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Crafting Sustainable Healthcare Environments Using Green Building Ratings for Aging Societies

Yijia Miao [1], Doris Sau Fung Yu [2], Weiguang Tan [3], Sunnie Sing Yeung Lau [4], Stephen Siu Yu Lau [1,5] and Yiqi Tao [5,6,7,*]

[1] Faculty of Architecture, The University of Hong Kong, Hong Kong 999077, China; miaoyj@connect.hku.hk (Y.M.); ssylau@hku.hk (S.S.Y.L.)
[2] School of Nursing, The University of Hong Kong, Hong Kong 999077, China; dyu1@hku.hk
[3] Landsea Group Co., Ltd., Shenzhen 518056, China; tanweiguang@landsea.com
[4] School of Architecture, The Chinese University of Hong Kong, Hong Kong 999077, China; slau@cuhk.edu.hk
[5] Center for Human-Oriented Environment and Sustainable Design, Shenzhen University, Shenzhen 518060, China
[6] School of Architecture and Urban Planning, Shenzhen University, Shenzhen 518060, China
[7] CHESD, Shenzhen Key Laboratory of Architecture for Health & Well-Being (in Preparation), Shenzhen University, Shenzhen 518060, China
* Correspondence: taoyiqi@szu.edu.cn

Abstract: As global demographics shift towards an aging population, the need for sustainable healthcare environments becomes increasingly critical. This study addresses this imperative by examining the application of Green Building Rating Systems (GBRSs) in healthcare facilities, such as hospitals and nursing homes. It emphasizes the urgency of developing environmental assessment criteria specifically tailored for healthcare buildings to meet the challenges posed by an aging society. The research involved an extensive examination of a wide array of sustainability indicators from the literature, coupled with a Delphi survey involving a panel of 15 experts to guide the rigorous selection and validation process. The Analytic Hierarchy Process (AHP) was then applied to assign relative weights to each indicator, culminating in a specialized evaluative framework that includes 54 sustainability indicators across various dimensions. This framework is designed to support decision-making in the design process of new or retrofitted healthcare buildings, offering a comprehensive tool for creating sustainable healthcare settings. The findings and proposed framework aim to act as a reference for future development, supporting the creation of sustainable healthcare settings in Hong Kong and potentially informing similar efforts in other urban areas with similar challenges.

Keywords: healthcare facilities; green building; rating system; BEAM plus; analytic hierarchy process

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1. Introduction

Healthcare buildings represent more than architectural landmarks. They serve as the vital hubs of community wellbeing, embodying the principles of health, wellness, and societal welfare [1]. The World Health Organization defines healthcare as services for individuals and populations to promote, maintain, and restore health [2]. These institutions, ranging from hospitals and medical centers to long-term care establishments like nursing homes, play a pivotal role in sustaining the health and welfare of communities, thus significantly impacting public health. Globally, an aging population is a widespread phenomenon [3], necessitating a shift towards sustainable healthcare infrastructure to support this demographic trend. This international emphasis on green building practices within healthcare environments reflects a collective endeavor to enhance patient care through environmentally responsible design, providing a broad context for our study's focus on Hong Kong. Particularly, Hong Kong is poised to face a significant demographic challenge. According to United Nations forecasts, Hong Kong will have the world's oldest population by 2050, with an estimated 40.6% of its population being 65 years or older [4]. This huge demographic shift, compounded by the ever-escalating dependency ratio, nuclear family and high chronic disease burden, is leading to increased dependence on nursing homes, challenging the region's traditional model of home based elder care [5]. Consequently, there is an anticipated need for a substantial increase in specialized healthcare facilities, including long-term care facilities and residential care homes [6], highlighting the growing demand for a sustainable and responsive healthcare infrastructure.

However, the journey towards green building has historically been tailored for commercial, office, and residential buildings [7], leaving healthcare facilities in a challenging quandary. For example, the BEAM Plus rating system in Hong Kong provides comprehensive performance metrics for various building types but notably lacks those specifically for healthcare buildings. This oversight is especially glaring considering the rapid growth of Hong Kong's healthcare sector, driven by an ageing population and a renewed societal focus on health and wellbeing.

Internationally, the trend toward sustainable healthcare facilities is gaining attention. The evolution of Green Building Rating Systems (GBRSs) and their application to healthcare facilities has been an emergent area of study, reflecting the urgency of sustainable practices in the built environment. GBRSs serve as a framework for measuring and recognizing sustainable design, construction, and operations [8–10]. They offer certification processes that lead to the creation of environmentally responsible and resource-efficient buildings [11]. For healthcare, GBRSs have a dual significance: they ensure that buildings contribute to environmental sustainability while fostering a therapeutic and healing environment [12,13]. The literature indicates a growing consensus on the importance of environmentally sustainable healthcare facilities due to their extensive energy use, waste production, and unique operational demands [14–16].

Several studies have examined the application of GBRSs to healthcare facilities. For instance, existing GBRSs such as the Leadership in Energy and Environmental Design (LEED) in the United States and the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK have been adapted to include healthcare-specific versions [17,18]. These adaptations have introduced criteria that address the peculiarities of healthcare buildings, such as indoor air quality and patient comfort, which have profound implications for patient recovery and staff wellbeing [19,20]. Comparative studies, such as those by Castro et al. [21,22], have delineated and compared the main building sustainability assessment methods specific to healthcare facilities. These studies suggest that while there is a general alignment on the broad principles of sustainability, substantial variation exists in how different systems prioritize and evaluate specific criteria.

The literature also points to the challenges for implementing GBRSs in the healthcare sector, including the higher initial costs, distinct energy and water consumption patterns [22,23], specialized ventilation requirements [24,25], intricate patient flow management [26], high equipment loads [27,28], and the need for operational continuity that cannot be compromised even with sustainability initiatives [29]. Moreover, their functional interdependencies with ancillary buildings add another layer of complexity in seeking efficient design solutions [30,31]. Despite these challenges, the benefits of green healthcare buildings such as reduced energy consumption, improved patient and staff satisfaction, and lower operational costs, make the pursuit of such certifications increasingly compelling [32,33].

However, a comprehensive comparative study on healthcare building rating systems is conspicuously missing in the academic discourse. A review by Cai and Gou [9] on Green Building Rating Systems corroborates this void, revealing that there has not been a comprehensive study of the criteria for a relevant building type in existing GBRSs, let alone healthcare as a building type. This gap limits our understanding of adapting existing frameworks for healthcare building in areas like Hong Kong, known for its high density, unique climate [34], shortage of buildable land and housing supply, and imbalanced economic income [35].

This paper aimed to address this research gap by conducting a comprehensive analysis of GBRSs for healthcare buildings. In doing so, this study endeavors to make two contributions to the field. First, it reviews the existing healthcare building rating standards globally, thereby laying the groundwork for a comparative analysis. Secondly, it proposes a bespoke rating system for the Hong Kong healthcare infrastructure. This system not only serves Hong Kong's needs but also offers a template for other densely populated cities facing similar challenges. The assessment framework developed herein aims to bridge the critical gap between the urgent demand for sustainable healthcare facilities and the specific environmental and societal goals of Hong Kong. The findings of this study are expected to stimulate further research and practical application of sustainability in healthcare facilities, reinforcing the global pursuit of sustainable development in this critical sector.

This paper begins with an examination of the impact of global demographic aging on the increasing demand for healthcare facilities and the role of Green Building Rating Systems (GBRSs) in promoting the sustainability of these environments. It then outlines the research methodology employed, incorporating desk research, the Delphi survey method, and the Analytic Hierarchy Process (AHP), to develop a comprehensive assessment framework suitable for healthcare facilities. Subsequent sections present the results, including a comparative analysis of five selected GBRSs and the exploration of the WELL Building Standard's applicability in healthcare settings. The discussion extends to the specific urban challenges and opportunities in Hong Kong's healthcare building design, leading to the proposal of a tailored evaluation framework for the region. The paper concludes with an overview of the research implications, potential applications, and directions for future studies, providing valuable insights for the development and assessment of sustainable healthcare facilities in similar urban contexts worldwide.

2. Methodology

The methodology adopted for this study is delineated into three stages, each integral to the development of a comprehensive assessment framework. The initial stage involved desk research, aimed at generating a preliminary list of indicators. This was followed by the Delphi survey, where a panel of experts was engaged to appraise the draft scoring criteria and to contribute recommendations. The final stage utilized the Analytic Hierarchy Process (AHP) to determine the weighting ratios of the indicators. The overview of the process is presented in Figure 1.

2.1. Desk Research

The genesis of the "Green Building" (GB) initiative in the 1990s signified a transformative approach to construction with a vision for sustainability [36,37]. In assessing the environmental integrity of buildings, Green Building Rating Systems (GBRSs) were developed [38], providing an objective and structured evaluation of their sustainable attributes. These systems, articulated through rigorous criteria, aim to quantify a building's adherence to established green standards.

This study systematically reviewed the literature from the past decade (2014–2023) on GBRSs to understand global research interests in specific systems, their focus areas, and the extent of research on healthcare assessment standards. The research employed Scopus and Web of Science for the literature search, leveraging these platforms which are widely acknowledged for searching peer-reviewed research papers and are frequently used by researchers globally to stay updated with the latest studies [9,39]. To refine the search and identify journals with substantial relevant publications, keywords such as "Green Building Rating Tool", "Green Building Rating System", "Green Building Evaluation System", and "Green Building Certification" were used in the "article title/abstract/keywords" field for Scopus and the "Topic" field for Web of Science. This approach identified 183 papers for initial consideration. A subsequent filtering process involved reviewing abstracts to exclude articles not directly related to the objective of the review, focusing solely on papers that primarily addressed Green Building Rating Systems.

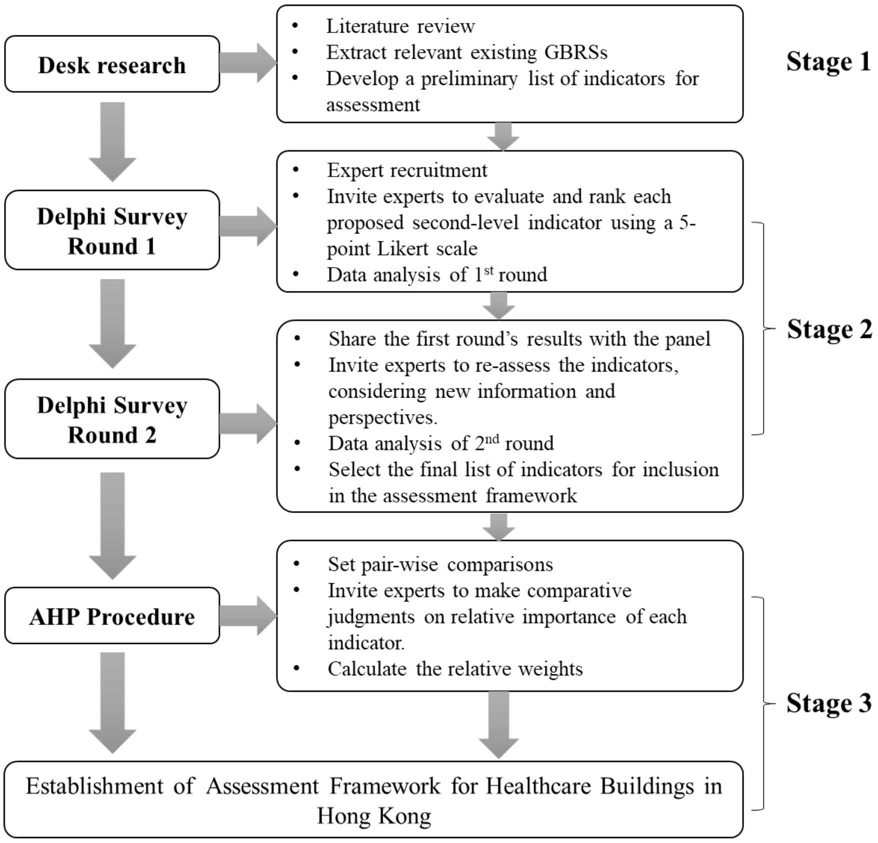

Figure 1. The process of developing the framework.

The data presented in Table 1 highlights key trends in Green Building Rating Systems (GBRSs) research. The studies predominantly compare various GBRSs, assessing their effectiveness in different contexts and adapting them to local and regional environmental needs, showcasing a drive towards global standardization in green building practices. Research primarily focuses on residential buildings, followed by neighborhood, office, and commercial buildings. However, healthcare facilities have not yet been discussed. Additionally, there has been a marked shift towards incorporating sustainability with wellness in GBRSs over the years. This includes a greater emphasis on biophilic design, indoor environmental quality, and the overall health and well-being of occupants, demonstrating a more comprehensive approach to sustainable building design.

Table 1. Published review papers about GBRSs during 2014–2023.

Year	Research Content	Type	GBRS Studied
2014 [40]	Assessment criteria and systems for building materials emitting greenhouse gases were developed in the Korea G-SEED.	Apartment house; Office	LEED; BREEAM; CASBEE; GG; G-SEED
2014 [34]	GBRSs were compared, and revisions and adaptations were made to better suit the context and challenges of Hong Kong.	Residential building	BEAM Plus; LEED; ASGB
2014 [41]	A fuzzy multi-criteria decision making approach was applied to analyze BEP-TR for building energy rating development.	Residential building	LEED; BREEAM; BEP-TR
2015 [42]	The issue of how environmental concerns are weighted in the LEED certification system was examined and highlighted.	N/A	LEED; BREEAM; SBTool; CASBEE; GS

Table 1. *Cont.*

Year	Research Content	Type	GBRS Studied
2015 [43]	Passive design methods within GBRSs were examined.	High-rise residential building	BREEAM; LEED; CASBEE; BEAM Plus; ASGB
2016 [44]	Five global GBRSs were compared regarding their effectiveness in managing construction waste, focusing on the "reduce, reuse, recycle" principles.	Residential building	LEED; BREEAM; GG; ASGB; GBI
2016 [45]	A new framework was introduced to assess sustainability indicators of five key sustainability ratings.	Neighborhood; Community	BREEAM; CASBEE; EPRS; GS; LEED
2017 [46]	The Iranian Green Building Assessment Tool was developed to prioritize energy and water efficiency in its evaluations.	Office	BREEAM; LEED; G-SEED; GS; GM; ASGB; LOTUS; SBTool; CASBEE; BEAM Plus; SABA
2017 [47]	Methodologies and indicators of various rating systems were compared, with suggestions made for enhancing ASGB.	N/A	CSH; LEED; ASGB
2017 [48]	An energy efficiency rating system for existing building was developed in Egypt using Analytic Hierarchy Process.	Existing building	LEED; BREEAM; GG; IGBC; EPRS; EGPRS
2017 [49]	An integrated building life-cycle assessment model was developed to improve South Korean G-SEED.	Apartment building	LEED; CASBEE; BREEAM; G-SEED
2017 [50]	A systematic comparison of the development of GBRSs was carried out.	New building; Neighborhood	BREEAM; LEED; CASBEE; GS NZ
2018 [51]	The differences among international GBRSs were reviewed and evaluated.	Residential building	CASBEE; GS; BREEAM; LEED; ITACA
2018 [8]	The study reviewed current GBRSs, analyzed existing research efforts in this area, and proposed future research directions for GBRS.	N/A	ASGB; BREEAM; BEAM Plus; CASBEE; CEPAS; CSH; EPRS; GBI; GG; GM; GS; GSAS; ISBT; IGBC; LEED
2018 [52]	A ranking methodology for green building design factors was developed based on criteria identified from major GBRSs.	N/A	LEED; BREEAM; CASBEE; GS
2019 [53]	The study reviewed global green building rating tools and suggested improvements for Australia's approach.	Commercial building; Residential building	GS; LEED; BREEAM; GM; BEAM Plus; GBI; IGBC
2019 [54]	Renewable energy assessment in GBRSs and green neighborhoods were compared, focusing on impact and improvement suggestions.	Neighborhood; Commercial building; Residential building	CASBEE; BREEAM; LEED; EEWH; BEAM Plus; DGNB; GM; HQE; PBRS; GBI; GG; IGBC; GRIHA; ASGB
2019 [55]	The GBRSs shifted focus from energy to people by incorporating biophilic concepts.	N/A	LEED; BREEAM; GM; ASGB; WELL; LBC
2019 [56]	The GBRSs in the EU were compared to assess their alignment with the EU's Level(s) sustainability indicators.	Office; Residential building	Level(s); BREEAM; DGNB; HQE; LEED
2020 [57]	Parameters for assessing indoor environmental quality in office and hotel GBRSs were analyzed.	Office; Hotel	HQE; BREEAM; KLIMA; DGNB; ITACA; LiderA; BES; CASBEE; LEED; WELL; NABERS
2020 [58]	Health and wellness in commercial buildings, aligned with sustainable building rating systems were reviewed.	Commercial building	Fitwel; WELL; BEAM Plus; BREEAM; DGNB; GG; GM; GS; HQE; LEED
2021 [59]	Ten leading building rating systems were analyzed to propose a unified sustainability framework.	Residential building Commercial building	BREEAM; LEED; CASBEE; PASSIVHAUS; ASGB; BEAM Plus; DGNB; HQE; GS; GG
2021 [60]	Assessment of neighborhood sustainability tools revealed their strong potential for sustainable urban development.	Neighborhood	LEED; BREEAM; CASBEE; GS

Table 1. *Cont.*

Year	Research Content	Type	GBRS Studied
2021 [61]	Dubai's Al Sa'fat system was assessed, showing notable energy savings and economic benefits, and suggesting improved certification differentiation.	Villa; Office; Hotel building	Al Sa'fat
2021 [62]	The study indicated that GBRSs focus on resilience but inadequately address airborne transmission and social distancing in buildings.	Buildings in operation	WELL; Fitwel; LEED
2022 [63]	The affinity of major international GBRSs with the European scheme was evaluated and analyzed.	N/A	BREEAM; LEED; DGNB; CASBEE; WELL; Level(s)
2022 [64]	The study concluded that the GBRS influence the indoor thermal environment in green buildings.	High-rise residential building	LEED; BREEAM; GS; GM; ASGB; BEAM Plus
2022 [39]	The current literature on GBRSs were reviewed, focusing on their capabilities, existing limitations, and unresolved issues.	N/A	BREEAM; LEED; LiderA
2022 [65]	The paper studied how GBRS indicators address sustainability and life cycle frameworks in residential buildings.	Residential building	DGNB; GG; GS; CASBEE; VERDE; Level(s); BREEAM; LEED
2022 [66]	The study reviewed neighborhood sustainability, focusing on efficacy and data adaptability challenges.	Neighborhood	LEED; BREEAM; CASBEE; GS; DGNB
2022 [67]	The paper evaluated the current state and future prospects of GBRS in Saudi Arabia.	N/A	SBC
2022 [68]	The current literature on Building Information Modelling and GBRSs was reviewed.	N/A	BREEAM; LEED; GS; DGNB; SBTool; GBI; GM; BEAM Plus; ASGB; CASBEE; SVAGRIHA; G-SEED; ARCA; GG
2023 [69]	Commonalities between sustainability and resilience in architecture were explored through a review of GBRSs.	N/A	BREEAM; DGNB; LEED; Level(s); RIBA
2023 [70]	Assessed BIM integration potential with GBRSs for certification achievement.	N/A	LEED; BREEAM; GS; CASBEE

Notes: ASGB, Assessment Standard for Green Buildings; BEAM Plus, Building Environmental Assessment Method Plus; BEP-TR, Building Energy Performance Calculation Methodology—Turkey; BES, Equitable and Sustainable Well-Being (Benessere Equo Sostenibile); BREEAM, BRE Environmental Assessment Method; CASBEE, Comprehensive Assessment System for Built Environment Efficiency; CEPAS, Comprehensive Environmental Performance Assessment Scheme; EEWH, Ecology, Energy saving, Waste reduction and Health; EPRS, Estidama Pearl Rating System; GBI, Green Building Index; GG, Green Global; GM, Green Mark; GRIHA, Green Rating for Integrated Habitat Assessment; GS, Green Star; GS NZ, Green Star New Zealand; GSAS, Global Sustainability Assessment System; G-SEED, Green Standard for Energy and Environmental Design; HQE, Haute Qualité Environnementale; LiderA, Leading the Environment for Sustainable Construction (Liderar pelo Ambiente para a construção sustentável); IGBC, Indian Green Building Council; ISBT, International Initiative for a Sustainable Built Environment; LBC, Living Building Challenge; LEED, Leadership in Energy and Environmental Design; NABERS, National Australian Built Environment Rating System; RIBA, Royal Institute of British Architects; SBC, Saudi Building Code; SBTool, Sustainable Building Tool; SVAGRIHA, Simple Versatile Affordable Green Rating for Integrated Habitat Assessment; WELL, WELL Building Standard.

Figure 2 presents a comprehensive overview of the GBRS as discussed in the 35 papers reviewed. The analysis reveals that 39 GBRSs were discussed across these papers. Among them, LEED and BREEAM were the most frequently mentioned systems, cited 31 and 28 times, respectively. Other systems like CASBEE, Green Star, and ASGB were also frequently referenced, each appearing over 10 times. Building upon this foundation understanding, the study delves into the application of GBRSs in healthcare, a sector known for its specialized demands and significant environmental impact. This phase involved an extensive examination of available rating manuals, compiling a detailed inventory of healthcare-related standards and evaluating them for inclusion in this research.

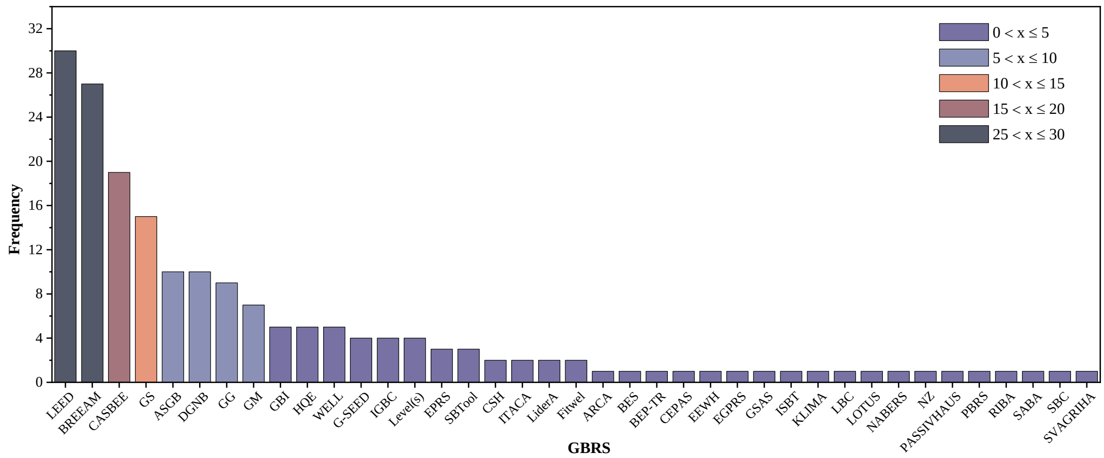

Figure 2. GBRS studied by the authors of identified articles.

The desk research conducted aimed to collate a holistic inventory of existing standards and to critically evaluate their suitability for healthcare facilities. The intent was to propose a refined framework capable of supporting a specialized rating system designed to meet the unique requirements of healthcare architecture and the imperative of patient-centered care facilities, thereby enriching the discourse on sustainability within the healthcare environment. Desk research and personal experience by member of the authors who have participated in the original development of green building rating tools such as the GB (Canada), LEED (USA), BREEAM (UK), have confirmed that expert opinions (Delphi Method) and AHP were being adopted as the process tool [71–74].

2.2. The Delphi Methodology

In this study, a systematic consensus building approach was facilitated through the Delphi method, which is known for its iterative multistage process, enabling a panel of experts to converge upon a common ground in terms of forecasts or decisions [72,75]. The selected panel comprised 15 professionals in the green building sector from Hong Kong, each bringing an average of 10 years of relevant experience and holding esteemed professional certifications such as WELL AP, LEED AP, and BEAM Professional. This diverse group included 40% from academic backgrounds, 20% practicing architects and engineers with direct involvement in sustainable healthcare projects, 20% from sustainability consulting, and 20% engaged in healthcare administration and management. Their collective expertise covered a wide range of green building and healthcare facility design aspects. The panel showcased diversity in demographics, featuring a gender distribution of 60% male and 40% female, and spanning ages from 30 to 65 years, to ensure a wide array of viewpoints. Geographically, 60% of the experts were sourced from Hong Kong to offer local context, while the remaining 40% were international experts, included to bring a global perspective to the study and ensure the incorporation of worldwide best practices.

The process involved two rounds. In the first round of the Delphi process, these experts were presented with 176 indicators derived from desk research and asked to rate the importance of each on a Likert scale. They were tasked with rating the importance of each indicator utilizing a 5-point Likert scale, where 1 signified 'extremely unimportant' and 5 denoted 'extremely important'. Experts were also encouraged to propose new indicators. This provision allowed for a diverse range of perspectives, ensuring a well-rounded evaluation. For the second round, experts were provided with the aggregate results from the first round, including median ratings and the interquartile range for each indicator, as well as any newly suggested indicators. This approach enabled experts to refine their assessments considering the collective feedback.

The Delphi process was completed once response stability was achieved, measured by the standard deviation in ratings across the two rounds. A pre-defined threshold for minimal change in standard deviation was used to determine stability. The study findings were validated when the majority of indicators met this stability criterion, indicating consensus among the expert panel. For inclusion in the final analysis, the criteria were clear: at least 80% of experts needed to rate an item's importance at 4 or higher, the average importance score needed to exceed 4, and the coefficient of variation had to be below 0.30. These standards ensured the reliability and validity of the results.

2.3. The Analytic Hierarchy Process (AHP)

With the indicators thus validated, the Analytic Hierarchy Process (AHP) was employed to derive the weights of various criteria for green building evaluation in this study [76]. Figure 3 illustrates the step-by-step methodology employed in the AHP process, from the initial establishment of criteria to the final computation of weights.

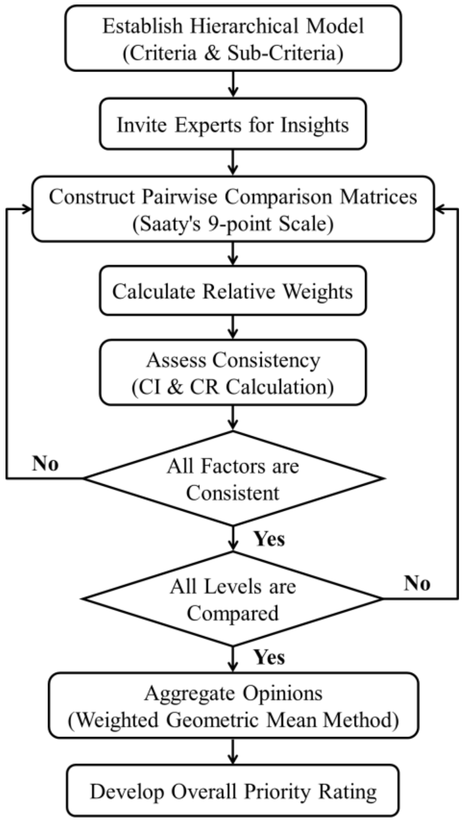

Figure 3. Flowchart of the AHP method.

AHP has been a popular method in green building evaluation, as demonstrated by numerous studies [46,77]. For example, Zarghami et al. utilized BREEAM, LEED, SBTool, and CASBEE as benchmarks to create a sustainability assessment tool for residential buildings in Iran, customizing categories and criteria using AHP to fit the local context [78]. In another instance, Yadegaridehkordi Elaheh, et al. applied AHP to assess and prioritize sustainability indicators for green building manufacturing in Malaysia, highlighting "Energy Efficiency" and "Indoor Environmental Quality" as paramount criteria [74]. Additionally, Yu et al. designed a green assessment tool specifically for store buildings in China, using AHP to rank dimensions and identifying environmental quality (EQ), energy efficiency (EE), and operation management as critical indicators for green store buildings [79]. These examples underscore the widespread application and effectiveness of AHP in the evaluation of green buildings. The methodology for determining the weights of the evaluation criteria through AHP includes the following steps:

First, a hierarchical model was established to categorize and structure the main criteria and sub-criteria related to healthcare building evaluation in Hong Kong. The indicators for this model were derived from comprehensive desk research and the Delphi process, ensuring a thorough and expert-informed foundation. These indicators were then systematically organized into a hierarchical framework guided by the AHP, which facilitated a structured and logical categorization. A total of 15 esteemed green building experts from Hong Kong were invited to share their insights and contribute to the determination of the weights for these indicators. For each level of the hierarchical structure, pairwise comparison matrices were created to evaluate the relative importance of the elements. The judgments for these comparisons were made on Saaty's 9-point scale [80], where a score of 1 indicates equal importance, 3 indicates moderate importance, 5 indicates strong importance, 7 indicates very strong importance, and 9 indicates extreme importance. Experts were also allowed to use intermediate values (2, 4, 6, and 8) to express their judgments. A typical pairwise comparison matrix is mathematically represented as:

$$A = \begin{bmatrix} 1 & x_{12} & \cdots & x_{1n} \\ 1/x_{12} & 1 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/x_{1n} & 1/x_{2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

where x_{ij} denotes the relative importance of element i compared to element j, as adjudicated by the panel of experts.

The next pivotal step in the AHP methodology encompasses the calculation of relative weights or priority vectors of the criteria. This is achieved by applying the row average method, which necessitates normalizing each row of the pairwise comparison matrix, followed by the computation of the average value of each row. To bolster the credibility of the expert evaluations and to ensure the robustness of the results, the Consistency Index (CI) and Consistency Ratio (CR) were calculated with the equation:

$$\mathrm{CI} = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (2)$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (3)$$

where $\lambda_{\max}$ is the maximum eigenvalue which is calculated by multiplying the priority vector weights by the corresponding values in the judgment matrix, n is the number of indicators being compared, and RI is the Random Index obtained from Saaty's table. The CR value smaller or equal 0.10 is considered acceptable [81], indicating a reasonable level of consistency in the assessments. In this study, the CR values were calculated using the YAAHP v12.3 software and were found to be below the threshold of 0.10. This indicates that the consistency of the results is within an acceptable range, underscoring the reliability of the assessment outcomes.

To synthesize the opinions of numerous experts and derive a consensus on the relative importance of the criteria, the Weighted Geometric Mean Method (WGMM) was employed. This method effectively handles multiplicative preference relations and ensures a balanced representation of diverse opinions. Each expert judged through pairwise comparison matrices, following Saaty's 9-point scale. The WGMM was then applied to aggregate these matrices into a single, collective pairwise comparison matrix. The formula for the weighted geometric mean of an element in the collective matrix is given by:

$$\mathrm{r_{ij}} = \left(\prod_{\mathrm{k=1}}^{\mathrm{n}} \left(\mathrm{x_{ij}^{k}} \right)^{\mathrm{w_k}} \right)^{\frac{1}{\sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{w_k}}} \quad (4)$$

where r_{ij} represents the element in the aggregated pairwise comparison matrix, x_{ij}^{k} is the element at the i^{th} row and j^{th} column of the k^{th} expert's pairwise comparison matrix, w_k is the weight of the k^{th} expert's matrix, and n is the number of experts.

In this study, equal weights were assigned to all experts, reflecting an egalitarian approach to opinion aggregation. Following the construction of the collective pairwise comparison matrix, the relative weights or priority vectors of the criteria were derived using the row average method, and the consistency of the evaluations was assessed using the Consistency Index (CI) and Consistency Ratio (CR), ensuring the reliability and robustness of the derived weights.

3. Results and Analysis

3.1. The Selected GBRSs

After a review of the official websites for the 39 Green Building Rating Systems (GBRSs) under study, it was found that only five GBRSs feature specific categories for Healthcare Buildings. Consequently, these five rating systems were selected for inclusion in this research. The basic information of these selected GBRSs is detailed in Table 2.

Table 2. Rating systems for healthcare buildings.

No.	GBRSs	Country or Region	Type of Rating System	Publication Year for Healthcare	Certification Ratings (from Low to High)
1	LEED for Healthcare	USA	International	2005	Certified; Silver; Gold; Platinum
2	BREEAM for Healthcare	UK	International	2008	Pass; Good; Very Good; Excellent; Outstanding
3	Green Star for Healthcare	Australia	Australia	2009	Certified; 4-Star; 5-Star; 6-Star
4	Green Mark for Healthcare	Singapore	Singapore	2018	Certified; Gold; Gold^{Plus}; Platinum
5	IGBC for Healthcare	India	India	2020	Certified; Silver; Gold; Platinum

3.2. GBRSs for Healthcare Buildings

In the realm of sustainable healthcare building assessment, five major Green Building Rating Systems (GBRSs)—LEED, BREEAM, Green Star, Green Mark, and IGBC—emerge as noteworthy contributors, each with distinct methodologies and priorities. While all five systems share a broad commitment to advancing sustainability and wellness, the weighting they assign to various assessment criteria elucidates the diverging emphases that characterize their approaches. Figure 4 shows the major indicators in the five GBRSs studied.

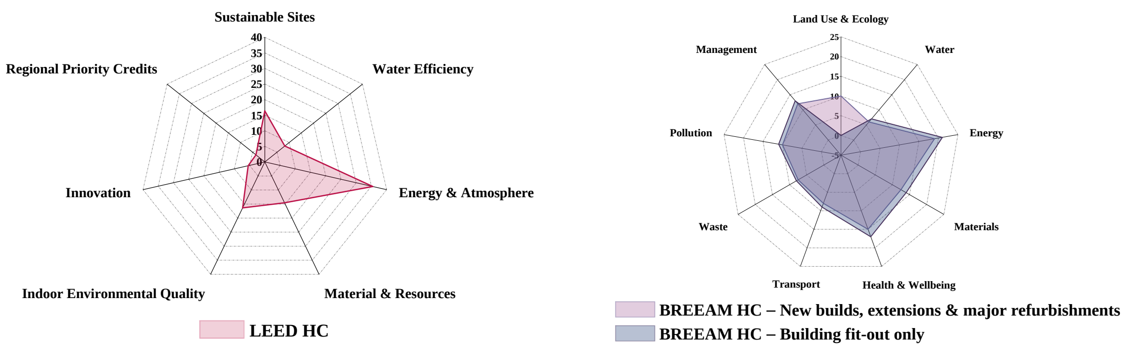

Figure 4. *Cont.*

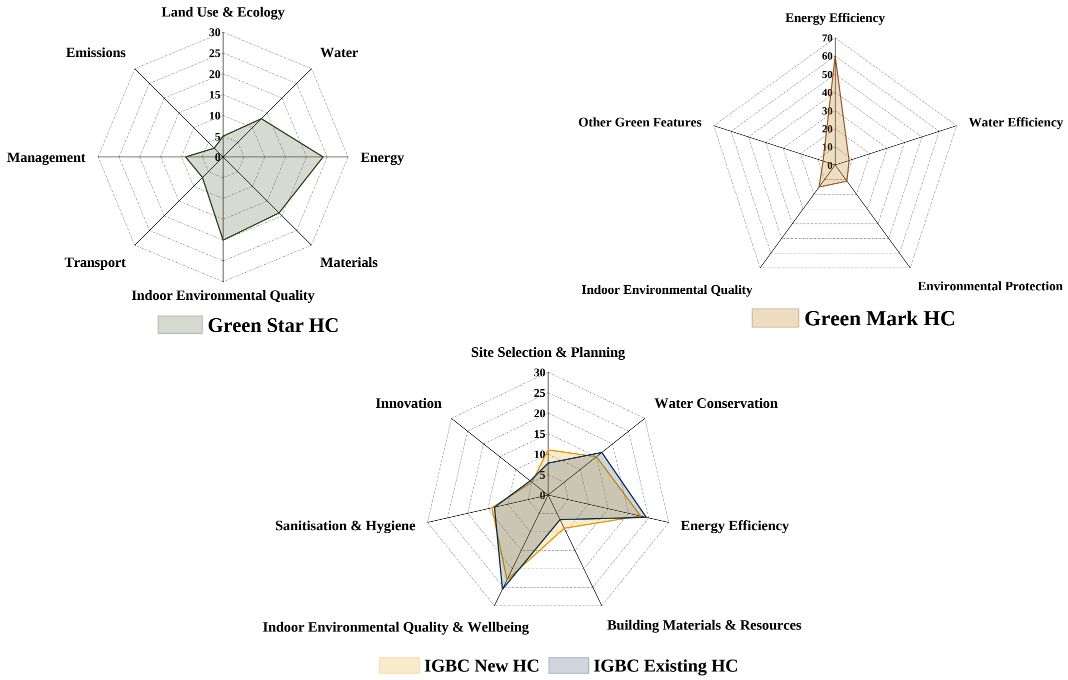

Figure 4. Major indicators in the GBRSs studied (percentages indicate the weight of each indicator's score relative to the overall score).

Among the similarities is the overarching focus on energy efficiency across all five standards, although the degree of emphasis varies. Green Mark notably leads with an exceptional 60% weighting dedicated to energy efficiency, highlighting its significant focus in this area. LEED follows with a substantial 35.5% allocation, demonstrating its strong prioritization of energy aspects. IGBC is close behind, assigning between 23–24% to energy efficiency, while BREEAM and Green Star allocate 19–21% and 24%, respectively. This distribution underscores a collective recognition of energy efficiency's centrality in sustainable healthcare building design. Water efficiency or conservation is another criterion that each system addresses, albeit to differing extents. IGBC and Green Star place greater emphasis on this aspect, with 15–17% and 13% weightings, respectively. Meanwhile, LEED, Green Mark, and BREEAM offer relatively lower weightings of 8.2%, 8%, and 6–7% to water efficiency, indicating a more varied approach to this vital resource.

The standards diverge more noticeably in other categories. Green Star and IGBC, for instance, strongly emphasize indoor environmental quality and wellbeing, allocating 20% and approximately 25.6%, respectively, to these aspects. In comparison, LEED, BREEAM, and Green Mark allocate less focus to this criterion, with weightings of 16.4%, 15–17%, and 15%, respectively. The approach to materials and resources also shows variation across these systems. Green Star leads with a 19% weighting in this category, followed by LEED at 14.5%, and BREEAM with 12.5–14%. IGBC trails has a 6.7–9% allocation. Green Mark, while not having a specific category for materials and resources, includes them under "Other Green Features", with a 7% weighting. Interestingly, LEED and IGBC have dedicated categories for innovation, while Green Star and BREEAM incorporate it within other categories. Green Mark, similarly, includes innovative features under "Other Green Features." Furthermore, the allocation of importance to management and specific categories like land use, transport, and pollution varies across these standards, reflecting the diverse perspectives and priorities within the realm of sustainable building practices.

These differences in criteria weightings highlight the unique emphases and priorities within each GBRS. Green Mark and LEED prioritize energy efficiency, while IGBC leans towards a balance of energy efficiency and indoor environmental quality. Green Star adopts a more holistic approach, focusing on energy, water, materials, and the indoor environment. BREEAM, on the other hand, gives substantial weight to land use and ecology, alongside energy efficiency. This diversity in approaches reflects the multifaceted nature of sustainability in the context of healthcare building design, demonstrating the broad spectrum of considerations that these standards encompass.

3.3. The WELL Building Standard

The WELL Building Standard, developed in 2014 by the International WELL Building Institute (IWBI) [82], represents a paradigm shift in Green Building Rating Systems (GBRSs) [38]. Today it is one of the popular and accepted rating tools in the commercial and residential markets in the world next to LEED. Distinct from traditional systems like LEED, BREEAM, Green Star, and IGBC, which are primarily focused on the environmental sustainability of buildings, WELL uniquely concentrates on enhancing the health and wellbeing of building occupants [83]. This human-centered approach is especially pertinent to healthcare facilities, transcending mere structural considerations to emphasize aspects such as patient comfort, staff wellbeing, and stringent hygienic standards, which are crucial in these settings.

Although the WELL Building Standard does not have a category specifically tailored for healthcare buildings, numerous studies have underscored its applicability and relevance in these settings [71,84,85]. The WELL Building criteria, encompassing air and water quality, nourishment, light, movement, thermal comfort, sound, materials, mind, and community, directly address the essential aspects of elderly care and staff wellbeing. This alignment is particularly significant as it bridges the gap between sustainable building practices and the unique demands of healthcare facilities, ensuring that buildings are designed and operated not only for environmental sustainability but also for the health and comfort of their occupants. Table 3 presents a comparison of the criteria used in WELL and LEED, outlining their specific descriptions and highlighting their relevance to healthcare buildings.

Table 3. Comparative analysis of WELL and LEED criteria and their relevance to healthcare buildings.

Criteria	WELL Description	LEED Description	Relevance to Healthcare Buildings (WELL)	Relevance to Healthcare Buildings (LEED)
Air Quality	Focuses on improving indoor air quality.	Prioritizes efficient HVAC systems.	Vital for patient and staff health; reduces risk of airborne diseases.	Contributes to energy efficiency; may improve air quality.
Water Quality	Prioritizes access to clean, safe water.	Focuses on water efficiency.	Essential for patient care and sanitation.	Important for resource conservation; indirectly impacts patient care.
Energy	Not directly addressed, but complementary to other standards.	Significant emphasis on energy efficiency.	Complementary when integrated with other standards like LEED.	Vital for reducing the building's environmental footprint.
Nourishment	Highlights healthy food options and nutritional transparency.	Not directly addressed.	Important for patient recovery and staff wellbeing.	Not applicable
Light	Encourages natural light and proper artificial lighting.	Includes lighting in the context of energy efficiency.	Contributes to patient wellbeing and staff efficiency.	Focuses more on energy-efficient lighting.
Movement	Advocates for physical activity and ergonomic design.	Not directly addressed.	Aids in patient recovery and staff wellbeing.	Not applicable
Thermal Comfort	Ensures a comfortable thermal environment.	Addressed as part of energy efficiency.	Important for patient comfort and recovery.	Primarily aimed at energy savings.
Sound	Addresses acoustic comfort and noise reduction.	Not directly addressed.	Crucial for creating a healing and comfortable environment.	Not applicable

Table 3. *Cont.*

Criteria	WELL Description	LEED Description	Relevance to Healthcare Buildings (WELL)	Relevance to Healthcare Buildings (LEED)
Materials	Prioritizes non-toxic and sustainable materials.	Emphasizes sustainable building materials.	Ensures a healthier and safer building structure.	Aims at environmental sustainability through material use.
Mind	Focuses on mental health aspects like stress reduction.	Not directly addressed.	Critical for patient recovery and staff mental health.	Not applicable
Innovation	Not a separate criterion but encourages innovative practices.	Has a dedicated category for innovative strategies.	Can be integrated for tailored healthcare solutions.	Encourages new strategies for environmental sustainability.

4. Proposed Assessment Framework for Healthcare Buildings in Hong Kong

4.1. The Hong Kong Urban Context

Before delving into the specifics of the proposed assessment framework, it is essential to understand the unique urban context of Hong Kong. As a densely populated metropolis, Hong Kong is marked by its high-rise architecture and compact urban layout (Figure 5a). Despite Hong Kong's status as a developed economy, it is characterized by significant wealth disparity, which profoundly affects various aspects of societal life, particularly the living conditions in nursing homes. Many of these facilities, catering to the less affluent segments of the aging population, face the challenge of providing adequate care within highly compact and constrained environments. This situation is exacerbated by the city's limited space and high property costs, leading to overcrowded nursing homes with limited room for amenities or recreational spaces (Figure 5b). The stark contrast between the city's economic prosperity and the modest living conditions in these homes underscores the urgent need for thoughtful and sustainable design solutions in healthcare facilities, particularly those serving older adults. The contrast highlights not only the necessity for efficient space utilization but also the importance of creating environments that respect and enhance the dignity and wellbeing of the elderly.

(**a**) (**b**)

Figure 5. (**a**) Hong Kong city (photo by the Hong Kong Tourism Board); (**b**) photo of a charity-run nursing home in Hong Kong (photo by Authors).

4.2. Determination of Evaluation Index

The BEAM Plus rating system, as it currently stands in Hong Kong, is structured around six core aspects that form the foundation of its assessment criteria. These include Integrated Design and Construction Management (IDCM), Sustainable Sites (SS), Materials and Waste (MW), Energy Use (EU), Water Use (WU), and Health and Wellbeing (HWB) [86]. Additionally, the framework incorporates a 'bonus' category focused on Improvement and Innovation, aimed at incentivizing the adoption of established innovative technologies. To enhance the evaluation framework for healthcare buildings within the existing BEAM Plus standard in Hong Kong, the study integrates secondary criteria from six globally recognized sustainability benchmarks: LEED HC, BREEAM HC, Green Star HC, Green Mark HC, IGBC HC, and WELL. This integration aims to enrich the BEAM Plus standards with a broader range of sustainability indicators, ensuring a more comprehensive and tailored approach to evaluating healthcare facilities. By integrating these diverse criteria, the framework expands its scope to effectively address the unique environmental and health-related challenges inherent in healthcare building design. The integration of various sustainability benchmarks into the BEAM Plus framework is clearly depicted using Sankey diagrams, facilitating a thorough assessment approach. Figure 6 offers a comparison of LEED HC, BREEAM HC, Green Star HC, Green Mark HC, IGBC HC, and WELL indicators, now reinterpreted within the BEAM Plus standards. This comparison effectively illustrates how these diverse criteria harmonize within the broader context of healthcare building sustainability in Hong Kong.

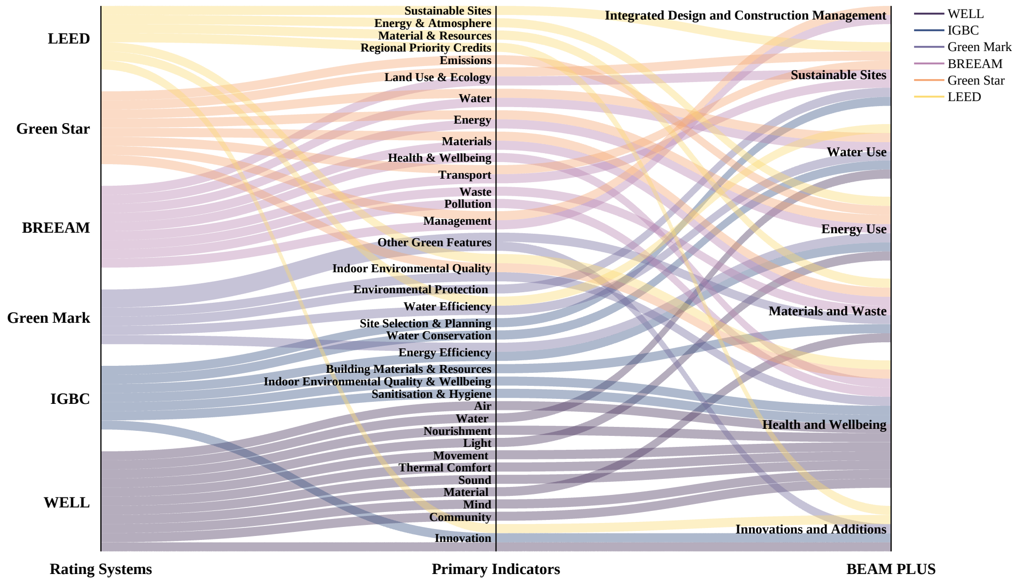

Figure 6. Summary of LEED HC, BREEAM HC, Green Star HC, Green Mark HC, IGBC HC, and WELL Indicators under the BEAM Plus framework.

4.3. Screening of the Evaluation Index

A total of 615 secondary indicators from six selected sustainability evaluation systems (LEED HC, BREEAM HC, Green Star HC, Green Mark HC, IGBC HC, and WELL) have been incorporated into the BEAM Plus framework by the authors. Through the elimination of duplicate indicators and the amalgamation of similar ones, a refined list of 176 indicators has been established. Specifically, the distribution is as follows: Integrated Design and Construction Management (IDCM) with 6 indicators, Sustainable Sites (SS) comprising 31 indicators, Materials and Waste (MW) with 28 indicators, Energy Use (EU) consisting of 31 indicators, Water Use (WU) with 21 indicators, Health and Wellbeing (HWB) represented by 55 indicators, and Innovations and Additions (IA) accounting for 4 indicators.

To evaluate the importance of these indicators, a Delphi method was employed via an online questionnaire. Through this structured online consultation, 54 secondary indicators that achieved a mean rating of 4 or above were chosen for the final assessment framework (Table 4), indicative of their perceived importance, from 'important' to 'extremely important'. During the evaluation process, experts also adapted and expanded the existing indicators to better align with the unique characteristics of Hong Kong, exemplified by the introduction of the 'Minimum Accommodation Space' indicator. This customization ensures that the framework is appropriately tailored to the specific environmental and societal needs of Hong Kong's healthcare buildings.

Table 4. Weights for each indicator in the proposed rating system.

Primary Indicator	The Weight	Secondary Indicator	The Weight
IDCM	0.07	Integrated Design Process	0.0070
		Environmental Management	0.0136
		Life Cycle Cost and Service Life Planning *	0.0282
		Responsible Construction Practices	0.0052
		Waste Management	0.0101
		Building Management Systems	0.0081
SS	0.16	Ecological Value of Site	0.0218
		Low-Emission Vehicles	0.0071
		Open Space	0.0136
		Pedestrian Routes	0.0050
		Provision of Car Parking	0.0037
		Reuse of Land	0.0158
		Site Development—Protect or Restore Habitat	0.0123
		Sustainable Transport Measures	0.0142
		Heat Island Reduction *	0.0320
		Light Pollution Reduction	0.0106
		Long Term Ecological Management and Maintenance	0.0153
MW	0.08	Certified Green Building Materials, Products, and Equipment	0.0107
		Implement a Waste Management Plan	0.0101
		Eco-friendly Furniture and Medical Furnishing	0.0093
		Improve Cleaning Practices	0.0093
		Restricting VOC Emissions from Furniture, Architectural, and Interior Products *	0.0186
		Reuse of Façade and Structure	0.0136
		Storage And Collection of Recyclables	0.0057
EU	0.25	Minimum Energy Efficiency *	0.0679
		Commissioning Plan for Building Equipment and Systems	0.0093
		Energy Metering and Management	0.0334
		High Efficacy External Lighting	0.0154
		Refrigerant Management	0.0279
		Green Power and Carbon Offsets	0.0255
		Lighting Zoning and Control	0.0187
		Energy Efficient Equipment	0.0544
WU	0.09	Water Consumption	0.0201
		Water-Efficient Equipment	0.0098
		Water Leak Detection	0.0131
		Verifying Water Quality Indicators *	0.0304
		Wastewater Treatment and Reuse	0.0121
		Rainwater Harvesting, Roof and Non-Roof	0.0039
		Landscape Irrigation Water Efficiency	0.0033

Table 4. *Cont.*

Primary Indicator	The Weight	Secondary Indicator	The Weight
HWB	0.35	Develop Emergency Preparedness Plan	0.0399
		Indoor air quality	0.0364
		Thermal Comfort	0.0328
		Visual Comfort	0.0210
		Reduction in noise pollution	0.0246
		Commit to Ergonomic Improvements	0.0211
		Mold Prevention	0.0138
		Provide Nature Access and Activity Space (Indoors and Outdoors)	0.0265
		Provide Operable Windows	0.0160
		Safe and Healthy Surroundings	0.0070
		Tobacco Smoke Control	0.0136
		Minimum Accommodation Space *	0.0282
IA	Bonus	BEAM Professional	-
		Carbon Inventory	-
		Innovation In Design Process	-

Notes: (1) The IA category is a bonus section and does not require weight calculation. (2) Indicators marked with an asterisk (*) are those with specific relevance to the Hong Kong context in the sustainability framework for healthcare buildings.

These indicators collectively represent the critical aspects of sustainability for healthcare buildings in Hong Kong. In the next phase, the Analytic Hierarchy Process (AHP) is employed to determine the relative importance of each primary and secondary indicator, assigning specific weights accordingly.

4.4. Weights of Evaluation Index

Based on the 6 primary indicators and 54 secondary indicators previously described, another questionnaire has been developed. This new questionnaire was instrumental in applying the Analytic Hierarchy Process (AHP) to determine the weights of these indicators. The weights derived from AHP analysis are comprehensively detailed in Table 4.

The results from the Analytic Hierarchy Process (AHP) applied to the healthcare building rating system suggest a hierarchical importance of indicators tailored for the context of Hong Kong. The Health and Wellbeing (HWB) indicator emerges as the most influential factor, holding the highest weight. This aligns with current GBRS research trends that emphasize the indoor environment's quality and its substantial impact on the health and comfort of occupants [55,58,83]. Researchers like Ascione, De Masi, Mastellone, and Vanoli [39] have underscored the importance of assigning strong weight to HWB in rating systems. In healthcare facilities, where the wellbeing of patients and staff is a foremost priority, prioritizing HWB is both pertinent and imperative. Following HWB, the Energy Use (EU) indicator is identified as the next most significant category. This underlines the critical role of energy efficiency and sustainable energy use in healthcare facilities, which are typically resource-intensive operations. The high weightage allocated to EU clearly indicates the drive towards minimizing the energy footprint of such buildings, which aligns with Hong Kong's increased efforts to combat climate change and promote sustainability in its built environment. The Sustainable Sites (SS) category also stands out as a key factor in the rating system. This reflects the importance of integrating the healthcare facility within its immediate ecological and social setting, acknowledging that the site characteristics—such as accessibility, ecological value, and connection with the community—are instrumental in fostering a sustainable healthcare environment.

The selection of secondary indicators further illustrates Hong Kong's distinctive approach to sustainability in healthcare buildings. The emphasis on Life Cycle Cost and Service Life Planning (IDCM) and Minimum Energy Efficiency (EU) reflects a commitment to enduring sustainability and efficiency—a necessity in a city constrained by space and high resource demands. Heat Island Reduction (SS) and Restricting VOC Emissions (MW) address the critical aspects of urban living quality. Meanwhile, Verifying Water Quality Indicators (WU) speaks to the essential concern of water safety in densely populated areas. The inclusion of Minimum Accommodation Space (HWB) is a response to the city's challenge of balancing limited space with comfortable living and working environments.

This framework goes beyond a mere checklist of environmental criteria. It represents a context-sensitive paradigm for assessing green healthcare buildings in Hong Kong. The city's dense urban landscape demands a nuanced balance between high-performance building operations and the creation of health-promoting environments. The insights derived from this AHP-based evaluation are instrumental in guiding the development of sustainable healthcare infrastructure that is responsive to the unique demands of the Hong Kong urban context.

5. Discussion

Based on the 39 Green Building Rating Systems (GBRSs) from literature review, the authors have further worked out that only five standards have addressed healthcare buildings as a distinct category. Unlike conventional buildings such as office towers and residential complexes, which are individually considered in many GBRSs, healthcare facilities appear to be underrepresented in Green Building Rating Systems due to specific challenges or considerations. This lack of focused attention on healthcare settings in GBRSs underscores a noteworthy gap in the current landscape of sustainable building practices.

To bridge this gap, the proposed assessment framework for healthcare buildings is benchmarked against the prevailing BEAM Plus standard for New Buildings, while also integrating considerations from internationally recognized healthcare-specific benchmarks: LEED HC, BREEAM HC, Green Star HC, Green Mark HC, IGBC HC, and WELL. This integrative approach consolidates the insights and criteria from these leading sustainability benchmarks into the BEAM Plus framework, aiming to create a more robust and healthcare-focused assessment tool. An analytical comparison of this proposed healthcare assessment scheme with the conventional BEAM Plus standard for New Buildings is graphically represented in Figure 7.

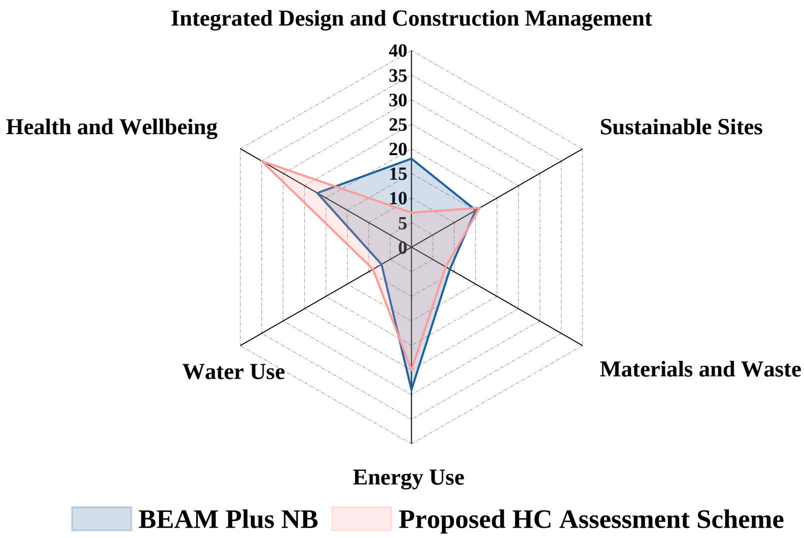

Figure 7. The comparation of major indicators in BEAM Plus NB 2.0 and the proposed healthcare building assessment scheme.

The comparison elucidates a marked recalibration towards Health and Wellbeing (HWB), which receives a higher weighting in the healthcare-focused system (35) as opposed to BEAM Plus NB (22). This highlights the healthcare system's prioritization of occupant health, a vital element in healthcare facilities where the environment can significantly impact patient care and recovery. Energy Use (EU) and Sustainable Sites (SS) are other areas where the healthcare rating system places significant emphasis, reflecting a focus on energy conservation and the integration of healthcare facilities into their natural and community settings. The weight given to EU (25) and SS (16) highlights the focus on reducing operational energy demands and enhancing the ecological relationship of healthcare buildings with their surroundings.

While the indicators for Integrated Design and Construction Management (IDCM), Materials and Waste (MW), and Water Use (WU) are slightly less emphasized in the healthcare model than in the BEAM Plus, they remain integral with the overall sustainability strategy. The adjustments in these categories suggest a nuanced approach that caters to the specificities of healthcare operations without undermining the core principles of sustainable construction and resource management.

Overall, the analysis of the weights indicates a deliberate shift in the healthcare building rating system towards a more patient- and health-centric approach, while still maintaining a strong commitment to environmental stewardship and resource efficiency.

6. Conclusions

The exploration into existing Green Building Rating Systems (GBRSs) has highlighted a significant gap in addressing healthcare facilities, emphasizing the necessity for a specialized framework. This need arises from the unique complexities and specificities of healthcare institutions, which differ markedly from other building types. Healthcare facilities not only require stringent standards to boost functionality and sustainability, but also exhibited unique demands in terms of building space, comfort, and landscape integration (reference to Figure 5b above) As societies age and the demand for healthcare services increases, these facilities become prudent and essential. Hong Kong represented a case of increasing demand for caring and servicing for the sharp increase in aged population percentage and quantity. The authors believe that the practical way forward is to introduce a customized green certification or label system as the means to achieving a sustainable living condition for both new and existing elderly homes and hospitals.

This study pioneers a healthcare focused GBRS for Hong Kong, thereby addressing the notable void in sustainable building assessments for healthcare facilities. By integrating key indicators from established GBRSs such as LEED HC, BREEAM HC, Green Star HC, Green Mark HC, and IGBC HC, with additional considerations for WELL-related indicators that pertain to the interior environments impacting users, a nuanced approach has been developed that addresses the unique challenges and priorities of healthcare facilities. The proposed system evaluates healthcare buildings through a rigorous methodology encompassing literature reviews, Delphi expert surveys, and the Analytic Hierarchy Process (AHP). This research is crucial in establishing a healthcare centric GBRS, offering a tailored evaluation framework for Hong Kong. It sets a higher standard for healthcare facilities, ensuring that they meet the rigorous demands for sustainability, functionality, and occupant wellbeing, which are increasingly vital in our rapidly urbanizing world. By adapting this assessment to Hong Kong's context, this study serves as a valuable model for corresponding initiatives elsewhere, aiming to incorporate healthcare infrastructure within the wider scope of sustainable development.

However, the study acknowledges its limitations. The reliance on expert surveys indicates that the weighting of indicators is subject to change based on the composition of the expert panel. This suggests that, although robust, the framework is influenced by the dynamics of expert opinions. Future iterations of the GBRS may benefit from an expanded range of expert inputs and the incorporation of real-world performance data to further refine the weighting and ensure the system remains responsive to evolving sustainability goals and healthcare needs. Additionally, a key limitation is the absence of empirical validation for the developed framework and its rating methods. Future research should prioritize the empirical testing and validation of this framework to ascertain its effectiveness and reliability in practical applications. Importantly, subsequent iterations of this research should also integrate feedback from medical professionals and the primary users of healthcare facilities. While expert guidance is invaluable, direct insights from those who interact with these spaces daily, including elderly people and healthcare staff, will provide a more nuanced understanding of the framework's practical implications. Engaging with these key stakeholders will ensure that the GBRS not only meets technical sustainability criteria but also addresses the comfort, well-being, and specific needs of healthcare facility users.

In conclusion, this research has concentrated on the design and construction aspects of new and renovated healthcare facilities, with a strong emphasis on space, comfort, energy efficiency, and environmental impact. The inclusion of WELL-related indicators further highlights the critical importance of interior environments in significantly influencing the health and wellbeing of users. Adopting a holistic approach, this study not only addresses the physical and operational aspects of healthcare facilities but also places a strong emphasis on experiential and health-centric elements, as defined by WELL standards. Future research should, therefore, continue to integrate and balance these considerations, ensuring that healthcare facilities not only adhere to high standards of environmental sustainability but also actively contribute to the wellbeing and comfort of their users. By incorporating these comprehensive metrics, the framework developed herein aims to set a new benchmark for the design, construction, and operation of sustainable healthcare environments that are responsive to both ecological and human health needs.

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