A.N. et al. 2016; Sanhudo L. et al. 2018; Feng H. et al. 2020).

Retrofit procedures employed in past studies show that replacing light fittings can boost illuminance while reducing energy use by up to 70%. Some options include replacing obsolete fluorescent lighting fixtures with Energy Star-certified or LED lighting or installing photo-sensors on fixtures that change the light output during the day to prevent unwanted illumination. Building heating and cooling systems consume a lot of energy. As a result, reducing the need for heating and cooling will result in a significant reduction in energy use. Good insulation helps in this scenario by retaining heat in the winter and trapping cool air inside during the summer. Insulated walls also help to reduce the amount of energy required to heat and cool a building. Painting walls in brighter, light-reflective colours is a cost-effective way to reduce heat absorption (Al-Kodmany 2014).

During recent years, the research has been more inclined towards technology-based retrofitting and optimization techniques internationally. Retrofitting with a building automation system centralizes the control of all operational systems, including the HVAC system, lighting, and appliances, among others, cutting utility costs and increasing user comfort (Al-Kodmany K. 2014). The MATLAB environment has been utilized in which the optimization parameters for the Adaptive Sparrow Search Optimization Algorithm have been coded to optimize the energy efficiency for building envelope and HVAC systems (Liu B. et al. 2021). An optimization approach called 'Dynamic PMV' that integrates BIM (Building Information and Modeling) with IoT (Internet of Things) sensors enables maximizing indoor thermal comfort by coupling the geometric and functional complexity of BIM models with real-time registering of meteorological data (humidity, temperature, etc.) via IoT sensors (Zahid H. et al. 2021). A flexible and controlled algorithm-driven automated operating mechanism for windows has been proposed after examining influencing factors for the opening and closing system of windows, which may ensure healthier and thermally friendly interiors in classrooms by incorporating temperature and carbon dioxide levels inputs (Stazi F. et al. 2017).

Thus, this paper attempts to modify the design parameters for an effective building envelope following the 'green retrofitting' framework based on simulation results to reduce the reliance on active mechanical systems, thereby improving the building's overall energy consumption.

METHODOLOGY

DATA ANALYSIS OF THE BUILDING ENVELOPE

An on-site investigation of the case study building 'New Industrial Academic Block-1' was carried out. Data for the building was collected as qualitative and quantitative data from the Administration Department; CAD working plans showing all dimensions, construction materials used in the building, and thermal conductivity (U-value) of materials.

A realistic and accurate architectural building information model (BIM) of the building was created using Autodesk Revit 2022, as shown in Figure 1. After the model's geometry was complete, "Rooms" were allocated to each unique space, and proper energy settings were produced. The entire architectural model was then converted by Revit into an Energy Analytical Model (EAM), which contains the thermal characteristics of building components represented by "Rooms and Spaces". The Green Building Extensible Markup Language (gbXML) file format was used to export the EAM into DesignBuilder. The process is illustrated in Figure 2.



FIGURE 1. BIM model of building in Autodesk Revit



FIGURE 2. Modelling process in Autodesk Revit

The thermal conductivity and specific heat values for each material used in the building were taken from a past study (UNEP; *Glob. Status Rep.* 2017) modified in Revit with reference to the Building Code of Pakistan before assigning rooms into the model, as shown in Figure 3.



FIGURE 3. Modification of thermal conductivity of materials

SIMULATION IN DESIGNBUILDER

The model imported into DesignBuilder automatically divided into zones with rooms having similar heat flow and ventilation. The model was checked for any errors in geometry. All the gaps were filled properly to allow heat transfer. It was confirmed that any construction assignments made in Revit are passed over to DesignBuilder after making the necessary geometry adjustments. The final rendered view of the building along with the sun path is shown in Figure 4.



FIGURE 4. Rendered view of three-dimensional model in DesignBuilder

In this study, the balance between net energy consumption and the total cost of the building has been optimized. Therefore, the design objectives were specified in the optimization settings. The design factors that best suited our objectives were selected as:

- 1. window to wall ratio (%)
- 2. external wall construction
- 3. internal glazing (%)
- 4. glazing type
- 5. flat roof construction
- 6. local shading type
- 7. cooling setpoint temperature
- 8. natural ventilation rate
- 9. site orientation.

Simulation for the base case was run via an integrated Energy Plus simulation engine. A graph showing the annual temperature distribution, heat gains, and energy consumption for the building was obtained as shown in Figure 5.

The Reporting tool in DesignBuilder generated the LEED (Leadership in Energy and Environmental Design) report for the building which displays the total energy use for the building and separately for building systems.

OPTIMIZATION IN DESIGNBUILDER

The optimization process in DesignBuilder employs EnergyPlus simulations run in batches of multiple iterations. The software's unique genetic or evolutionary algorithm assesses each batch and passes 'strong' solutions in future iterations, finally displaying the set of 'Paretooptimal' solutions, as depicted in the flowchart in Figure 6.

	Process Subtotal [kWh]	Total Energy Use [kWh]
Electricity	17092.72	743942.55
Natural Gas	0.00	2914.58
Additional	0.00	0.00
Total	17092.72	746857.13
		Electricity Energy Use [kWh]
Heating — General		0.00
Heating — Boiler		0.00
Heating — Boiler Parasitic		0.17
Cooling — General		410389.16
Interior Lighting — General		261223.49
Exteriore Lighting — Not Subdivided		0.00
Interior Equipment — General		17092.72
Interior Equipment — Not Subdivided		0.00
Fans — General		61570.48
Pumps — General		2666.54
Hot Rejection — General		0.00
Humidification - Not Subdivided		0.00
Heat Recovery — Not Subdivided		0.00



FIGURE 5. Temperature distribution, heat gain and energy consumption by existing building system



FIGURE 6. Optimization process in DesignBuilder

Following this mechanism, the process of generating batches of design alternatives repeated until the optimal designs had been found. The set of suggested solutions on the "Pareto front" was graphically analyzed to determine which designs best satisfy the design priorities defined on the employed objectives. Energy-optimization findings were obtained, and the perfect 'optimal' design solution was selected based on minimum energy usage and lowest cost.

RESULTS AND DISCUSSION

A graph of optimization analysis was obtained after optimization simulation as shown in Figure 7, which clearly displays the "Pareto Front" of optimal design solutions constituting all red dots. This set of suggested solutions was further analyzed graphically to determine which designs best satisfy the design priorities defined on the employed objectives.



FIGURE 7. Energy Optimization Analysis Results

The following graphs in Figure 8 and Figure 9 show the monthly energy consumption and percent energy saving achieved by the 17 optimal designs respectively. It can be devised from both graphs that 'optimal design 6' is the most energy-efficient and economical optimal design solution achieved in the optimization analysis. By adopting the 6th optimal design, 46% of energy saving has been achieved with reference to the energy consumption of the existing building as shown in the LEED Report shown in Table 1. The optimal design achieved in this study has been compared with the design parameters of the existing building in terms of all the design variables selected in this study and the comparison is as discussed in Table 2.



FIGURE 8. Energy Consumption (kWh) by Optimal Designs



FIGURE 9. Energy Saving (%) by Optimal Designs

Design Variable	Existing Building Model	Green-Retrofitted Model	Pictorial/Graphical Representation
External Wall Construction	9" thick general brick wall with ordinary plaster U-value = 2.071 W/ m2-K	Double-layer cavity wall with gypsum plastering U-value = 1.255 W/ m2-K	Duter surface
Flat Roof Construction	Flat Roof with five layers; RCC Slab, Earth, Polyethene, Cast Concrete, Tile U-value = 2.805 W/ m2-K	Same	Outer surface 25:40mm Clay Tile (noting) 50:81mm Card Constrate 2:0:00mm Felentherese / Pelentherese (sigh density) set to scale) 76:33mm Earth, common 152:40mm Concrete, cast - dense, reinforced Inner surface Inner surface
Glazing Type	Single glazing U-value = 5.894 W/ m2-K	Double glazing low emission Elec Abs Bleached with 6mm of glass and 6mm of air in between two panels U-value = 2.429 W/ m2-K	
Local Shading	No shading	1.0 m overhang	
Window to Wall Ratio (%)	30%	80%	30% Existing Building Proposed Design

 TABLE 2. Comparison of Existing Building and Green-Retrofitted Building Design Parameters

continue ...



CONCLUSION

This research targeted to modify the design parameters for an effective building envelope based on simulation results, thereby improving the building's overall energy consumption, and transforming it into a greener, sustainable structure. A green-retrofitted sustainable solution for the existing building was proposed which saved up to 46% of total energy consumption. The building's design properties were recommended as 80% window-to-wall ratio, cooling setpoint temperature of 27.4°C, cavity brick wall with gypsum plastering, 94% internal glazing, flat roof with layers of cast concrete, polythene, earth, and RCC slab, overhang shading of 1.0 m and double-glazing low emission outer panel windows, site orientation of 140° relative to north and natural ventilation rate of 4.90 ac/h.

In previous studies on energy and thermal retrofitting, default parameters of the Building Information Modelling (BIM) tools have been used and established conventions have intervened in the reliability of optimum results. However, in this research, researchers adopted a very premiere strategy in terms of selecting parameters according to societal requirements. The major aim of the study was to control the high energy consumption in the existing buildings to save fuel as well as cut costs as far as possible. Achieving targets for energy and emissions reduction, all while minimizing the expenditure requires an innovative strategy which has been effectively adopted in this research. It has contributed to the overall well-being of the local community as they would come to know which design parameters must be devised or modified while designing new constructions or renovating existing structures.

This study was circumscribed to scrutinizing the energy performance of the existing and proposed greenretrofitted sustainable building. In future studies, a greenbuilding retrofit can be carried out by analysis and optimization of further building design parameters for achieving overall sustainability of the building which satisfies all the Sustainable Development Goals (SDGs) such as daylighting, wind analysis, thermal comfort optimization, carbon emission minimization, structural performance, etc. Furthermore, this study was based on whole building retrofitting however, in further studies, every design parameter can be optimized separately specific to individual zones in the existing building.

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DECLARATION OF COMPETING INTEREST

None

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