CONSTRUCTION
E-ISSN: 2785-8731
VOLUME 6, ISSUE 1, 2026, 18 - 32
DOI: https://doi.org/10.15282/construction.v6i1.13058

RESEARCH ARTICLE

Green building index in enhancing healthcare facility sustainability

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Abstract - The green building index (GBI) is an important certification tool to promote sustainable practices and energy-efficient building designs. This study investigates the implementation and effectiveness of the GBI in public hospital buildings in Malaysia. A qualitative research approach was employed, combining an extensive literature review with semi-structured interviews involving five key stakeholders from the Ministry of Health and the Public Works Department, including engineers and an architect involved in the planning, construction, and management of healthcare facilities. Thematic analysis identified three themes: GBI's influence on sustainability outcomes, GBI's overall effectiveness in promoting sustainable healthcare facilities, and the measurable benefits achieved through GBI's implementation. The results show that GBI implementation in Malaysian public hospitals provides substantial benefits including improved energy and water efficiency, reduced operating and maintenance costs, and enhanced indoor environmental quality that supports patient recovery, staff well-being, and overall operational sustainability. The study also underscores alignment with Malaysia's commitment to the United Nations Sustainable Development Goals, particularly SDG 11 on sustainable cities and communities. The findings offer practical guidance for policymakers, facility managers, and designers on utilising GBI criteria to enhance sustainability in the planning, design, and management of healthcare facilities. Future research could expand the scope to private healthcare facilities and apply mixed method approaches to deepen understanding GBI's impact across diverse healthcare contexts.

Article History
Received : 4 September 2025
Revised : 5 December 2025
Accepted : 12 January 2026
Published : 30 June 2026

Keywords
Green building index
Healthcare facility
Sustainable healthcare
Energy efficiency

1. Introduction

Malaysia, classified as an upper-middle- income country, is currently undergoing a transition towards sustainable development, with a growing emphasis on integrating sustainability into the built environment [1]. Malaysia's population had reached approximately 34.1 million, driven by an annual growth rate of 2.0% [2]. This continuous population growth leads to a rising demand for infrastructure and healthcare services nationwide. In response, there is an increasing need to develop healthcare infrastructure that is accessible, resilient, and sustainable to ensure the welfare of future generations [3]. Malaysia operates a dual healthcare system comprising a government-administered public sector and a privately funded healthcare sector. Both sectors function in a complementary manner to deliver comprehensive medical services nationwide. However, even though healthcare facilities prioritise public health, their infrastructure and operations contribute significantly to environmental degradation, including hazardous waste, climate change, and global warming [4]-[5]. To mitigate these impacts, the concept of green hospitals has gained increasing significance as a strategy to reduce the environmental impact of healthcare facilities [3]. The Green Buildings Index (GBI) serves as a comprehensive framework for advancing sustainability in healthcare facilities, supporting the integration of eco-friendly design, improved energy and water efficiency, and sustainable resource management into hospital operations. These initiatives promote the transition toward sustainable healthcare facilities that support environmental sustainability while enhancing patient health and recovery [6]. Despite growing awareness, hospitals exhibit limited engagement in pursuing green building certification, and existing research reveals a significant knowledge gap regarding the actual impacts and effectiveness of GBI implementation in Malaysia's healthcare sector. As reported by Mustaffa et al., there remains insufficient understanding of how green buildings influence sustainable practices in this sector [7]. This limited understanding reflects a critical research gap that could hinder the adoption of sustainable practices and policies within Malaysian healthcare facilities. Despite the availability of green frameworks such as GBI, their implementation in Malaysia's healthcare sector remains limited and underexamined. Existing research has largely focused on general sustainable practices and GBI applications in sectors other than healthcare, leaving the specific impacts and effectiveness of GBI in the healthcare sector largely unexplored and requiring further investigation [8] - [10]. Hence, this study aims to address this gap by identifying current sustainability practices in public healthcare facilities and evaluating the effectiveness of GBI in enhancing their overall environmental performance.

This study addresses this gap by exploring two key research questions: What sustainability practices are currently implemented in Malaysian public healthcare facilities? and how does the implementation of the GBI affect and improve sustainability outcomes in Malaysian public healthcare facilities? It is hypothesised that GBI implementation significantly enhances environmental performance, operational efficiency, and occupant well-being, thereby advancing sustainable healthcare infrastructure development. This study is limited to public hospital facilities in Malaysia and specifically assesses the impact of GBI adoption on sustainability outcomes. To achieve these objectives, an extensive literature review and semi-structured interviews were conducted with key stakeholders from the Ministry of Health and the Public

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Works Department of Malaysia (PWDM), including engineers and an architect involved in the planning, construction, and management of healthcare facilities. These efforts align with Malaysia's commitment to the United Nations Sustainable Development Goals (SDGs), particularly SDG 11, which emphasises sustainable cities and communities. The findings aim to guide future healthcare facility design, construction, and maintenance by promoting environmentally responsible and resource-efficient practices and may serve as a model for other regions.

1.1 Green Building

A green building is a structure that is designed, built, operated, maintained, or repurposed to safeguard occupant health, improve occupant productivity, conserve natural resources, and reduce environmental impact [11]. Similarly, Manzoor et al. [10] stated that green buildings play a critical role in preventing climate change and resource depletion. Green buildings reduce the environmental footprint of the built environment by enhancing energy efficiency, conserving water, and utilising sustainable materials. Internationally established rating systems, including Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method, Building Environmental Assessment Method, Green Mark, and GBI, have significantly driven the growth of green building initiatives and contributed to their increasing global adoption [8]. In Malaysia, healthcare facilities primarily utilise two rating systems for certification: GBI and LEED [12]. The GBI offers a systematic framework for evaluating and accrediting healthcare facilities that meet sustainability standards, ensuring the effective implementation of green building principles across the design, construction, and operational stages.

1.1.1 Green building index

The Green Building Index serves as Malaysia's official benchmark for evaluating environmentally friendly buildings with the objective of promoting sustainable practices within the construction industry and to inform developers, architects, engineers, planners, designers, contractors, and the public about environmental issues and the importance of conserving resources for future generations [13]. Malaysia has implemented the GBI since 2009. This assessment tool was established by the Malaysian Institute of Architects (PAM) and the Association of Consulting Engineers Malaysia (ACEM) [8], [11]. GBI also provides a certification framework that targets measurable outcomes, including reducing ecological impact, increasing property value, and delivering societal benefits. Furthermore, GBI was specifically designed to address Malaysia's tropical climate, cultural and social needs, and the nation's environmental and developmental context [1]. Within the GBI, healthcare facilities are generally categorised as Non-Residential New Construction (NRNC) or Non-Residential Existing Building (NREB), depending on whether they are newly developed facilities or existing structures undergoing assessment [14]. The point allocation for NRNC and NREB differs and is further illustrated in Table 1.

Table 1. GBI point allocation for NRNC and NREB

Parameters	NRNC	NREB
	Maximum points	
Energy efficiency	35	38
Indoor environmental quality	21	21
Sustainable site planning and management	16	10
Material and resources	11	9
Water efficiency	10	12
Innovation	7	10

Table 2. GBI rating classification [8]

Points	GBI rating
86-100	Platinum
76-85	Gold
66-75	Silver
50-65	Certified

GBI evaluates building designs for green certification based on six core sustainability parameters: energy efficiency (EE), indoor environmental quality (EQ), sustainable site planning and management (SM), material and resources (MR), water efficiency (WE), as well as innovation (IN) [8]. Buildings that meet the required threshold under GBI are awarded a certification level (Certified, Silver, Gold, or Platinum), as shown in Table 2. Gleneagles Hospital has achieved Gold certification, while Amanjaya Specialist Centre, Pantai Hospital Laguna Merbok, and Bandar Dato'Onn Specialist Hospital have been awarded Silver. Additionally, Hospital Pakar KPJ Damansara and Hospital Pakar Kanak-Kanak Universiti Kebangsaan Malaysia have achieved certification, demonstrating their dedication to sustainable design and environmental performance. To encourage wider adoption of GBI standards, starting 1 September 2024, projects involving team members certified by PAM or ACEM are eligible for a 20% discount on the GBI Project Registration Fee [13].

1.2 GBI Components

1.2.1 Energy efficiency

The engineering service systems in healthcare facilities consume substantial amounts of energy and require high power levels due to strict service requirements, regulatory compliance, and the need for continuous operation [15]. Energy is essential in healthcare facilities for controlling indoor air temperature and humidity, heating water, operating ventilation systems, and supporting various clinical procedures [6]. Consequently, energy efficiency plays a major role in all green building rating systems, as it contributes significantly to the overall scoring point [12]. To support long-term sustainability, green buildings must prioritise environmental responsibility and energy efficiency that can be achieved through innovative design and technology [16]. Implementing energy-efficient technologies, such as light-emitting diode (LED) lighting, optimised Heating, Ventilation, and Air Conditioning (HVAC) systems, and automated building management systems, not only reduces energy consumption but also directly contributes to achieving higher GBI ratings while maintaining occupant comfort. By the same token, Silva et al. [17] stated that retrofitting measures, including improved insulation, window upgrades, and the adoption of green roofs, can lead to energy efficiency of up to 89%. Besides, the rapid advancement of digital technology has facilitated the development of smart building solutions that enable monitoring, management, and optimisation of building systems to enhance energy efficiency and sustainability. For instance, smart grid systems improve energy management by integrating renewable energy sources, storage solutions, and demand-side management technologies [10]. The implementation of systematic energy-saving measures in public hospitals resulted in significant reductions in both energy consumption and operational costs [12]. Enhancing the energy infrastructure of healthcare facilities not only improves efficiency but also helps reduce emissions. In line with this, Yu et al. [18] recommended installing photovoltaic systems at strategic locations within healthcare facilities to reduce dependence on conventional electricity sources and maximise geographical advantages [19]. This recommendation is particularly relevant to Malaysia, as the country receives high levels of solar irradiance throughout the year, averaging approximately 1643 KWh/m^2 annually.

1.2.2 Indoor environmental quality

Indoor environmental quality (IEQ) refers to the condition of a building's interior environment, encompassing factors such as indoor air quality, acoustic comfort, lighting, and thermal comfort that influence the occupant experience [5]. Good IEQ plays a crucial role in accelerating patient recovery, reducing stress, reducing hospital stays, and enhancing staff performance in care delivery [20]. HVAC systems are critical in healthcare facilities, as they ensure the comfort and safety of building occupants by providing appropriate thermal comfort, maintaining indoor environmental quality, regulating humidity and air circulation, and reducing the risk of airborne infections. In this context, thermal comfort modelling has become an essential strategy for enhancing IEQ in smart buildings, where environmental conditions are continuously monitored through sensors connected to digital platforms, such as smartphone applications and web-based storage systems [17]. Daylighting can be incorporated into areas such as waiting rooms, corridors, and staff rest zones, while artificial lighting is necessary to complement natural light [17]. It has been shown that effective lighting management can lead to improved patient recovery, reduced depression, shorter hospitalisation periods, improved sleep quality and circadian rhythm, pain relief, and increased staff adaptability to night-shift schedules [20]-[21]. These strategies directly align with the GBI criteria for indoor environmental quality and energy efficiency, enhancing occupant well-being and productivity while promoting sustainable building performance through optimised energy use and smart environmental control. Table 3 presents the GBI indoor environmental quality criteria and components.

Table 3. GBI indoor environmental quality criteria and components

GBI EQ Criteria	Description	Components
Air quality	Ensuring healthy and safe indoor air through ventilation, pollutant control, and CO_2 regulation.	Includes criteria such as minimum IAQ performance, recirculating air treatment, CO_2 monitoring, pollutant control, and mould prevention.
Thermal comfort	Optimising indoor temperature and humidity for occupant comfort, alongside efficient ventilation.	Covers design and controllability of thermal systems and air change effectiveness.
Lighting, visual and acoustic comfort	Enhancing occupants' well-being through optimized lighting (natural and artificial), views, and balanced acoustics.	Comprises daylighting, glare control, lighting levels, high-frequency lighting ballasts, external views, and internal noise levels.

1.2.3 Management and sustainable planning area

Healthcare facilities in Malaysia are located across diverse regions encompassing rural, urban, and suburban areas. Therefore, incorporating sustainable site design is essential to minimise the environmental impact on surrounding ecosystems [5]. For newly constructed healthcare facilities, GBI emphasises site planning, construction management, transportation, and design, whereas existing facilities focus on operational sustainability, transportation management, and mitigating urban heat island effects [22]-[23]. These approaches enable GBI to address both planning and operational stages of healthcare facilities, ensuring that sustainability is maintained throughout the facility’s lifecycle. Sustainable planning involves selecting sites that avoid environmentally protected areas, integrating landscaping with native or drought-resistant plants, managing stormwater with permeable surfaces, and creating well-planned green spaces to improve environmental performance and occupant well-being. Considering the site location is a crucial step in the initial phases of design, as the project's location directly influences its environmental impact [17]. Site planners must incorporate practical sustainable design strategies in green buildings to reduce negative impacts on the environment and surrounding communities [11]. Furthermore, aligning the project's design and orientation with the chosen site helps optimise natural ventilation, daylighting, and the local microclimate [17]. By implementing these strategies, healthcare facilities can meet GBI standards related to sustainable site planning. In addition, healthcare organisations must prioritise social responsibility in their strategic planning to promote sustainable healthcare practices. Ensuring patient satisfaction and the reliability of medical services is a primary focus in a green hospital [24]. Practical measures include designing accessible, strategically located parking areas, providing shaded walkways, and using environmentally friendly materials in patient-facing spaces to enhance comfort, safety, and the overall experience. To address the parking shortage, Setyowati et al. [24] proposed a Green Parking Building capable of accommodating up to 400 cars and 800 motorcycles. The building relates to the main buildings and other medical facilities through the flying corridor. Consequently, Hussain et al. [25] suggested that healthcare organisations should collaborate with patients, community groups, and other stakeholders to develop and implement sustainable practices that meet the specific needs of their local communities.

1.2.4 Material resources

Material resources include strategies to encourage the use of environmentally friendly materials sourced from sustainable or recycled sources, as well as effective construction waste management practices, including proper storage, collection, and reuse of recyclable materials and construction formwork [13]. One of the strategies is utilising green materials, which aligns with the Green Technology Master Plan 2030, which mandates that the healthcare sector utilise green building materials [5]. Materials that are durable or made from renewable sources are considered green. Green materials are environmentally sustainable as they help prevent negative environmental impacts [26]. Utilising environmentally friendly materials reduces building maintenance requirements without compromising the project's quality, while the use of renewable resources improves longevity, reduces carbon emissions, and reduces dependency on limited raw materials [11], [26]. In addition to green materials, effective waste management is also essential. Waste generated during healthcare operations is often hazardous and potentially harmful; therefore, it must be carefully segregated by category to ensure safe handling and proper disposal. In contrast, construction waste is typically non-hazardous and can be managed through on-site segregation and the reuse of raw materials through recycling [26]. Mohd Rahim et al. [11] stated that a specific area should be allocated for storing hazardous and recyclable materials to ensure safe management. Furthermore, GBI guidelines recommend selecting and using cleaning supplies that are low in volatile organic compounds, non-toxic, and environmentally friendly, thereby improving indoor air quality and overall sustainability in healthcare facilities.

1.2.5 Water efficiency

Hospitals consume large volumes of water due to their continuous operation, high patient occupancy, and a wide range of water-intensive processes, including sanitation, laundry, sterilisation, and cooling systems [6]. GBI prioritises water efficiency through measures such as water-saving fittings, water recycling, and rainwater harvesting [13]. A rainwater harvesting system allows the collection and storage of rooftop runoff from hospital buildings for applications such as landscape irrigation, toilet flushing, plant watering, cleaning purposes, and emergency supply [5]. In Malaysia, the installation of rainwater harvesting systems at Hospital Sultanah Maliha, Langkawi, Hospital Slim River, and Hospital Pulau Pinang in 2018 reflects a strong commitment to water conservation. Although these approaches show compliance to GBI standards, further innovations such as the Hydroponic Green Roof System (HGRS) could enhance water efficiency by combining stormwater management with alternative water reuse. The HGRS was developed to reduce urban runoff while simultaneously treating and reusing collected water streams, thereby contributing to sustainable water management in green buildings. The system automatically processes greywater during dry periods and manages rainwater collection and greywater treatment during rainy seasons [27]-[28]. Thus, integrating conventional GBI measures with innovations like HGRS could create a more resilient water management strategy for healthcare facilities.

1.2.6 Innovation

Innovation is crucial for advancing sustainable healthcare facilities by integrating innovative approaches that surpass conventional building practices. Smart healthcare facilities incorporate advanced technologies and integrated management systems to increase patient care, optimise operational efficiency, and improve overall building performance [17]. One of the innovative approaches is the implementation of the industrialised building system, which reduces labour dependency, accelerates construction, and improves on-site quality [11]. Complementing this, digital innovation can further enhance the efficiency of green buildings in mitigating the impacts of climate change [10], [29]. Key components of digital transformation include Building Information Modelling (BIM) and Internet of Things (IoT). BIM enables the evaluation of life-cycle carbon emissions and detailed calculations of energy consumption for HVAC, lighting, water distribution, and equipment during the healthcare building's operational phase [17]. Meanwhile, IoT uses smart sensors to monitor temperature, indoor air quality, and water consumption in real time, enabling healthcare facilities to optimise resource utilisation and improve overall building sustainability.

2. Materials and Methods

This study assesses the efficacy of the GBI in enhancing sustainability in healthcare facilities. To identify the current sustainability practices in health facilities, an extensive literature review was conducted. To strengthen the qualitative element of this research, data were collected through semi-structured interviews with key stakeholders from the MoH and the PWDM, including engineers and an architect involved in planning, constructing, and managing healthcare facilities. Subsequently, the collected data were analysed through thematic content analysis, a methodical approach for identifying significant patterns and insights. The methodology for this study is illustrated in Figure 1.

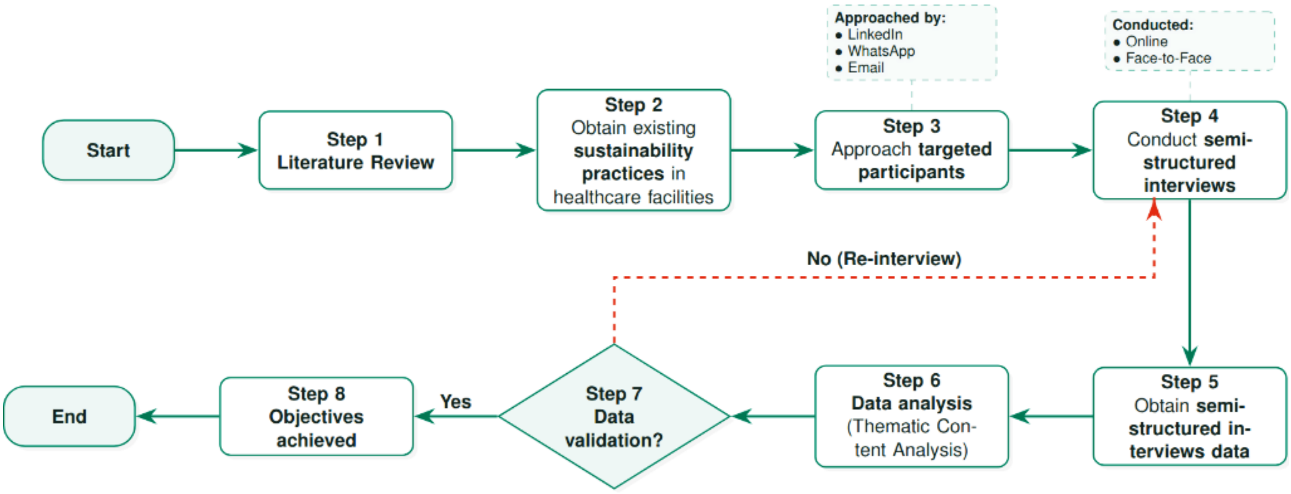

Figure 1.Flowchart of the research methodology

2.1 Sampling Procedure

To assess the efficacy of the GBI in advancing sustainability in healthcare facilities, purposive sampling was employed during the participant selection phase to ensure data validity [9]. Participants should have at least 5 years of industry experience. Subsequently, semi-structured interviews with the selected participants were conducted to gather their insights from their experiences and professional perspectives. Table 4 outlines the specific inclusion criteria applied in the purposive sampling method used for participant selection.

Table 4. Criteria for participant selection

Experts	Description
Engineers from Ministry of Health	Represents Healthcare Facilities Management Department.
Government Representatives	Government officer from the relevant department, specifically the Public Works Department in Malaysia, holding position of J41 grade and above.
Professionals involved in designing using GBI Principles	Professionals specializing in design with a focus on GBI principles constitute another key participant group. This group includes architects, engineers, and experts involved in the planning and implementation of sustainable features within healthcare facility projects.
Professionals in charge of sustainability initiatives	Individuals responsible for overseeing sustainability initiatives, such as facility managers or sustainability coordinators, offer a specialized perspective on the effectiveness of GBI in achieving sustainability goals within the operational context of health facilities.

2.2 Semi-Structured Interview

This study gathers qualitative data through semi-structured interviews with multidisciplinary experts in healthcare sustainability and green building practices. Semi-structured interviews enable participants to share diverse perspectives, often leading to new findings based on what they personally consider important [30]. Besides, Saad et al. [31] stated that semi-structured interviews provide the researcher with substantial information by clarifying, interpreting, and exploring participants' perspectives and real-life experiences. The sample size of five expert participants from the Ministry of Health and the Public Works Department was determined following established qualitative research guidelines for expert interviews and was validated by previous studies confirming that the number of experts is considered sufficient, as it falls within the suggested range of one to ten experts [32]. After potential participants were identified, they were approached via various communication methods including LinkedIn, Email, and WhatsApp. In accordance with ethical standards, participants were provided with informed consent forms before participating in interviews. These documents clearly outlined the study's purpose, confidentiality assurances, and participants' rights. Upon obtaining their consent to participate, semi-structured interviews were conducted either virtually via Microsoft Teams or face-to-face, depending on the participants' availability and preferred time slots. Interviews were conducted not only during standard business hours but also on weekends or in the evenings, when necessary. Upon agreement, the sessions were recorded and transcribed to facilitate analysis and ensure accurate capture of participants' insights. The interview began with a brief overview outlining the aim of the session and the key themes to be addressed. The main interview question was then introduced, followed by supplementary questions that were adjusted based on the participants' responses. Each session lasted approximately 20-30 minutes. After the data were obtained, they were analysed using thematic content analysis to identify key patterns, themes, and insights relevant to the research objectives.

2.3 Thematic Content Analysis

After the data from semi-structured interviews were obtained, they were analysed using thematic content analysis to identify emerging themes and patterns that highlight the participants' perceptions and experiences [33]-[34]. Thematic analysis was chosen since it is a suitable strategy for interpreting and understanding the qualitative data collected [31], [34]. Furthermore, thematic analysis is recognised as a primary method in qualitative research. It provides researchers with essential skills to implement various qualitative research methodologies [34]. This study followed Braun & Clarke's thematic analysis framework [34]. The first step in conducting thematic analysis involved familiarising the researcher with the data by thoroughly reading the interview transcripts and replaying the recordings multiple times to ensure a comprehensive understanding of the participants' responses. Next, the key elements of the data that aligned with the research objectives were identified to generate the initial codes. Afterwards, the codes were grouped into broader potential themes by identifying patterns and relationships in the coded data. This process involved examining how different codes could be appropriately categorised under major themes. Then, the themes were reviewed and refined by checking their relevance to the coded data and the entire dataset. Lastly, the themes were named and defined to accurately reflect the main ideas of the data they represented. This ensured that each theme conveyed a specific and perceptive way in which the GBI contributes to enhancing sustainability in healthcare facilities. Table 5 illustrates the coding structure for thematic content analysis.

Table 5. Thematic analysis coding structure

Phase	Process Step	Action Taken	Output Generated	Description (Example)
1	Familiarisation	The data were familiarised through multiple readings of transcripts and replays of recordings	Comprehensive data understanding	Identified GBI implementation challenges mentioned by MoH/ PWDM experts
2	Generating Initial Codes	Key elements aligned with research objectives was identified	Initial codes generated	"Budget constraints delay certification"; "EE criteria saved 25% energy"
3	Searching for Themes	Codes were grouped into potential themes	Broad themes identified	"Implementation Barriers/Enablers"; "EE/EQ Effectiveness"
4	Reviewing Themes	Theme relevance to the coded data and full dataset was reviewed	Themes refined	Theme 1: "GBI Implementation → Sustainability Outcomes" validated
5	Defining/Naming Themes	Themes was named to reflect main data ideas	3 Final Emergent Themes defined	The Implementation of GBI Influenced the Sustainability Outcomes of Health Facilities", " Overall Effectiveness of GBI ", and " Measurable Impacts or Benefits Have Been Realized as a Result of Implementing GBI "
6	Producing Report	Themes convey GBI's sustainability contribution	Results discussed	Themes linked to research objectives (GBI → healthcare sustainability)

3. Results and Discussion

3.1 Overview of Semi-Structured Interview

The interview sessions were conducted via online platforms and face-to-face, depending on the participants' preferences and availability. A total of five participants were involved in this study. Of the five respondents, four participated via online platforms, while one attended a face-to-face interview. The online interviews were conducted via Zoom and Google Meet. The interview sessions conducted via Microsoft Teams were recorded using its built-in recording function, while the session conducted via Google Meet was captured using the screen recording feature on a Microsoft laptop. The face-to-face interview was recorded using the voice notes feature on a smartphone. Each interview session lasted approximately 20–30 minutes. Details of the expert participants are presented in Table 6.

The first participant, abbreviated as R1, is a civil engineer with the Public Works Department of Malaysia and is registered with the Board of Engineers Malaysia. The second participant, R2, is a Senior Engineer from the Public Works Department of Malaysia with more than 15 years' experience in the construction industry. The third respondent, R3, is a senior architect registered with the Board of Architects Malaysia. The fourth participant, R4, is an engineer who holds the position of a Superintendent Civil Engineer and is involved with healthcare facility construction. Finally, the fifth practitioner is the operations engineer, who is an engineer from the Ministry of Health representing the Healthcare Facilities Management Department. To analyse the qualitative data from semi-structured interviews, the transcripts were imported into qualitative analysis software for systematic analysis. Three (3) primary themes emerged, aligned with the previously formulated semi-structured interview questions. These themes were "The Implementation of GBI Influenced the Sustainability Outcomes of Health Facilities", "Overall Effectiveness of GBI", and "Measurable Impacts or Benefits Have Been Realised as a Result of Implementing GBI", which address the evaluation of the GBI. The findings from the expert interviews are presented in Figures 2-4. The initial number represents the respondent, while the second number refers to the initial quotation from the original transcript, formatted as 1:1 (Respondent: Quotation).

Table 6. Detail of the participants

Participant references	Designation	Years of experience (Year)
R1	Engineer	5
R2	Senior engineer	>15
R3	Senior architect	>15
R4	Superintendent civil engineer	>15
R5	Operations engineer	10

3.2 Analysis of Semi-Structured Interview

3.2.1 Insights on implementing GBI standards in Malaysian healthcare facilities

The first question asked the respondent about their experience and insights into implementing the GBI standards in healthcare facilities in Malaysia. The response to this question is presented in Table 7. The responses from all participants aligned with expectations, as each respondent had been carefully pre-selected during the screening stage. An expert form was distributed via WhatsApp as part of the selection process to ensure that all respondents possessed the necessary qualifications and experience to provide valuable insights for this study. The participants' answers clearly reflect their extensive experience in implementing GBI standards in healthcare facilities across Malaysia. This not only confirms their eligibility but also underscores their expertise in this specialised field, making them highly suitable to serve on the expert panel for this study.

Table 7. Expert experience and insights regarding implementing GBI standards in health facilities

Question	Expert references	References response
Could you share your experience and insights regarding the implementation of GBI standards in healthcare facility in Malaysia?	R1	Generally, the Green Building Index highlights how project management relates to our environment. We can see that the first government hospital to be awarded the Green Building Index is Cyberjaya Hospital, which has been awarded platinum. Implementing GBI standards has been a significant step towards sustainability in our health facilities.
	R2	Implementing GBI standards in a healthcare facility has been immensely rewarding but also challenging. Healthcare facilities have unique needs, especially concerning hygiene and patient care
	R3	Implementing GBI standards in health facilities been a comprehensive and detailed process. We need to ensure that the design not only meets functional and aesthetic requirements but also aligns with GBI standards.
	R4	The GBI standards provide a comprehensive framework that ensures buildings are designed and operated in a sustainable manner. One of the significant insights we've gained is the importance of integrating these standards from the very beginning of the design process. This holistic approach helps in addressing sustainability goals more effectively.
	R5	Green buildings involve significant costs whether converting an old hospital or constructing a new one. Although the expenses are substantial, Green Buildings provide numerous benefits, including energy savings, environmental advantages, and a more comfortable workplace.

3.2.2 Existing sustainability initiatives in healthcare facilities

The second interview question (Q2) examined the sustainability initiatives currently being implemented in the respective healthcare facilities, as presented in Table 8. From the interviews, it was found that the sustainability initiatives currently implemented within health facilities encompass energy efficiency measures (e.g., energy-efficient lighting, ACMV systems, use of solar power), water efficiency practices (e.g., rainwater harvesting), improved indoor environmental quality (e.g. low-VOC materials, natural ventilation, daylight optimisation), the use of sustainable building materials, effective waste management, and the responsible management of material resources (e.g., eco-friendly building orientation, EV and bicycle parking facilities). These initiatives reflect a systematic approach to sustainability in healthcare facilities and align with GBI criteria. All five experts (R1-R5) consistently highlight energy-saving initiatives as their core sustainability focus, with widespread implementation of energy-efficient lighting (LEDs, advanced bulbs), ACMV, and motion sensors across facilities. As hospital buildings are the primary energy consumers among government facilities in Malaysia, with ACMV alone accounting for approximately 50% of consumption, implementing energy-saving strategies is essential to reduce annual operational costs and conserve environmental resources [12]. In addition, this prioritisation reflects the high weighting of energy efficiency under the GBI NRNC and NRBC Hospital criteria, where it accounts for the largest share of scoring points [14].

Table 8. List of sustainability initiatives that are currently being implemented within the healthcare facility.

Question	Expert references	Expert response
Can you describe the sustainability initiatives that are currently being implemented within your healthcare facility?	R1	For Sri Iskandar Hospital, we have a comprehensive approach to sustainability that includes energy-efficient lighting and Air Conditioning and Mechanical Ventilation (ACMV) systems, water conservation measures, waste management strategies, and the use of eco-friendly materials in construction and maintenance.
	R2	Firstly, we installed motion sensors in appropriate locations and implemented an ACMV system to reduce energy consumption. We also have a rainwater harvesting system to minimize water wastage and promote water conservation during construction. Additionally, we used eco-friendly building materials such as eco-glass and designed the hospital layout to enhance natural ventilation.
	R3	The orientation of our buildings is carefully planned to maximize natural light and minimize heat gain. We prioritize the use of eco-friendly materials, and we installed advanced, energy saving light bulbs.
	R4	Firstly, we have installed energy-efficient lighting systems and ACMV systems that significantly reduce our energy consumption. Secondly, we have implemented a rainwater harvesting system that helps in reducing our dependency on the municipal water supply.
	R5	We focus on energy-saving initiatives, such as replacing conventional lights with LEDs. Additionally, we utilise solar power and implement food waste management, turning waste into compost. We also practice rainwater harvesting. Furthermore, we are increasing the number of electric vehicle (EV) car parking spaces and bicycle parking facilities. Lastly, we're using low-VOC materials for better indoor air quality, which is crucial for a healthcare facility.

Aside from energy efficiency, the experts emphasise a comprehensive approach to sustainability in healthcare facilities, incorporating water conservation, waste management, and improvements in indoor environmental quality as critical components. R2, R4, and R5 adopt rainwater harvesting systems (RWHS) to promote sustainable water management and reduce municipal water dependency, while only R5 and R1 incorporate waste management practices such as waste-to-compost. Previous studies have demonstrated that water conservation practices in green hospitals can reduce overall water consumption by approximately 20–30% [6]. By adopting RWHS as one of its key sustainability measures, Hospital Sultanah Maliha, Langkawi became the first government hospital in Malaysia and the first hospital globally to achieve the U.S. Green Building Council LEED v4 Operations & Maintenance Gold-level certification in 2020 [5]. The effective utilisation of sustainable materials such as eco-glass, low-VOC paints, and optimum building orientation for natural ventilation and daylighting demonstrates a commitment to improved indoor environmental quality. These selections not only reduce hazardous indoor pollutants and enhance air quality but also create a healthier, more comfortable healing environment for patients and staff. Studies indicate that employing sustainable materials and design techniques minimises the risk of airborne infection, improves respiratory health, reduces patient stress, and expedites recovery times, thereby promoting overall well-being and operational efficiency in healthcare environments [35]. By focusing on energy-efficient technologies, water conservation measures, optimising indoor air quality, and promoting responsible management of material resources, health facilities are not only reducing their environmental impact but also creating healthier and more sustainable environments for patients, staff, and the community. This further justifies the views from Ministry of Health that green building awareness emphasises the importance of green innovation and comfort for all. It brings ecological benefits that transform healthcare buildings into more environmentally friendly and comfortable spaces and can increase productivity among building occupants/users [5].

3.2.3 Implementation of GBI affected health facilities' sustainability outcomes in Malaysia

Question 3 (Q3) examines how the implementation of GBI influenced the sustainability outcomes of health facilities. Q3, Q4, and Q5 will be presented as a network analysis. Figure 2 demonstrates the linkage between responses regarding the implementation of GBI and the sustainability outcomes of health facilities. The code used in the study is that “1:1” refers to (respondent 1: quotation 1), hence “2:1” (respondent 2: quotation 1), “3:1” (respondent 3: quotation 1), followed by “4:1” (respondent 4: quotation 1) and “5:1” (respondent 5: quotation 1).

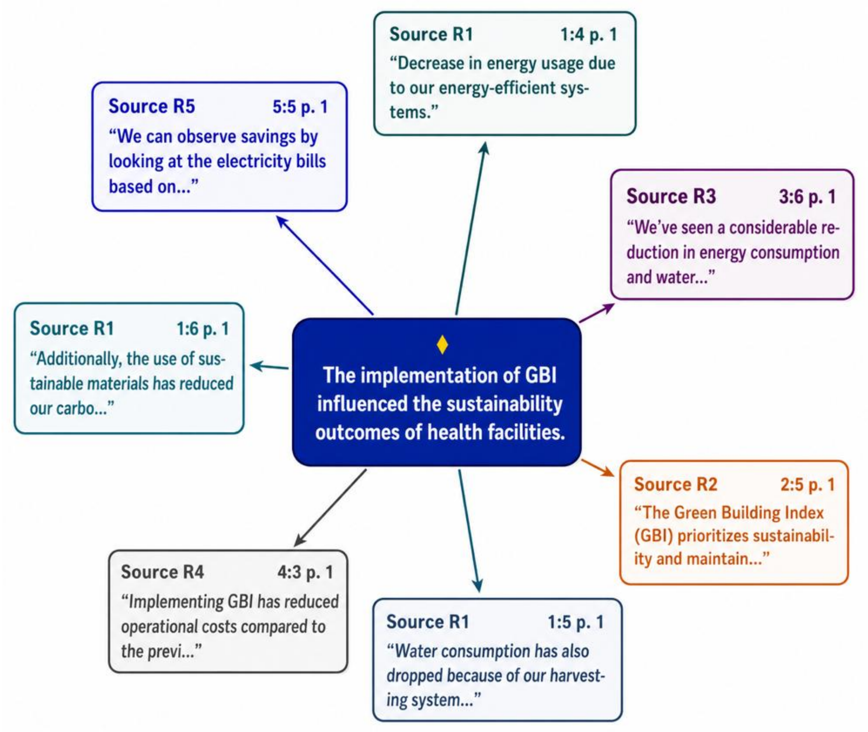

Figure 2. Experts' perspectives on how GBI implementation impacts the sustainability of health facilities in Malaysia

Based on Figure 2, most experts agreed that implementing GBI standards, such as energy and water efficiency, material resources, and indoor environmental quality, can influence the sustainability outcomes of health facilities in Malaysia. All five experts (R1-R5) similarly indicated that substantial energy savings resulting from GBI adoption are primarily achieved through efficient ACMV systems and LED lighting. (R5, Q5) noted "*Under the GBI, from a technical perspective, we can observe savings by looking at the electricity bills based on kilowatt-hour usage. For example, costs can range from RM50,000 to RM60,000. Technically, if we calculate based on kilowatt-hour usage, we can see the difference in savings, primarily due to more efficient air conditioning systems, which are the largest contributors to energy consumption"*. This statement is aligned with a Chinese hospital case study which demonstrated hospital HVAC upgrades, including air conditioning, hot water systems, and intelligent controls, resulting in annual savings up to 1,845,586 MWh, with maximum potential of 784,035 MWh (42%) from air conditioning and refrigeration system upgrades optimised for local climate characteristics [18]. This international benchmark is corroborated by Malaysian evidence, in which Abd Rahman et al. prioritised chiller retrofitting techniques as a pilot project due to their potential to generate the highest energy savings for hospitals, based on energy audit findings [12]. (R2: Q5) and (R4: Q3) also converge on GBI's cost advantages. R2 highlights reduced maintenance and operational costs for MOH as the end user. This is compatible with Mehra & Sharma, who stated that sustainable healthcare frameworks such as circular practices, integrated design, and effective waste management yield operational cost reductions, increased profitability, enhanced patient satisfaction, and improved service affordability [36]. This view is further supported by (R4: Q3), who observed, "*Based on my observations, implementing GBI has reduced operational costs compared to the previous system. Moreover, the hospital environment has improved significantly. For example, older hospitals that did not incorporate GBI are less comfortable, while newer hospitals that utilise GBI are more comfortable due to better natural ventilation and lighting.*" These findings align with evidence that green hospitals enhance occupants' quality of life, decrease staff absenteeism, and improve comfort through aesthetic features [6]. Moreover, R4's ventilation/lighting improvements directly correspond to the Indoor Environmental Quality (EQ) criteria, contributing to the maximum 21 EQ points for both NRNC and NREB, the second-highest total. These multi-perspective findings collectively validate GBI's comprehensive sustainability impact.

Additionally, R1 and R3 highlighted that GBI-driven water efficiency through rainwater harvesting and recycling systems directly supports the Water Efficiency (WE) component of the GBI framework. As noted by (R3: Q6) "*The GBI framework has significantly influenced sustainability outcomes by setting clear guidelines and benchmarks. For instance, at Sri Iskandar Hospital, we've seen a considerable reduction in energy consumption and water usage with specific improvements such as lower energy demand from efficient systems and reduced water consumption through rainwater harvesting*." Another expert (R1: Q5) supported this view, noting that "*Water consumption has also dropped because of our harvesting system and recycling efforts during construction*". These findings align with prior studies showing that green-certified healthcare facilities frequently attain resource efficiencies and improved environmental performance [6], [17], [36]. Furthermore, (R3: Q6) noted that integrating green spaces and gardens not only enhanced aesthetics but also improved the well-being of patients and staff. Such elements provide access to natural views that can reduce stress, elevate mood, and create a more therapeutic environment for occupants [35]. Lastly, (R1:Q6) highlighted, "*The use of sustainable materials has reduced carbon footprint and improved indoor air quality*", which is consistent with global evidence that low-emission, non-toxic building products can significantly reduce healthcare-related greenhouse gas emissions and exposure to indoor pollutants [17]. Based on the implementation of the GBI standard, these environmentally friendly practices can help reduce resource consumption, protect the environment, promote sustainable development, and enhance patient and staff well-being [5]. Concern for the environment and the future of the earth has become a global priority. In recent years, an increasing number of construction projects have shifted toward sustainability, with healthcare facilities progressively adopting greener design and operational approaches. Without significant changes, current buildings are unlikely to achieve long-term sustainability [1].

3.2.4 The effectiveness of GBI in promoting healthcare facility sustainability

In the following questions, experts were asked about the overall effectiveness of GBI in promoting sustainability in healthcare facilities. All the experts agreed that GBI is effective in promoting healthcare facility sustainability. The responses provided by the experts are exhibited in Figure 3. Based on Figure 3, the experts consistently emphasised the multifaceted benefits of the GBI in healthcare facilities, highlighting its environmental, economic, and occupant health advantages. Upon review, it is observable that the participants (R1: Q7, R2: Q6, R3: Q7, R4: Q4, and R5: Q6) provided similar responses. One of the participants (R1: Q7) stated, "GBI has significantly improved sustainability in healthcare facilities*. We have minimised our environmental footprint and realised cost savings through reduced utility bills and maintenance expenses. Moreover, occupants benefit from better indoor air quality and a healthier environment, which enhances their productivity and well-being*". Similarly, (R2, Q6) noted "*From my perspective, the GBI has proven to be highly effective. It has led to lower emissions and better resource management, benefiting the environment. Economically, while the initial investment may be higher, the long-term savings in energy and water costs, along with reduced waste management expenses, make it a cost-effective choice. For occupant health and well-being, incorporating non-toxic materials, improving air quality, and natural lighting have created healthier, more comfortable spaces for patients and staff, which is crucial in healthcare settings*. Past studies have indicated that green rating tools such as GBI drive both environmental benefits and improvements in occupant health [9], [6]. These perceptions triangulate precisely with Malaysian GBI-certified hospitals: Cyberjaya Hospital (Platinum) enhanced patient recovery through daylighting and IAQ improvements while cutting operating costs 15-20% [37]; Duchess of Kent Hospital, Sandakan achieved 50% electricity savings via solar tubes (EE) [5]; Pantai Hospital Laguna Merbok reduced 20% CO_2 emissions and 44% water use alongside 15-20% operating cost savings [38]; and Hospital Sultanah Maliha, Langkawi improved energy efficiency through ACMV retrofitting while enhancing indoor air quality [5].

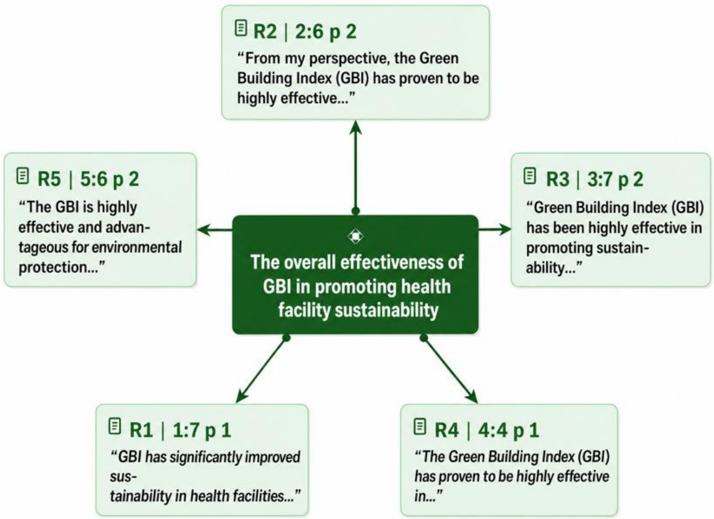

Figure 3. The overall effectiveness of GBI in promoting sustainability in healthcare facilities

In concurrence with that, (R3, Q7) mentioned, "*The GBI has been highly effective in promoting sustainability in health facilities. Environmentally, we've witnessed notable reductions in energy and water use, which are crucial to reducing our carbon footprint. Economically, although there's a higher initial investment in green technologies and practices, substantial long-term savings in operational costs are evident. Regarding occupant health and well-being, the enhancements in air quality, natural lighting, and the incorporation of green spaces have created environments more conducive to healing and have notably improved the overall work environment for staff*". In line with this consensus, both (R4: Q4) and (R5: Q6) emphasised the effectiveness of the GBI, stating that it 'has proven to be highly effective in promoting environmental sustainability, cost savings, and enhancing the well-being of building occupants'. Adapting such systems to prioritise health-focused design could further accelerate the creation of healthier built environments [39]. Overall, the experts agree that GBI is effective in promoting sustainability in healthcare facilities. This statement is consistent with , who stated that green building is designed to preserve resources at the highest level throughout its life cycle, including land, energy, materials, and water, thus reducing pollution, saving the environment, cost and providing individuals with comfort and a healthy living space [40]. Implementing green buildings can reduce natural resource consumption and carbon emissions, thereby mitigating the impact of global warming [8].

3.2.5 Measurable Impacts of Implementing GBI

Based on Figure 4 and the respondents' answers, they provided numerous insights, including those from R1 (Q39), R2 (Q5), R3 (Q5), R4 (Q5), and R5 (Q5). They firmly believe that implementing GBI has led to significant, measurable benefits, including reduced operational costs through improved energy and water efficiency, enhanced indoor air quality, better environmental protection, and increased comfort for building occupants. The detailed responses regarding the measurable impacts or benefits of implementing GBI are presented in Table 9.

Table 9. Reported measurable benefits of implementing the GBI in Healthcare Facilities

Expert References	Feedback response
R1	We've noted various tangible benefits, including decreased energy and water usage, reduced operating expenses, enhanced indoor environmental quality, higher occupant satisfaction, and lower maintenance costs. These advantages contribute to a more sustainable future and improve the overall quality of healthcare delivery.
R2	Adopting GBI standards has yielded significant measurable impacts. For example, there has been a noticeable reduction in utility bills, with some facilities reporting savings on energy costs. Water consumption has also decreased due to the use of efficient fixtures and rainwater harvesting systems. Additionally, the enhanced indoor air quality has resulted in better patient outcomes and a decrease in instances of hospital-acquired infections.
R3	Energy consumption has decreased, alongside a reduction in water usage. Moreover, there's been an improvement in indoor air quality, resulting in fewer health issues related to poor air quality. Patients now experience faster recovery times due to the improved indoor environment, and staff morale has seen an increase. These changes not only enhance the quality of care but also improve the overall efficiency and sustainability of the healthcare facilities.
R4	The measurable impact we can see is from the reduction from operational costs due to enhanced energy and water efficiency.
R5	In my view and based on my observations, the effectiveness of the GBI project can be seen in how it benefits the occupants. For example, issues like building syndrome, where workers feel dizzy and drowsy due to poor ventilation, this can be addressed through the implementation of GBI. This includes choosing safe paints and ensuring natural lighting and ventilation. Additionally, GBI significantly reduces operational costs and helps protect the environment.

The experts consistently emphasised the advantages of implementing GBI in terms of practical performance enhancements rather than abstract perceptions. Collectively, R1, R2, and R3 observed reductions in energy and water consumption, which aligns with empirical studies that demonstrated green and energy-efficient hospital buildings can significantly lower electricity demand and water usage through strategies such as optimised HVAC systems [17] , efficient lighting [6], and water-saving fixtures [41]. The connection between expert evidence and previous findings suggests that GBI implementation effectively addresses the critical resource-constrained areas highlighted in the GBI literature, especially in energy and water management.

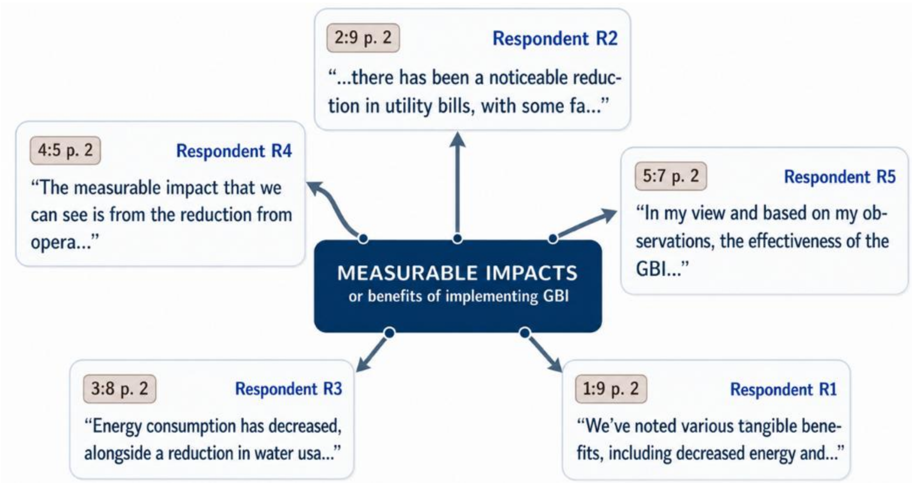

Figure 4. Measurable impacts of implementing GBI

Beyond resource efficiency, several experts linked GBI to measurable financial and health outcomes, indicating that the benefits are multidimensional rather than purely environmental. R2, R4, and R5 highlighted substantial decreases in utility expenses and overall operational costs following the GBI implementation. This is consistent with existing studies that report green healthcare facilities achieve long-term cost savings through reduced energy and water use, optimised maintenance, and improved infrastructure performance [6], [42]. In contrast to other experts who prioritised energy and cost efficiency, R5's approach focuses on the social aspect of GBI, highlighting its importance in safeguarding occupants from building-related symptoms due to poor ventilation. R5's observations validate GBI EQ standards aimed at minimising building-related symptoms through recirculating air treatment, mould prevention, and daylighting, aligning with research that such interventions in healthcare facilities reduce occupant complaints and enhance health outcomes [[14], [35]. Green hospitals offer both quantifiable and intangible advantages. Quantifiable benefits include energy and water conservation, which reduce utility costs and support economic savings. Intangible benefits include enhanced quality of life for occupants, increased comfort in well-designed, aesthetically pleasing spaces, and improved staff morale [6]. Together, these benefits show how GBI standards contribute to a more sustainable, efficient, and health-promoting healthcare environment. Taken as a whole, these findings indicate that GBI provides integrated environmental (resource efficiency), economic (cost savings), and social (health and well-being) advantages, aligning with the triple-bottom-line framework for sustainable healthcare.

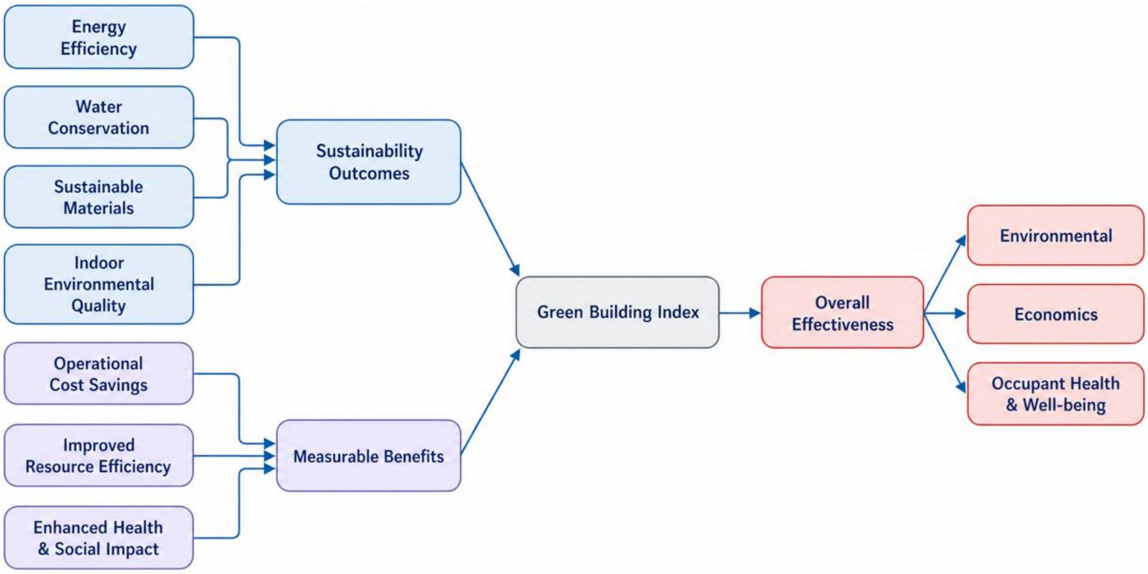

Figure 5. Conceptual Framework of GBI implementation in healthcare facility sustainability

Table 10. Thematic analysis findings

Theme	Sub-themes	Sub-Factors
GBI's Influence on Sustainability Outcomes	Energy Efficiency Indoor Environmental Quality Water Efficiency Conservation Sustainable Materials	– Efficient ACMV/HVAC and LED lighting – Chiller retrofitting – Natural ventilation and lighting – Integration of green spaces/gardens with natural views – Rainwater harvesting/recycling systems – Materials sourced from sustainable or recycled sources – Use of durable or renewable materials
GBI's Overall Effectiveness	Environmental Economics Occupant Health & Well-Being	– Reduced energy/water usage and carbon footprint – Lower emissions and optimized resource management – Minimized environmental footprint across lifecycle – Long-term operational cost savings – Reduced utility bills, maintenance, and waste expenses – Cost-effective return on investment – Enhanced indoor air quality (IAQ), natural lighting, non-toxic materials – Healthier spaces supporting patient recovery and staff productivity – Improved comfort, reduced stress, healing environments
Measurable Impacts or Benefits Have Been Realized	Operational Cost Savings Improved Resource Efficiency Enhanced Health & Social Impact	– Substantial decreases in utility expenses – Overall operational cost savings – Long-term Return of Investment through energy/water reductions – Reduced energy consumption – Lower water usage – Quantifiable electricity demand and water reductions in resource-constrained areas – Reduced building-related symptoms – Minimized occupant complaints – Enhanced health outcomes

3.3 Synthesis of Thematic Analysis

This synthesis process systematically grouped related codes into three main themes that incorporate stakeholder opinions on GBI implementation challenges, contributing factors, and its effectiveness across core sustainability parameters. Table 10 presents the thematic analysis, providing a summarised and organised view of these themes and associated codes, supported by expert statements, while Figure 5 shows a conceptual framework for GBI implementation. The conceptual framework allows a clearer understanding of how GBI influences sustainability in healthcare facilities by highlighting key areas such as energy efficiency, indoor environmental quality, and resource management.

4. Conclusions

The primary purpose of this study is to identify existing sustainability practices in healthcare facilities and evaluate the effectiveness of the Green Building Index in enhancing their sustainability. Semi-structured interviews were conducted with experts, including construction engineers, architects, and facility managers, from the Ministry of Health and the Public Works Department of Malaysia. Subsequently, the collected data were analysed using thematic content analysis to identify themes and insights. From the analysis, three primary themes emerged: the implementation of GBI influenced the Sustainability Outcomes of health facilities; the overall effectiveness of GBI; and Measurable Impacts or Benefits Have Been Realised as a Result of implementing GBI. This study advances green building certification theory through three (3) emergent themes that demonstrate how national standards such as GBI deliver measurable sustainability outcomes in public healthcare facilities. The findings highlight practical advantages of GBI implementation in public hospitals, including improved resource efficiency through energy and water conservation, reduced operational and maintenance costs, and enhanced indoor environmental quality that supports patient recovery, staff well-being, and sustainable infrastructure aligned with SDG 11 targets. Beyond the Malaysian context, this framework offers actionable insights for upper-middle-income countries seeking to incorporate green building standards into public healthcare infrastructure, given similar socioeconomic and environmental conditions. The results provide practical guidance for policymakers, facility managers, and architects to improve design, construction, and operational strategies, thereby promoting environmentally responsible and resource-efficient healthcare practices.

Despite achieving its objectives, this study has limitations. These limitations primarily arise from professional restrictions and the limited availability of experienced stakeholders within health facilities. This study relied on the participation of engineers and architects from the MoH and the PWDM, who are directly involved in planning, constructing, and managing healthcare facilities, as they were the most suitable respondents given their role in implementing and managing sustainability practices. However, the relatively small number of experienced respondents may have limited the range of insights gathered. Furthermore, this study was conducted exclusively in public-sector health facilities, which may limit the applicability of the findings to private healthcare settings. Based on the study's findings, several recommendations can be made to further evaluate the effectiveness of the green building index in enhancing the sustainability of health facilities. Firstly, the study's data collection could be enhanced by increasing the number of interview sessions to obtain more comprehensive and valuable insights. Next, employing additional methods, such as surveys or a mixed-methods approach, could yield a broader, more robust dataset. Lastly, expanding the research to include the private healthcare sector would help refine and broaden the current findings, thereby providing a more comprehensive understanding of the GBI's effectiveness across different types of health facilities.

Acknowledgement

The authors would like to express sincere gratitude to the Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah and the participants for generously contributing their time, insights, and expertise, which were invaluable to the successful completion of this research. This study was not supported by any grants from funding bodies in the public, private, or not-for-profit sectors.

Declaration of Competing Interests

All authors certify that they have no affiliations with any organisation with a financial or non-financial interest in the subject matter of this manuscript.

Credit Authorship Contribution Statement

Anis Syahmina Mohd Soleh: Writing-original draft; Data curation)
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Nurhidayah Binti Azmy (Visualisation; Editing)
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Norhaliza Wahab (Writing- review & editing)

Availability of Data and Materials

The data supporting this study's findings are available on request from the corresponding author.

Ethics Statement

Not applicable

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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