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Original Article

Evaluation of Existing Building under Green Building Concepts and to Assess its Performance Parameters using Different Green Building Rating System

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Abstract *- Buildings play an important role in socio-economic and environmental systems, yet their environmental footprint is considerable, surrounding energy and water usage, waste production, and greenhouse gas outputs. The building, functioning, and tearing down of structures utilize precious resources and worsen climate change. To tackle these challenges, Green Building Standards and Rating Systems (GBRS) have been created to minimize the environmental impact of buildings throughout their complete life cycle. These systems prioritize Energy Efficiency (EE), Water Conservation (WC), and eco-friendly building materials. Also, the important study conducted on new constructions, there is still limited exploration of prevailing buildings. The majority of research highlights individual sustainability elements rather than offering a thorough examination of Green Building (GB) principles. The absence of uniformity across various rating systems, including LEED, BREEAM, and GRIHA, NGBS, and Green Star, hinders the effective comparison of their sustainability performance. Moreover, insufficient data and budget limitations obstruct the adoption of green certification for current buildings. This research intends to address these gaps by assessing the performance of current structures in relation to GB principles.*

Keywords *- Building Performance, Climate Change, Energy, Green Building, Rating System, Energy, Water Usage.*

1. Introduction

1.1. Background of the Study

Building holds a crucial position in today's world, serving not just as shelter but also contributing to wider socio-economic and environmental frameworks. Nonetheless, the ecological effects of these structures are vital, encompassing energy and water usage as well as waste generation and greenhouse gas emission. The building, functioning, remodelling, and teardown of structure uses an important resource, while also producing waste that adds to global warming. This awareness has resulted in a growing demand for sustainability methods in the construction sector [1]. Consequently, the GB standard and rating system have been created to assess and lessen the environmental footprint of buildings, encouraging Sustainability throughout the entire lifespan of the building, including its design, construction, operations, and final demolition [2, 3].

At the heart of green architecture lies the aims of designing buildings that reduce the ecological footprint while simultaneously improving the comfort, health and productivity of their occupants. This holistic approach includes the using renewable energy, effective Water and waste management systems, and sustainable construction materials [4]. Evaluating the performance of current buildings against these green principles is vital for enhancing the Sustainability of the existing build environment, which constitutes a substantial portion of the global building stock. Moreover, integrating green principles into the retrofit of existing buildings is an effective process for reducing resource consumption and emissions. Such assessment also provides respected feedback for the property owner and the community by helping monitor main viability metrics such as energy and water usage [5, 6]. Previous studies have demonstrated that green buildings improve energy efficiency, reduce resource consumption, and enhance occupant comfort and productivity [7-9].

The world has seen the creation of multiple GB rating systems, which assess building Sustainability through their unique evaluation methods. The primary assessment systems for buildings include Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Methods (BREEM), green Globes, and GRIHA (Green Rating for Integrated Habitat Assessments) because they evaluate multiple environmental factors, which include EE, water consumption, material sustainability, and indoor environmental quality [10].

Existing studies mainly investigate new building projects, which creates a research void about how to achieve Sustainability in already built structures. The research gap shows its strongest effects when researchers study ways to improve environmental performance through retrofitting existing structures. Current research studies Sustainability through specific elements instead of examining all components that define GB standards. The restricted research area prevents researchers from creating complete methods that would improve building environmental sustainability [11]. The research domain encounters its main challenge because different GB evaluation systems assess projects through their unique evaluation standards and assessment techniques, which lack international assessment norms [12, 13]. The worldwide recognition of LEED and BREEM as established systems marks their full implementation, while the GRIHA assessment system provides Indian organizations with solutions to assess their environmental effect through the consumption of energy and management of waste assessment. The different assessment frameworks create difficulties for assessing sustainability results from buildings that received certification through various assessment systems [14, 15].

Obtaining precise performance metrics for contemporary buildings proves challenging, particularly for older structures that lack complete documentation or contain insufficient information [16]. The existing building assessment process fails to provide complete environmental performance information because essential data is unavailable. Property owners face obstacles in pursuing GB certification because they need to pay high initial expenses, which create barriers, particularly for sections with incomplete financial resources. The current lack of effective regulatory frameworks and policy incentives prevents widespread adoption of GB practices, which emphasizes for comprehensive policies necessity foster the international development of sustainable construction practices [17, 18].

The research sector faces multiple limitations despite the significant advancements achieved by GBRS. The primary challenges include the focus on new construction projects, the inconsistent standards of various rating systems, the difficulties in collecting data about established structures, and the budget constraints that damage the accreditation process. The plan and building of buildings, together with their operational phase and final demolition, need sustainable practices to be implemented through effective solutions, which will solve these existing challenges [19-21].

1.2. Significance of the Study

This study is significant because it evaluates the sustainability performance of existing buildings using multiple green building rating systems. The findings provide insights into the strengths and limitations of different assessment frameworks while supporting decision-makers in selecting appropriate rating systems based on project requirements and regional conditions. The study also contributes to sustainable retrofit practices by highlighting the importance of operational performance, occupant well-being, and environmental impact reduction.

1.3. Problem Identification

The problem being addressed in this study within the fragmented and inconsistent approach of existing GBRS in assessing and improving the Sustainability of buildings. In this context, existing GBRSs are found to over-emphasize the importance of design and construction phases of buildings while ignoring the importance of operational effectiveness that crucial for long-term Sustainability. Moreover, existing GBRSs are also found to be completely unaware of the regional characteristics such as climate, economic, and socio-cultural factors. Additionally, they are also unaware of the importance of social equality and economic feasibility. Moreover, the lack of proper guidelines for selecting the most appropriate GBRS for specific project objectives is also creating confusion among stakeholders. Moreover, the cost of obtaining certifications is also creating a major hurdle in adopting GB concepts. These problems are creating a major hurdle in achieving eco-friendly buildings that can reduce ecological impacts while improving occupant comfort and community resilience.

1.4. Research Objective

The main purpose of the study paper is to examine how environmentally sustainable buildings protect nature,

- To examine how GBs support occupant health through their effects on indoor air quality, lighting, thermal comfort and heat emission control.
- To assess different GBRS to identify their sustainable development strengths and weaknesses across different sustainability aspects.
- To identify essential elements and effective methods that lead to better results in the GB certification program through their impact on EE, water conservation, material selection and indoor environmental quality
- To assess the effectiveness of GBRS in reducing the environmental impact of building, including carbon emission, resource consumption, and waste generation.
- To provide direction and recommendations for selecting the most appropriate GBRS based on project goals, building type, and regional context.

1.5. Research Hypothesis

- **(H_1):** GBs, through enhanced quality of air in indoor, optimized lighting, and enhanced thermal comfort, positively impact occupant health and well-being.
  (H_0): There is no significant relationship between GB design elements (indoor air quality, lighting, thermal comfort) and occupant health and well-being.
- **(H_2):** Different GBRS vary significantly in their strengths and weaknesses in addressing various aspects of Sustainability.

(H_0): There is no important modification in the strengths and weaknesses of different GBRS in addressing various aspects of Sustainability.

- **(H_3):** EE, WC, material selection, and IEQ are key factors that significantly contribute to achieving higher ratings in GB certification programs.
  (H_0): E, WC, material selection, and indoor environmental quality do not significantly contribute to achieving higher ratings in GB certification programs.
- **(H_4):** GBRS are effective in reducing the environmental impact of buildings, including carbon emissions, resource consumption, and waste generation.
  (H_0): GBRSs do not significantly reduce the environmental influence of buildings, including carbon emissions, resource consumption, and waste generation.
- **(H_5):** The most appropriate GBRS can be selected on the basis of specific project goals, building type, and regional context.
  (H_0): Project goals, building type, and regional context are not significant factors in selecting the most appropriate GBRS.

2. Literature Review

The review explores the existing research on GBRS, focused on their impact on Sustainability, energy effectiveness, and occupant well-being, while identifying gaps in the evaluation of existing buildings and the challenges integrated with different rating systems.

The prevailing study [22] address the critical need to integrate climate adaption measures into Smart Building Rating Systems (SBRS) to tackle the growing of Climate change. Using a sectoral analysis approach and a 4-point Likert scale, the research evaluates four prominent SBRS: Smart Readiness Indicators (SRI), Smart score, Wired score, and Ready2Service (R2S) to assess their incorporation of climate hazard adaptation measures across multiple building sectors. The results revealing strong integration in the urban sector, like communication and human well-being, but identified significant gaps in domains such as building envelope, Water and sanitation, and blue green infrastructure. Similarly, the study [23] progress in GB construction using the LEED rating system for the past two eras to address climate change and resource depletion. Researchers analyzed data from approximately 61,000 LEED-registered buildings sourced from the U.S. GB Council (USGBC) website using Google Data Analysis modules. The outcome of the model shows the trends in GB growth and gives insights into the influencing factors of the process, offering developers of the rating system with valuable information. Multiple researchers have studied how various GBRS perform in different climate zones and regional settings. The findings demonstrate that international rating systems, which include LEED and BREEAM, have achieved widespread use while regional systems, namely GRIHA and IGBC, require for specific climatic conditions and local regulations. The research demonstrates that building performance improvements depend on the capability to adapt systems to different regional requirements. The research demonstrates that sustainability assessment frameworks become more effective when local environmental factors, which include climate conditions, material availability and socio-economic constraints, are integrated into their assessment.

This research work [24] is about the investigation of the low popularity of the GBRS LOTUS in Vietnam comparing with the international systems like LEED and Singapore's Green Mark (GM). Through a systematic review of literature, the study examined and juxtaposed the effectiveness of LOTUS, LEED, and GM by using different criteria, including energy, Water, materials, and indoor environment. The research results show that LEED is the far most adopted system in Vietnam, GM putting special attention to Sustainability and climate-responsive design, whereas site location was the priority of both LOTUS and LEED. Besides, the delaying introduction of LOTUS and its initial complexities is the main reasons of its limited adoption.

Besides that, [25] investigates how green roofs and walls help reduce Urban Heat Islands (UHI) and offer good thermal comfort in hot and humid climates. By means of Design Builder simulation software, the energy performance of structures with green roofs and walls were analyzed. The findings showed a considerable positive change, such as a decrease in air temperature, radiant temperature, humidity, and solar gain. Energy consumption reduced by 10. 5%, whereas district cooling demand lowered by 13%, showing the potential of greening systems to improve the air quality and EE in urban areas. Recently, research has delved into how architectural design can help promote Sustainability. Evidence from various studies reveals that incorporating passive design methods, installing EE HVAC systems, and tapping into renewable power sources greatly advance the EE of a building. Besides, the incorporation of environmentally friendly construction materials and state-of-the-art building management systems keeps the benefits to the environment adequately covered over time. Such results underscore the necessity of not only bringing in new technologies but also in using sustainable design methods for reaching better ratings of GBs.

This study [26] aims to address the lack of in-depth data on the energy consumption patterns of buildings in Singapore by creating two different whole-building energy models for a large commercial office constructions in the tropics, one with a fully glazed façade and the other with a concrete façade. Using the old building codes in Singapore and working in collaboration with experts in the design and operation of buildings in the tropics, the study was able to develop two different energy models that established the standardized input variables for office buildings in the region. Using the established models, the study was able to determine the overall energy use intensity of 146 kWh/m²/year, where air conditioning and mechanical ventilation (43%), lighting (29%), and plug loads (21%) were the major contributors to the overall energy consumption of the building, while the major contributors to the overall cooling load were ventilation (29%) and window conduction/radiation (20%). Shading devices also contributed to the overall energy consumption cases fully glazed façade.

As well as, the study [27] aims to examine the crucial role that financial incentives, energy performance certification, government policies, and technologies play in promoting the development of EE in buildings. Using the mixed research approach, the research was able to analyze the impact of financial incentives, certification, and policy in the promotion of EE in buildings. The research data was based on the use of various metrics for the measurement of energy performance in buildings, as well as various buildings using renewable energy sources such as solar panels and geothermal heat pumps. The research concluded that financial incentives reduce costs, certification improves market value, and the use of advanced technology improves efficiency in the operations of buildings while reducing emissions. Besides, fresh studies have turned their attention to the running efficiency of old structures under the GB ideas. Scholars have come to understand that the modification of old buildings or changing their features with energy-saving technologies and green materials can lead to an excellent environmental flair. Nevertheless, difficulties like scarce performance data, expensive retrofit projects, and unawareness of GB among the involved parties are still acting as barriers to the spread of GB practices. These problems point out the importance of developing proper assessment tools and detailed schemes for evaluating old buildings.

The paper [28] proposed the development of the Artificial Intelligence-based Energy Management Model (AI-EMM), which could optimize the efficiency in GBs by providing comfort and safety. The proposed model has various features, such as universal infrared communication systems also smart identification systems. Furthermore, the proposed model also has the capability to use the LSTM models to improve the predictions made by the proposed model. By using the data obtained from the GBs, the research was able to prove the efficiency of the proposed model by obtaining 94.3% efficiency ratio, 15.7% reduction in the use of energy, 97.4% accuracy in predictions, also 95.7% in the management of the energy.

This study [29] compared the results obtained by using the EDGE and SEFAIRA software in the simulation of the performance of the GBs in three high-rise buildings. By using the primary data collection approach, the research was able to analyze the simulation results obtained by using the two software programs in the analysis of the performance of buildings with 7,800 m², 6,333 m², as well as 9,501 m². The research concluded that the two programs gave very divergent results in the analysis of the GBs, as the SEFAIRA program gave higher rates compared to the EDGE program. In addition, the research in the existing paper [30] addressed the problem of Gs using 2.5 times as much energy as required. The research developed a predictive model using machine learning to minimize energy consumption and improve indoor Sustainability in GBs. Utilizing a dataset for cooling and heating predictions, the study employed various ML regressors, including Random Forest, Decision Tree, and CatBoost, with the CBR-AL model achieving high accuracy rates of 0.9975 for cooling and 0.9883 for heating.

Research in GB studies has started to focus on using new technologies, which include artificial intelligence and smart sensors and data analytics. The technologies provide organizations with the ability to track building operations continuously while using data analysis to make decisions that enhance their sustainability results. Research demonstrates that intelligent building management systems enable organizations to operate more efficiently while consuming less energy and providing better comfort to their occupants. Future GB projects will implement these technologies because they will become essential components of upcoming developments.

2.1. Comparative Review of Existing Green Building Rating Systems

Green building rating systems have been developed from mere environmental assessment instruments to sophisticated sustainability setups. Mainly focusing on energy efficiency, water conservation and indoor environmental quality, LEED contrasts with BREEAM, which, life-cycle-oriented sustainability-wise, covers lots of management, ecology and pollution criteria. On top of these GRIHA India-centric rating system, besides other things, also deeply considers climatic responsiveness, passive design strategies and resource conservation [31, 32].

The latest publications show that no single rating system can sufficiently cover all dimensions of the sustainability requirements of different geographical areas. LEED is well known for its effective energy optimization and indoor environmental quality modules; still, it faced criticism due to its high cost of certification and the minimal care it takes of regional socio-economic conditions. BREEAM conducts a comprehensive sustainability assessment [33, 34]. Yet relying on it involves a lot of paperwork. GRIHA, thanks to its eco-friendliness and regulatory compliance with local conditions, is a good solution for poor countries.

Besides, new articles address the need for post-occupancy performance evaluation, smart building technologies, occupant well-being and lifecycle sustainability assessment as indicators of actual sustainability performance of buildings rather than just design-stage certification. As a result, comparative analyses that assess existing buildings by multiple sustainability criteria and also consider operational performance, occupant, and regional context factors are needed.

The limitations of the existing works are stated, which the proposed method overcomes through analysis,

- The existing studies have validated GB technologies and actual performance using project-specific data, restricting in-depth analysis.
- Existing research predominantly evaluates GBRS using the building and model phases, neglecting their effectively during operational stages.
- The issues of studies assessing the applicability of international GBRS to local climate conditions, particularly in Nigeria.
- On the role of government, the limited research exists as a supporting mechanism and incentives for the promotion of GB practice within the local context.
- Several criteria and weighting in the GBRSs like GRIHA, IGBC and LEED, where mainly inconsistent comprehensive data from previsions performance from usage of Water, energy consumption, and existing building makes precision sustainability challenges.

2.2. Research Gap and Novelty Contribution

Apart from investigating various green building rating systems, including LEED, BREEAM, GRIHA, Green Star, and NGBS, previous research has really highlighted new construction projects, mainly simulation-based evaluations, or even individual sustainability indicators. Only a few studies have analyzed the performance of existing operational buildings through several rating systems within one common assessment structure. Besides, the effect of regional factors, e.g. climate conditions, local regulations, and socio-economic characteristics on green building assessment, is still quite a mystery.

In addition, the literature shows a lack of a thorough examination of the sustainability criteria prioritized by different rating systems and the ways in which such differences affect building performance outcomes. And, many of the existing studies mainly focus on the certification at the design stage rather than on the operational performance and occupant-related outcomes.

The current research is a response to these issues, and it examines a pre-existing building using multiple green building rating system perspectives as well as combining environmental, operational, and occupant-related performance indicators. Contrary to previous studies, this research associates comparative assessment with statistical validation techniques, such as regression analysis, ANOVA, and reliability testing, to investigate the importance of sustainability parameters.

The main contributions of this research are:

- Comparative analysis of different green building rating systems for a single existing and operational building.
- Development of a single assessment tool combining environmental, operational, and occupant well-being aspects.
- Use of statistics to confirm the importance of key sustainability parameters on green building performance.
- Consideration of regional and other external aspects that may limit or enhance the use of rating systems.
- Drafting of useful guidelines for the selection of green building rating systems in line with the project's objectives and local environment.
- Such contributions establish a complete approach for the assessment of existing buildings and encourage better sustainable building implementation.

3. Methodology

The methodology of this study combines a qualitative research approach to evaluate the performance of the existing building according to different GBRS conditions through using both primary and secondary data sources.

3.1. Research Design

The aim of the research design is to incorporate various processes, for instance, the methods and procedures, to obtain data for the research objective. Well-designed research is significant to ensure the achievement of trustworthy and accurate results. It involves the approach used for the specific research, for instance, the questions answered for the specific research [35]. The research approach used for the specific research was the mixed approach, which involves the use of qualitative and quantitative analysis. The qualitative analysis was related to the theme of the interview, while the quantitative analysis was based on the survey. The survey was used for the quantitative analysis.

3.2. Sample size and Population

For objective 1: focusing on health and well-being, the Population is GB residents, particularly those who have experience in indoor air quality, lighting, thermal comfort, and heat emission. The sample size is approximately seven experts who will provide information regarding GB principles and 20 residents who will provide information regarding their experiences and perceptions. For objective 2: comparing GBRS such as LEED and GRIHA, the Population is existing studies and documents regarding these rating systems. The sample size is based on secondary data obtained from various sources; the sample size will depend on the availability of data. For objective 3: identify key factors in GB ratings, the Population is experts in these rating systems, such as LEED and GRIHA assessors and managers of buildings. The sample size is seven experts who will provide information regarding how to achieve high ratings in GBs.

For objective 4: evaluating the effectiveness of GBRS, the Population is experts in reducing Sustainability and environmental impacts. The sample size is 10 experts who will provide information regarding the thematic evaluation of GBs in relation to Sustainability. For objective 5: selecting the most effective GBRS, the Population is diversified experts in GBs, such as architects, project managers, and experts in Sustainability. The sample size is determined by insights obtained from the above-mentioned objectives. The study included 385 residents and 80 experts who provided information in a qualitative evaluation. The residents provided information regarding indoor environmental quality, comfort, and health and well-being, while experts provided information regarding how buildings perform in relation to various GBRS. The sample size of residents was sufficient to provide enough statistical power in quantitative evaluation, while experts were sufficient in providing thematic evaluation, as well as comparing various rating systems.

3.3. Sampling Techniques

The research team selected specific building sites through purposive sampling to investigate multiple critical elements. The particular selection method enables a complete assessment of how various elements impact perceptions and performance in sustainable buildings because services are selected on the basis of their commercial, residential, and instrumental classification, together with their operational history and geographic distribution across different climate zones, and their current sustainability features. The research achieves various results through diverse experiences that relate to sustainable construction methods. The 385 resident respondents exceed the minimum requirement for regression and ANOVA testing, which provides sufficient statistical power to analyze the data. The 80 expert responses meet industry standards for applied building-performance research because experts primarily come from specialized professional fields.

3.4. Data Collection

The researchers collected data through qualitative methods, which primarily involved conducting interviews and administering surveys to achieve a complete understanding of their research subject matter. The researchers employed two separate assessment tools for their study. The structured questionnaire, which residents completed, enabled researchers to conduct statistical analysis of indoor environmental response data. The semi-structured expert questionnaire enabled researchers to identify themes that sustainability strategies and rating system performance were used as their basis. The researchers employed this distinction to successfully capture both direct user feedback and technical assessment results. The researchers conducted organized interviews together with surveys to collect primary data, which showed how indoor air quality, lighting and thermal comfort affected residents' health and well-being according to Objective 1. Semi-structured interviews or focus groups are conducted with GB experts, sustainability specialists, and building managers for Objectives 3, 4, and 5 to collect qualitative information on strategies, efficacy, and assessments. For Objective 2, such studies, evaluations, and standards that exist are considered sources of secondary data. This is done, for example, by reviewing data of prominent systems of GBs, such as LEED, GRIHA, etc., along with other sustainability-related research to lay the groundwork for benchmarking.

3.4.1. Building Selection Criteria and Rating System

The case-study building was selected based on the following criteria:

- Continuous operational history exceeding five years.
- Availability of energy, water, and maintenance records.
- Occupancy levels sufficient for collecting occupant feedback.
- Accessibility for physical inspection and sustainability assessment.
- Presence of building systems relevant to green building evaluation.

The selection of LEED, BREEAM, GRIHA, Green Star, and NGBS was justified based on their international recognition, widespread adoption, and comprehensive sustainability assessment frameworks. These systems collectively represent different geographical regions and assessment philosophies, enabling a balanced comparison of environmental, economic, and social sustainability indicators.

Data collection involved three stages: Physical building inspection, Occupant survey and expert consultation, and Collection and analysis of operational performance records, including energy consumption, water consumption, waste generation, and indoor environmental quality indicators. This methodology improves reproducibility and allows future researchers to replicate the assessment procedure in similar building contexts.

3.5. Data Analysis

The study follows a comprehensive analytical tool to assess the performance of sustainability structures. Comprehensive analysis is performed on the available building performance data based on the benchmark established by reliable GBRS and industry standards. Analysis is performed to assess how effectively the buildings perform and achieve or even exceed established performance standards. The analysis provides key advantages and possible opportunities for improvement. Assessing energy consumption is a fundamental step towards improving EE and reducing carbon footprint. Benchmarking is performed to evaluate energy consumption and compare it to similar buildings or established standards. The study makes use of tools such as ENERGY STAR Portfolio Manager to evaluate building efficiency and establish performance benchmarks for buildings.

Qualitative information collected through interviews and surveys is subject to analysis based on thematic and content analysis. Thematic analysis involves identifying major topics from gathered data, which enables a thorough examination to assess main factors and approaches for installing GB certifications. To carry out interviews among residents (Objective 1), thematic analysis is conducted to draw out major topics concerning how different GB components, like air quality, lighting, and thermal comfort, impact health. When interviewing experts, major themes center on methods for securing higher ratings, lessening environmental impacts, and selecting suitable GBRS.

Also, secondary data sourced from the latest studies, the Internet, and other channels is extensively analyzed to determine the pros and cons of different GBRS. Detailed examination is undertaken to look at various sustainability aspects, such as energy use, water saving, and indoor environmental quality, in order to decide if a building deserves to be a GB or at least meets the set sustainability standards. The mix of these methods offers a deep understanding of people's experiences and building sustainable operations influenced by human behaviors and the physical environment, respectively.

4. Result

The research results show essential details about building systems that function under different testing scenarios of the GBRS framework. The research establishes which sustainability metrics show different results and which factors help organizations achieve higher GB certification results. To evaluate the performance of the building in question, it was first compared with baseline benchmarks. These benchmark data sets were sourced from the performance of typical, non-green buildings and/or the most recent standards published by green building rating systems such as LEED, BREEAM, and GRIHA.

Among the most important indicators were energy consumption intensity, water consumption per capita, indoor environmental quality via various indicators, waste generation, and levels of occupant satisfaction. Utilizing these baseline scenarios, the building's sustainability level was not only objectively measured, but also the results could be understood within a specific reference system.

4.1. Thematic Analysis

Thematic analysis is applied to analyze qualitative data that investigators obtained through their in-depth interview sessions. The method requires researchers to discover all existing patterns in the collected data, which researchers use to create themes that produce overarching research understanding through increased research insights [36].

Hypothesis 1:
H_1: GBs implement better indoor air quality and lighting systems together with improved thermal comfort solutions, which lead to better health results for building users.

H_0: The design elements of GBs, which include both indoor air quality and lighting and thermal comfort, do not show any connection to how people experience health effects according to H0.

Table 1 shows the residence response. GBs, through improved indoor air quality, optimized lighting, and improved thermal comfort, positively impact occupant health and well-being. This is because improved air quality is related to improved health, while improved lighting conditions impact occupant mood and productivity. Thermal comfort also impacts occupant well-being both physically and emotionally. Thus, it can be concluded that the design elements of GBs help to create a healthier environment that is beneficial to occupants and promotes health benefits and stress relief among occupants.

H_1: GBs, through improved indoor air quality, optimized lighting, and improved thermal comfort, positively impact occupant health and well-being, as proven from the above analysis.

Hypothesis-2:
(H_2): Different GBRS vary significantly in their strengths and weaknesses in addressing various aspects of Sustainability.

(H_0): There is no significant difference in the strengths and weaknesses of different GBRS in addressing various aspects of Sustainability.

Table 1. Residents response

Codes Generated	Themes
[C1]Impact of Air Quality on Health [C2]Air Quality Challenges	Health Impacts & Environmental Challenges
[C3]Lighting Impact on Mood & Productivity [C4]Lighting Design Importance	Psychological & Productivity Effects of Lighting
[C5]Thermal Comfort & Health [C6]Temperature-Related Stress	Physical Health & Emotional Well-being Impacts
[C7]Energy-Efficient Insulation [C8]Smart Temperature Control	Sustainable Building Solutions & EE

[C9]Satisfaction with Current Measures [C10]Needed Improvements	Perceived Effectiveness & Areas for Improvement
[C11]GB Health Benefits [C12]Reduced Stress Factors	Health Advantages & Stress Reduction in GBs
[C13]Smart Technology Benefits [C14]Real-Time Monitoring Impact	Technological Innovations for Enhanced Well-being

5. Quantitative Analysis

5.1. Regression-Residences

Table 2. Model summary

Model	R	R Square	Adjusted R-Square	Std. Error of the Estimate
1	.820[a]	.672	.669	.751

Table 3. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	440.234	3	146.745	260.200	.000[b]
	Residual	214.872	381	.564		
	Total	655.106	384			

Table 4. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.761	.256		-2.976	.003
	How do you rate noise levels at night?	.974	.041	.737	23.979	.000
	How do you rate daylight levels in the morning?	.203	.032	.195	6.336	.000
	How do you rate humidity levels during rainy/moist seasons?	.099	.047	.061	2.079	.038

Tables 2-4 multiple regression models revealed a strong and statistically significant relationship between indoor environmental parameters and overall occupant satisfaction. The model explained 67.2% of the variance in perceived indoor comfort ($R^2 = 0.672$), confirming good explanatory power. The ANOVA results ($F = 260.20$, $p < 0.001$) indicate that the predictors collectively contribute significantly to the model. Among the variables considered, night-time noise levels emerged as the strongest predictor ($\beta = 0.737$, $p < 0.001$), followed by daylight availability in the morning ($\beta = 0.195$, $p < 0.001$) and humidity during rainy seasons ($\beta = 0.061$, $p = 0.038$). These findings demonstrate that improvements in acoustic comfort, natural lighting, and humidity control substantially enhance overall indoor environmental satisfaction, thereby supporting the hypothesis that GB design elements positively influence occupant health and well-being.

5.1.1. Energy Efficiency of HVAC across GBRS

Table 5. ANOVA

How do you rate the overall EE of HVAC systems?					
	Sum^2	df	Mean2	F	Sig.
Between Groups	11.403	4	2.851	3.031	.023
Within Groups	70.547	75	.941		
Total	81.950	79			

Table 5 presents the one-way ANOVA results indicated a significant difference in perceived HVAC EE across different GBRS ($F = 3.03$, $p = 0.023$). However, although the results of Levene's test indicated that the variances of the buildings' EE ratings were not equal, the Tukey's test results indicated that the difference in the buildings' EE ratings was between the LEED and BREEAM rating systems. In particular, the buildings rated by the LEED rating system had higher EE ratings than the buildings rated by the BREEAM rating system, with a significant difference of 0.914 in the EE ratings ($p < 0.05$). This indicates that the hypothesis that different GBRS have different strengths and weaknesses is correct.

Table 6. Homogeneous subsets

How do you rate the overall EE of HVAC systems?		
Tukey HSD[a,b]		
GBRS	N	Subset for alpha = 0.05
		1
BREEAM	21	3.29
GRIHA	13	3.46
IGBC	17	3.94
Others	9	4.11
LEED	20	4.20
Sig.		.093

Table 6 above indicates the homogeneous subset analysis grouped buildings' EE ratings. It is clear that the BREEAM and GRIHA buildings' EE ratings fell in the lower range of the efficiency spectrum, while the buildings rated by the IGBC, Others, and LEED rating systems had higher and higher levels of EE ratings, respectively.

5.1.2. Reliability

Table 7. Case processing summary

		N	%
Cases	Valid	80	20.8
	Excluded[a]	305	79.2
	Total	385	100.0

Table 8. Reliability statistics

Cronbach's α	Cronbach's αBased on Standardized Items	N of Items
.474	.773	2

Tables 7 and 8 show that reliability analysis indicated good internal consistency when items were standardized, with Cronbach's being 0.773. The raw alpha values, on the other hand, seemed rather low (0.474). However, after standardization, the reliability reached a very good level. It means that the items from which the performance scores was calculated are consistent enough to justify further statistical analysis.

5.1.3. Regression - Factors Contributing TO Rating Score

Table 9. Model summary

Model	R	R Square	Adjusted R-Square	Std. Error of the Estimate
1	.621[a]	.386	.370	.24282

Table 10. ANOVA[a]

Model		Sum^2	df	Mean^2	F	Sig.
1	Regression	2.853	2	1.426	24.192	.000[b]
	Residual	4.540	77	.059		
	Total	7.393	79			

Table 11. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	β		
1	(Constant)	2.828	.113		25.013	.000
	Q16 Water efficiency	.100	.028	.331	3.495	.001
	Q19 Material reuse	.098	.022	.426	4.495	.000

The regression model which is shown in Tables 9 through Table 11, demonstrated that sustainability factors directly impacted overall rating performance since the model achieved statistical significance with an F value of 24.192 and p value below 0.001, and the model explained 38.6 percent of rating results. The research found that both water efficiency and material reuse served as essential positive predictors, which demonstrated that improved building scores in these areas resulted in higher certification outcomes. The EE variable needed to be excluded because collinearity restrictions showed that its shared variance with other sustainability measures exceeded acceptable limits. The results show that resource conservation, together with sustainable material practices, serve as essential factors which drive success in green certification programs.

5.1.4. Secondary Data

The secondary data analysis method evaluates different GBRS systems to determine their sustainability strengths and weaknesses through comparative analysis. The research method gathers existing studies and analyzes their content through systematic processes. The evaluated GBRS, which include LEED GRIHA, IGBC, and other systems, assess their performance in EE, WC, selection of material and indoor environmental quality through certification comparison in Table 12 and the rating levels and sustainability indicators in Tables 13 and 14.

5.1.5. Comparison Analysis of Certification

Table 12. Certification comparison across building types and rating systems [37]

Rating System	Certification Levels	Criteria Weightage (%)	Building Types	Key Features
BREEAM	Outstanding: 85+, Excellent: 70-84, Very Good: 55-69, Good: 45-54, Pass: 30-44	Energy (17), Health and Well-being (14), Management (11), Materials (11), Pollution (9), Innovation (9), Land Use and Ecology (9), Transport (7), Waste (7), Water (6)	New Construction, Refurbishment, In-use	Emphasizes lifecycle sustainability performance, integrating regional priorities.
LEED	Platinum: 73-100, Gold: 55-72, Silver: 45-54, Certified: 36-44, No Rating: <35	Sustainable Sites (SS) (23.63), Water Efficiency (WE) (9.09), Energy and Atmosphere (EA) (31.82), Materials and Resources (MR) (12.73), Indoor Environmental Quality (EQ) (13.64), Innovation (5.45)	New Construction, Existing Buildings, Renovation	Focuses on EE, WC, and indoor environmental quality. Offers flexibility through optional credits.
GRIHA	One Star: 2540, Two Stars: 4155, Three Stars: 5670, Four Stars: 7185, Five Stars: 86	SS Planning (12%), CM (Construction Management) (4%), EO (Energy Optimization) (18%), OC (Occupant Comfort) (12%), WM (16%), Solid Waste Management (6%), Sustainable Building Materials (12%)	Offices, Retail Spaces, Institutional Buildings, Hotels, Hospitals, Healthcare Facilities, Residences, Multi-family High-rise Buildings	Concentrated on energy saving, making occupants comfortable, and sustainable ways of building.
NGBS (National GB Standard)	Bronze (231), Silver (334), Gold (489), Emerald (611)	Lot Design and Development (10%), Resource Efficiency (15%), Water Efficiency (14%), EE (30%), IEQ (21%), OM (10%)	Single-family Homes, Multi-family Residential, Mixed-use Buildings,	Emphasizes performance in residential construction, addressing

			Remodelling Projects	design, operation, and maintenance.
Green Star (Australia, New Zealand)	1-6 Stars (Minimum Practice to World Leadership)	Management (15%), IEQ (21%), Energy (27%), Transport (8%), Water (13%), Materials (9%), Land Use & Ecology (6%), Emissions (5%), Innovation (5%)	New Buildings, Interiors, Communities, Performance Assessments	Evaluates environmental impact across energy, Water, and indoor air quality
Living Building Challenge (LBC)	Core, Petal, Living Certification	Place (16.67%), Water (16.67%), Energy (16.67%), Health & Happiness (16.67%), Materials (16.67%), Equity (16.67%), Beauty (16.67%)	New Construction, Existing Buildings, Communities, Landscapes	Focuses on regenerative design principles and actual performance over modelled outcomes

5.1.6. Comparative Rating Levels

Table 13. Certification across GBRS [24]

Rating System	Lowest Level	Intermediate Levels	Highest Level
BREEAM	Pass	Good, Very Good, Excellent	Outstanding
NGBS	Bronze	Silver, Gold	Emerald
LEED	Certified	Silver, Gold	Platinum
GRIHA	One Star	Two Stars, Three Stars, Four Stars	Five Stars
Green Star	1 Star (Minimum Practice)	2-5 Stars (Average to Best Practice)	6 Stars (World Leadership)
Living Building Challenge (LBC)	Core	Petal Certification	Living Certification

5.1.7. Sustainability Indicators

Table 14. Score limitation and sustainability indicator [38]

Indicator	Score Limitation
Biodiversity	≤9
Greenery	≤9
Daily Energy	≤12
CO2 Emission Reduction	≤9
Construction Waste Reduction	≤9

The various GBRS vary significantly based on their strengths and weaknesses in dealing with different facets of Sustainability. LEED and BREEAM are well-established rating systems worldwide. LEED primarily deals with indoor environmental quality and EE, whereas BREEAM deals with all aspects of environmental, social, and economic Sustainability. CASBEE provides a holistic approach by dealing with environmental, social, and economic factors by using lifecycle assessments. DGNB deals with lifecycle performance and economic viability, providing customized services based on regional needs. Green Star, popularly used in Australia, rigorously tests environmental Sustainability by dealing with various aspects like energy and WC. Each of the systems has its own advantages and disadvantages in terms of the cost of certification, applicability of the system in different areas of the country, and the criteria of assessment. This has an impact on the application of the systems in different areas and projects [39].

The analysis has shown the major differences between the various GBRS in terms of the strengths and weaknesses of the systems in relation to sustainability factors. All the systems, like the LEED, BREEAM, and Green Star systems, have their own way of addressing the sustainability factors with different criteria of calculation and prerequisites. In summary, these distinction underscores the crucial need to choose a GBRD that fits particular project objectives and local sustainability priorities. Also Table 15 and Figure 1 show the comparison of certification cost comparison across building types and rating systems.

5.1.8. Comparison Analysis of Certification Costs

Table 15. Certification cost comparison across building types and rating systems [37]

Building Type	**Certification Level**	BREEAM (%)	NGBS (%)	LEED (%)	GRIHA (%)	Green Star (%)	LBC (%)
SF Home	1 Star / Certified	0.60	0.21	0.72	0.50	0.55	1.00
	2 Stars / Silver / Good	1.80	2.20	2.40	1.70	1.65	2.50
	3 Stars / Gold / Very Good	3.20	3.70	6.10	3.00	3.10	5.00
	Highest Level / Platinum	7.60	7.40	7.80	7.50	7.30	9.00
Townhouse	1 Star / Certified	0.80	0.31	0.74	0.65	0.70	1.20
	Highest Level / Platinum	11.00	10.10	10.60	10.00	9.90	12.50

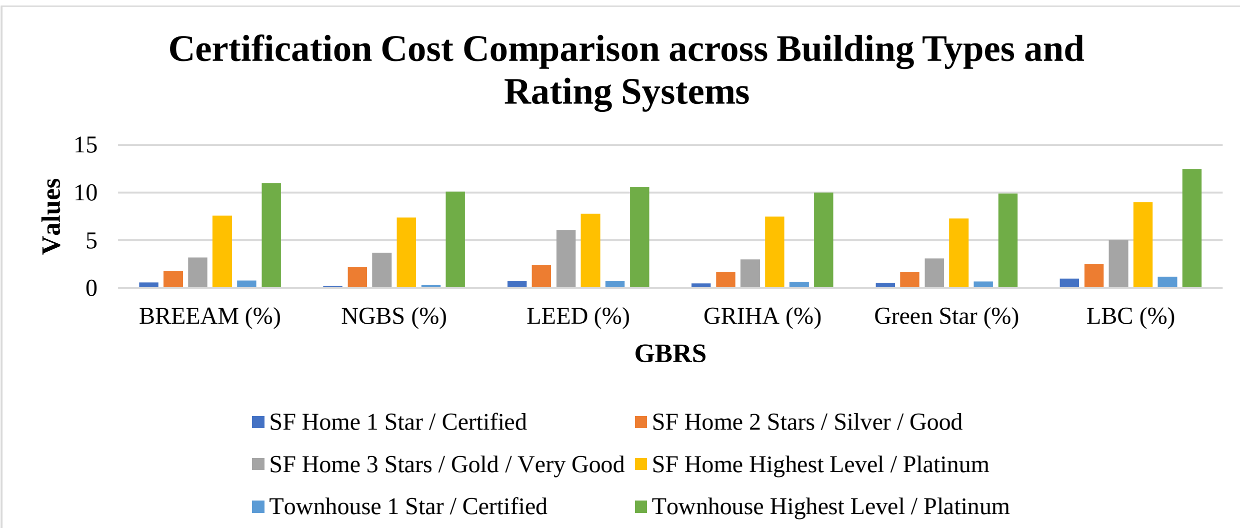

Fig. 1 Comparison of building types and rating systems

Hypothesis-3:

H_3: EE, WC, material selection, and indoor environmental quality are key factors that significantly contribute to achieving higher ratings in GB certification programs.

H_0: EE, WC, material selection, and indoor environmental quality do not significantly contribute to achieving higher ratings in GB certification programs.

H_4: GBRS are effective in reducing the environmental impact of buildings, including carbon emissions, resource consumption, and waste generation.

H_0: GBRSs do not significantly reduce the environmental influence of buildings, including carbon emissions, resource consumption, and waste generation.

H_5: The most appropriate GBRS can be selected on the basis of specific project goals, building type, and regional context.

H_0: Project goals, building type, and regional context are not significant factors in selecting the most appropriate GBRS.

Table 16. Expert's response

Code	**Theme**
[C1] Resource Optimization [C2] Environmental Performance	Sustainability Health and Environment
[C3] Renewable Energy Integration [C4] Energy Efficiency Optimization	Renewable Energy Efficiency and Design

[C5] Sustainable Material Use [C6] Environmental Impact Reduction	Sustainable Practices Environmental Stewardship
[C7] Indoor Air Quality Management [C8] Environmental Health Enhancement	Indoor Environmental Quality Occupant Health
[C9] Carbon Emission Reduction [C10] Sustainable Practice Implementation	Carbon Footprint Reduction Sustainable Operations
[C11] Waste Management Practices [C12] Resource Conservation Strategies	Waste Reduction Resource Efficiency
[C13] Continuous Monitoring [C14] Operational Efficiency Maintenance	Performance Monitoring Sustainability Maintenance
[C15] Sustainability Goal Alignment [C16] Regional Context Consideration	Strategic Alignment Contextual Adaptation
[C17] Carbon Neutrality Integration [C18] Social Equity Consideration	Future-Proofing Social Responsibility
[C19] Energy Efficiency Focus [C20] Regional Sustainability Alignment	Energy Efficiency Regional Sustainability

Table 16 shows the expert's response. GB certification programs emphasize several key factors that contribute to achieving higher ratings, including energy efficiency, WC, material selection, and indoor environmental quality. Each of these factors will be very important in minimizing the negative environmental aspects of buildings by reducing carbon emissions, consumption of resources, and production of waste. Energy-efficient buildings and water-saving techniques will be at the core of cutting down running costs and the environmental footprint, whereas choosing circumstances-friendly materials will raise one's level of concern for nature. For example, the quality of the indoor environment, such as the freshness of the air, contributes significantly to the health and comfort of the occupants. The success of GBRS in reducing environmental impacts is thoroughly discussed in the literature, with certifications such as LEED and BREEAM offering guides to sustainable practices. Choosing the right GBRS is a matter of understanding the particular project goals, type of building, and the surrounding environment of the region, so that the chosen certifications are in line with the local sustainable development requirements and the aims of the project. Therefore, from the above discussion, H3, H4, and H5 are confirmed.

A comparative evaluation was done and found that selected green building rating systems vary A lot. LEED led the pack in the energy efficiency and indoor environmental quality categories. Meanwhile, BREEAM was clearer in its sustainability assessment over a lifecycle, and GRIHA reflected well the local climatic conditions and the resource conservation priorities that are typical of developing countries.

In contrast with international studies, the results show that rating systems that focus on the operation efficiency and the occupant well-being yield sustainability outcomes that are closer to reality than systems that focus mainly on a design-stage compliance. Besides that, the results reveal that a regional adaptation greatly affects the sustainability performance, In particular about energy consumption patterns, water availability, and climatic conditions. From one point of view, no rating system can universally cover sustainability objectives altogether. Instead, a rating structure is to be chosen considering several aspects like project type, regional conditions, stakeholder priorities, and long-term operational goals.

Green building rating systems nowadays are moving towards the integration of smart technologies such as Internet of Things (IoT) sensors, artificial intelligence (AI), digital twins, and building automation systems. These tools allow for continuous tracking of the energy usage, the quality of the indoor environment, the patterns of occupancy, and the scheduling of maintenance.

Energy management systems powered by AI have been able to reduce energy consumption Much, while at the same time, enhancing the comfort of the occupants. Same here, the IoT-enabled monitoring tools give real-time information of the building's performance, which makes it easier to manage Sustainability in a more evidence-based manner. In the future, green building rating systems will likely focus more on the analysis of operational data, predictive maintenance, and smart performance adjustment rather than just relying on design documentation.

Post-Occupancy Evaluation (POE) is one of the key elements of assessing green building performance, and has been greatly acknowledged. Even though certification systems largely assess design and construction characteristics, the real sustainability performance is definitely demonstrated through building operation. In this research, occupant survey outcomes show that the bedroom air quality, thermal comfort, availability of daylight, acoustics, and noise can have a major impact on the level of satisfaction and well-being of the occupants. The statistical data also indicated a strong correlation between indoor environmental quality parameters and the comfort levels of the occupants. This evidence is in line with the studies that highlight the importance of including occupant-related performance parameters in the next sustainability evaluation models. Ongoing POE initiatives are crucial to uncovering the discrepancies between intended design and actual building operation performance.

6. Discussion

This research assesses the performance of an old building according to the GB principles and compares its features with different GBRS. Results are in line with previous ones that revealed the importance of incorporating GB design features for improving the health and well-being of occupants. For instance, better indoor air quality, adequate lighting, and enhanced thermal comfort are factors that bring healthier results, just like different leadership styles influence employee engagement by creating a pleasant work environment.

Previous literature [40] has underscored the role of GBs in facilitating the well-being of occupants through the provision of a healthy indoor environment. This paper confirms these findings by establishing a link between air quality, lighting, and thermal comfort and the well-being of occupants. The emphasis on indoor environmental quality is similar to the benefits of transformational leadership in tech start-ups, where cultivating a positive work environment leads to employee engagement and motivation [41].

The assessment of various GBRS shows notable disparities in their advantages and disadvantages concerning sustainability factors. The LEED and BREEAM frameworks receive recognition for their complete framework details, which differ from Green Star's approach, which allows regional customization. The different GBRS systems used in this study show similarities to the various leadership methods employed by technology companies, which include transformational leadership, agile leadership and servant leadership to meet their organizational demands [42].

The research shows that energy efficiency and WC, together with proper material selection and indoor environmental conditions, create the essential factors that lead to improved results in GB certification programs [43]. Successful leadership approaches require vision, individual support and flexibility, which technological start-ups need to enhance their employee engagement and job satisfaction.

The analysis verifies that GBRS successfully lower the environmental impact of buildings by decreasing carbon emissions, resource use, and waste production. The study demonstrates that effective leadership methods improve organizational performance while driving innovation initiatives.

6.1. Limitation

The limitations of this paper stem from a number of factors that limit a thorough assessment of GB practices. One of the factors that research on existing buildings cannot fully address is that there is missing accurate data on performance, and therefore, one cannot fully evaluate how sustainable the buildings are. The research also encounters difficulties since it relies on secondary data from GBRS, which have different criteria for assessment and certification, as well as costs and regional applicability. The lack of standardization among GBRS systems makes it hard to do direct sustainability comparisons between these systems.

6.2. Future Research

Future research endeavors ought to be directed towards the design of unified assessment schemas that will allow the comparison of various GB certification tools in a harmonious manner. Besides, authors may consider expanding their inquiries by including not only more buildings but also different types of structures located in diverse climatic conditions so that the findings can be generalized with a high level of confidence.

On the other hand, the incorporation of high-tech innovations like AI (Artificial Intelligence), IoT (Internet of Things), and real-time monitoring to improve the evaluation of building performance is an area worth investigating in the future. Moreover, undertaking a longitudinal study of the volume of green retrofitting in existing buildings could be beneficial in shedding light on Sustainability.

6.3. Policy and Practice Recommendation

Based on the findings of this study, the following recommendations are proposed:

- Encourage governments to provide financial incentives for green building certification and retrofit projects.
- Promote mandatory post-occupancy performance evaluation for certified buildings.
- Integrate smart monitoring technologies into sustainability assessment frameworks.
- Develop region-specific sustainability criteria that account for climate conditions and local resource availability.
- Improve stakeholder awareness regarding the long-term economic and environmental benefits of green buildings.
- Encourage harmonization among major rating systems to improve comparability and standardization of sustainability assessments.
- Support research initiatives focused on operational performance and occupant well-being metrics.

7. Conclusion

This study brings valuable information about building evaluation procedures that use GB concepts. The study provides a solution to the existing research gap, which investigates sustainable practices for current building structures. The study evaluates building performance through assessments that use different GBRS. The results demonstrate that GBs enhance occupant health through better indoor air quality and natural light, and comfortable temperature control systems. The research evaluates multiple GBRS, which include LEED, GRIHA, NGBS, Green Star, and BREEAM, to demonstrate their respective benefits and drawbacks for measuring different sustainable aspects. LEED focuses on energy efficiency and WC, whereas BREEAM and other evaluation systems provide more complete assessments that include environmental, social and economic aspects. Stakeholders can determine the appropriate GBRS for their project when they comprehend the differences between rating systems. The research states that GB assessment methods need more development to create systems that match local and international sustainable development requirements. The research provides methods that help organizations reach higher GB Assessment ratings. Organizations can enhance their GB Assessment ratings by improving energy efficiency, reducing water use, selecting eco-friendly building materials, and enhancing their indoor spaces.

The research demonstrates that GB methods successfully minimize environmental harm by decreasing greenhouse gas emissions and other ecological effects. The research provides a solid basis for measuring existing building sustainability, but researchers need to conduct additional studies to create a standardized comparison system between different GBRS.

Conflict Of Interest

The author reports that there is no conflict of interest

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Data Availability

Data sharing not applicable to this article as no datasets were generated.

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