sustainability

Article

BIM-Based Green Hospital Building Performance Pre-Evaluation: A Case Study

Zhaoxi Zhan [1,*], Wenna Xu [1], Lin Xu [1], Xinyue Qi [1], Wenjie Song [1], Chen Wang [1] and Ziye Huang [2]

[1] Department of Civil Engineering, College of Civil Engineering, Huaqiao University, Xiamen 361021, China; 20013086042@stu.hqu.edu.cn (W.X.); 18014086026@stu.hqu.edu.cn (L.X.); 19014086025@stu.hqu.edu.cn (X.Q.); 19014086028@stu.hqu.edu.cn (W.S.); wch@hqu.edu.cn (C.W.)
[2] Department of Human Geography and Urban and Rural Planning, College of Tourism, Huaqiao University, Quanzhou 362021, China; ziye.huang@kcl.ac.uk
* Correspondence: zhaoxi@hqu.edu.cn

Abstract: With ecological problems and energy crises intensifying today, greening is essential to sustainable development. Compared with other types of buildings, hospital buildings account for a relatively larger proportion of building energy consumption. In order to realize the rapid cycle optimization of a green hospital project in the design stage and improve the green grade of the building, a pre-evaluation Building Information Model (BIM) of green hospital building performance was established in this study. Firstly, the literature review and expert consultation established the building performance pre-evaluation index system for green hospitals. Then, BIM technology is taken to extract data needed for building a performance pre-evaluation system, and the Cloud Model and the Matter–Element Extension Theory are used to build models. The final green grade calculation is realized in MATLAB. Finally, the Maluan Bay Hospital is taken as an example to test the applicability and effectiveness of the proposed model. The results show that the green hospital building performance pre-evaluation model has advantages of simulation, cyclic optimization and fuzzy quantification, which can effectively guide the design and construction of a green hospital.

Keywords: building information model; green hospital building; pre-evaluation; building performance

Citation: Zhan, Z.; Xu, W.; Xu, L.; Qi, X.; Song, W.; Wang, C.; Huang, Z. BIM-Based Green Hospital Building Performance Pre-Evaluation: A Case Study. *Sustainability* **2022**, *14*, 2066. https://doi.org/10.3390/su14042066

Academic Editors: Víctor Yepes, Ignacio J. Navarro Martínez and Antonio J. Sánchez-Garrido

Received: 5 January 2022
Accepted: 7 February 2022
Published: 11 February 2022

1. Introduction

With the rapid development of the construction industry, ecological problems and energy crisis are becoming increasingly severe. The construction sectors account for nearly 40% of global energy consumption [1,2] and produce more than 30% of carbon dioxide emissions [2] as well as more than 10 billion tons of construction waste per year [3]. Among them, environmental pollution and energy consumption problems caused by a hospital building should not be underestimated. The 2018 Commercial Buildings Energy Consumption Survey (CBECS) shows that healthcares' total floorspace accounts for 4% of commercial buildings in the United States but consumes nearly 6% of energy sources [4–6]. Energy consumption of the unit building area of hospitals can reach up to 2–3 times than that of other public buildings [7]. Thus, examining how to improve hospital buildings to achieve sustainable development is crucial.

The green concept is an inevitable requirement of building sectors to retain sustainable development [8,9]. A green building has higher goals in promoting sustainability, such as reducing energy and carbon emission and improving indoor comfort [10]. As an important example of sustainable urban development, the green hospital is committed to realizing the "Four Savings and One Protection" throughout the entire construction cycle, for instance, saving land, water, materials, energy and environmental protection, so that people can live in harmony with nature [11]. In particular, green hospitals are often designed to minimize energy consumption and ecological pollution through monitoring, assessing and improving relevant performance, making green hospital buildings more attractive as an incentive to prompt sustainability of the construction sector [12].

A scientific evaluation system is a significant force for promoting the development of green buildings [10]. Currently, the green hospital building evaluation system is primarily based on green measures where a lot of data need to be collected. However, the data collection process is complex and inefficient; thus, it is difficult to evaluate the effectiveness of green measures. By comparison, the performance index of hospital buildings is more targeted. Performance means the result of sustainable measures, which will orient the green evaluation process [13–15]. Moreover, the benefits of performance evaluation are more visible in the design phase, which has the largest impact on a project throughout its entire life cycle [13–15]. Therefore, performance optimization measures in the design stage are critical for achieving the green grade goal.

BIM is an effective tool for building performance analysis. BIM integrates project systems, building information and the project management team to provide safe and convenient data transmission and storage methods, which improves the efficiency of green evaluation [16,17]. However, the research of green BIM technology in the design stage is not sufficient. Moreover, few studies focus on applying BIM for building simulation analysis, with little analysis of hospital building performance. This paper will construct a simulative and fuzzy quantitative pre-evaluation model of green hospital building performance by BIM technology to assess the performance of hospital architecture during the design phase. Furthermore, the study out feedback and optimization of hospital building design based on pre-evaluation results to improve the green level of hospital construction. To achieve these aims, there are some specific steps: (1) Create a green hospital building performance pre-evaluation index system; (2) integrate the BIM and the BIM-related tools for building performance pre-evaluation; and (3) obtain optimization measures based on the evaluation results. These steps will demonstrate the application possibilities of the model.

2. Literature Review

As one of the most significant initiatives to address environmental issues, green hospital buildings have drawn widespread attention [18,19]. The green hospital building aims to maximize resource savings, protect the environment and reduce pollution, providing patients and medical staff healthy, applicable and efficient use spaces [20]. To reach this goal, various performance assessment methods have been raised [21,22], such as Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), WELL building standard (WELL) and Evaluation standard for green hospital building (GB/T 51153-2015). Unlike other methods, WELL emphasises occupant health and places "human-centred" as a key issue [23,24].

The previous green hospital building performance studies mostly focus on individual indicators, with a few referring to systematic indicators including users' needs. Chamseddine et al. temporally monitored the indoor air quality (IAQ) of hospitals to analyze seasonal variations and indoor-outdoor (IO) correlations [25]. Shi et al. investigated energy consumption and building layout of 30 hospitals in the cold region of China to conclude energy-saving strategies in hospital building layouts for architects in the design stage [26]. Alzoubi and Attia measured sound transmission loss and insulation of two selected inpatient wards to evaluate Sound Transmission Class (STC), aiming to achieve acoustic comfort [27]. Leccese et al. performed illuminance and luminance analysis of different activities in the hospital and matched them with the optimum visual task [28]. However, those studies rarely involve patients' needs.

Building performance evaluation conducts constant assessment and feedback to optimize the entire lifecycle of buildings. As mentioned above, the building performance pre-evaluation in the design stage has the greatest influence on the project, and scholars discussed it from different perspectives. Based on the criteria of improving energy efficiency and indoor thermal comfort, Si et al. established a model with high prediction accuracy by using an artificial neural network, which replaced previous complex simulation models [29].

Liu et al. analyzed colleges' planning layout and energy consumption, and developed an energy-saving model based on green performance analysis [30]. Jia et al. added dynamic characteristics of users to building performance simulation coupled with EnergyPlus^{TM}, building energy consumption simulation engine PMFServ and habitant behaviour modelling tools to solve the information exchange mechanism of dynamic characteristics of users and static characteristics of buildings [31]. Building performance evaluation should be supported by tools, and BIM is an ideal tool for it.

BIM technology is mature and introduced into green building performance evaluation. For example, Gerrish et al. explored the suitability of BIM management for building performance and demonstrated the ability of BIM and building management systems to capture, organize and link data [32]. Zhuang et al. built a lifecycle data management and application framework based on BIM technology [33]. Ansah et al. developed a BIM-based approach to lifecycle assessment (LCA) prefabricated buildings that combine different assessment levels with unique system boundaries and functional units [34]. Guo et al. proposed a green building evaluation system based on BIM technology to highlight the advantages of the BIM model and quickly conduct green building evaluation [35]. The above research has made a great contribution to green BIM. However, the research on BIM technology and green building evaluation mainly focuses on single building performance analysis. There are few studies on building performance evaluation systems adapted to BIM technology.

As reviewed, there are some studies for green hospital building performance evaluation, but they often refer to individual indicators and lack an evaluation tool. The BIM has huge potentials in promoting the development of green hospital buildings, such as information integration and interaction, simulation and visualization. This paper aims to construct a BIM-based performance pre-evaluation system for green hospital building, which not only improves the systematicity and scientificity of traditional index but also can efficiently achieve performance evaluation. Based on model results, optimization measures should also be provided.

3. Materials and Methods

This research will adopt a BIM-based pre-evaluation system to achieve green hospital building performance pre-evaluation. The system contains three steps. The first stage is to propose an index system. To be specific, the first step is to identify performance indexes and build a multifactor pre-evaluation framework around them, and then the next step is to determine the weight of the indexes by the G1 Method and Entropy Weight Methods. Then, a BIM model that contains all the needed information is needed. Finally, simulate and evaluate green hospital buildings' performance. In this stage, Ecotect is used to simulate performance, Dynamo and Matlab are used to evaluate performance and then green hospital building optimization strategies are presented according to the results.

3.1. Performance Pre-Evaluation System Construction

The evaluation starts from constructing an index system. The key indicators of green hospital building performance were screened out by a literature review and expert interviews, and then the weight of each indicator was determined accordingly.

Step1: Performance Indicators Identification. According to the "people-oriented" concept of "Green Building Evaluation Standard (GB/T 50378-2019)" and from the perspective of patients' building needs, the green hospital building performance pre-evaluation system is divided into three sectors: indoor comfort, hospital environment and resource utilization. The three first-level indicators are the basis for the selection of second-level indicators. Second-level indicators are refined and expanded based on the literature search. The three parts of the evaluation system and their related details are shown in Table 1.

Step2: Multi-factor Pre-evaluation Framework. The authors interviewed 21 experts to construct a multi-factor pre-evaluation framework for green hospital building performance. The respondents are all stakeholders in green hospital construction; thus, their views are relatively scientific (The background of 21 experts is detached in Table A1 of Appendix A). They will answer the questionnaire according to the purpose and indicators of the research. The multi-factor pre-evaluation framework is shown in Figure 1.

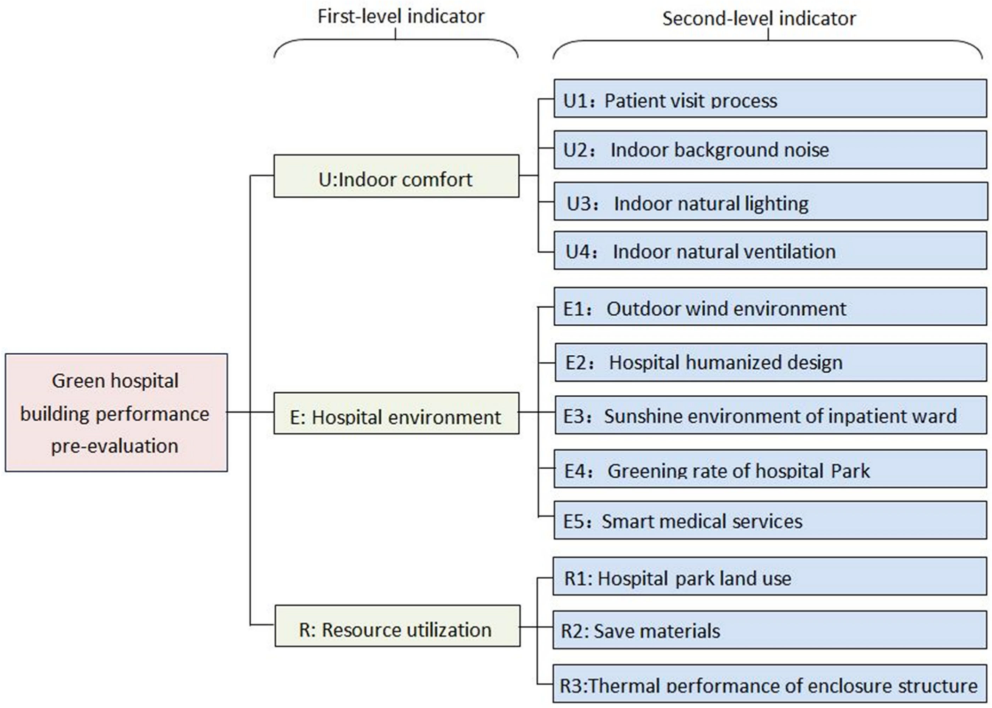


Figure 1. Multifactor pre-evaluation framework.

Step3: Index Weight Measurement. The index weight is related to the result accuracy. In order to minimize the error of a single method, this study adopted the G1 method [36,37] and the Entropy Weight Method [38–40] to assign index weight by linear weighting. By the G1 Method, experts ranked indicators according to their importance and then calculated the subjective weight by quantifying the importance between indicators. After that, the Entropy Weight Method was used to determine the objective weight. Finally, the index weight was determined after several repetitions (Table 1).

3.2. The BIM Model Construction

Then, a 3D model was established in the BIM to evaluate and optimize green building performance. BIM is the process of intelligent 3D modeling, which provides tools for planning, designing, constructing and operating [33,54]. Then, the the information required by green hospital building performance pre-evaluation will be placed into the BIM model.

BIM provides technical support for the comprehensive pre-evaluation of green hospital building performance by simulating wind, lighting, sunshine and thermal environments. The lighting environment simulation contains daylight factors, sunlight hours and illumination. Natural and artificial lighting can be simulated by loading urban meteorological data and installing lamps. Moreover, combining natural and artificial lighting can be simulated. Wind environmental performance analysis needs to simulate the impact of wind environment in different seasons on the building, which can be supported by a computational fluid dynamics (CFD) model to obtain indicators such as airflow rate, airflow vector and cell pressure. Sunshine simulation analysis is used to analyze the sunshine duration of the building on a specified day. Thermal environment simulations can effectively analyze the thermal performance of building envelope structures by setting outer wall materials, which can be mainly reflected by fabric gains, hourly temperature, gains breakdown and monthly degree days. Table 2 shows the assignment method and output of indicators based on BIM technology.

Table 1. Pre-evaluation index system of green hospital building performance.

First-Level Indicator	Second-Level Indicator	Description	References	Weight		
				Subjective	Objective	Comprehensive
U: Indoor comfort	U1: Patient visit process	Patients in the hospital registration, consultation, medicine and a series of medical services.	Sun [41], Giao [42], Zhou [43], Mazaheri Habibi [44], Wang [45].	0.2348	0.1337	0.1523
	U2: Indoor background noise	The envelope structure of the main functional space has good sound insulation performance and low indoor noise value.	Candas [21], Sadatsafavi [46], Nimlyat [47].	0.0899	0.1072	0.1040
	U3: Indoor natural lighting	The indoor natural lighting of the main function space.	Jamshidi [48], Enache-Pommer [49], Candas [21], Sadatsafavi [46], Wood [50].	0.0198	0.0723	0.0626
	U4: Indoor natural ventilation	Indoor ventilation of main functional space in the hospital building.	Enache-Pommer [49], Candas [21], Sadatsafavi [46], Wood [50].	0.0299	0.0814	0.0719
E: Hospital environment	E1: Outdoor wind environment	The wind environment of the outdoor space in different seasons should be conducive to walking and activities.	Wood [50], Buonomano [51].	0.0359	0.0344	0.0347
	E2: Hospital humanized design	Humanized design inside hospital building, outdoor rest place, privacy and eye-catching sign system.	Giao [42], Zhou [43], Jamshidi [48].	0.0494	0.0553	0.0542
	E3: Sunshine environment of inpatient ward	Sunshine exposure in inpatient wards in different seasons.	Enache-Pommer [49], Sadatsafavi [46], Wood [50].	0.0858	0.0525	0.0586
	E4: Greening rate of the hospita park	The greening situation in the hospital park can meet the ornamental and recuperative needs of inpatients and medical staff.	Jamshidi [48], Wood [50].	0.0291	0.0726	0.0646
	E5: Smart medical services	Intelligent medical services and intelligent office systems.	Kim [52], Wang [45], Shen [53].	0.2348	0.0805	0.1088

Table 1. *Cont.*

First-Level Indicator	Second-Level Indicator	Description	References	Weight		
				Subjective	Objective	Comprehensive
R: Resource utilization	R1:Hospital parkland use	Hospital building land use.	Enache-Pommer [49], Candas [21].	0.1906	0.3102	0.0866
	R2: Save materials	The use of building materials in hospital architectural design.	Enache-Pommer [49], Candas [21], Wood [50].	0.0404	0.0993	0.0885
	R3: Thermal performance of envelope structure	The thermal insulation performance of the envelope can achieve the purpose of energy saving.	Enache-Pommer [49], Buonomano [51].	0.1211	0.1114	0.1131

Table 2. BIM-based green hospital building pre-evaluation index assignment method and output.

First-Level Indicator	Second-Level Indicator	Indicator Assignment Mode	Indicator Output
U: Indoor comfort	U1: Patient visit process	BIM visualization—Revit roaming	3D animation and text information
	U2: Indoor background noise	BIM family type-wall and outside window family type parameters	Design parameters and text information
	U3: Indoor natural lighting	Autodesk Ecotect Analysis building performance simulation	Daylight factor and daylight compliance rate
	U4: Indoor natural ventilation	Autodesk Ecotect Analysis building performance simulation	Indoor air flow vector and rate
E: Hospital environment	E1: Outdoor wind environment	Autodesk Ecotect Analysis building performance simulation	Outdoor airflow vector and rate
	E2: Hospital humanized design	Revit list-BIM visualization	Design parameters and text information
	E3: Sunshine environment in inpatient wards	Autodesk Ecotect Analysis building performance simulation	Sunlight hours and sunlight compliance rate
	E4: Greening rate of the hospital park	Revit list-area and volume calculations	The area ratio
	E5: Smart medical services	Revit equipment list-BIM visualization	Equipment list and text information
R: Resource utilization	R1: Hospital parkland use	Revit list-area and volume calculations	The area ratio
	R2: Save materials	Revit material list-define family type parameters	Material list and text information
	R3: Thermal performance of envelope structure	Autodesk Ecotect Analysis building performance simulation	Fabric gains and design parameters

3.3. Green Hospital Building Performance Evaluation and Optimization

The last step is to evaluate green hospital building performance and find potential optimization measures by using the constructed 3D model and integrated engineering information.

3.3.1. Performance Simulation

The Ecotect contains a variety of simulation and analysis functions, providing technical support for building performance optimization measures. Thus, it can perform a building performance simulation, which allows the 3D model in Revit through gbXML or IFC standards. Then, loading meteorological data and related technical parameter settings into Ecotect software input building insolation, wind environment, lighting environment and thermal environment for comprehensive simulation analysis and then then output energy consumption, thermal comfort, wind environment and noise values.

Figure 2a depicts simulation parameter settings used: materials setting and the zone properties setting of the thermal environment; and the grid should be drawn as a certain size (b). Considering current climate temperature changes and wind speed being unstable, this paper uses five-day sliding temperatures, wind speed and wind direction to determine wind environment simulation parameters, shown in Figure 3. In addition, the building information for the following evaluations, such as greening rate, land use and save materials could ultimately be exported to excel files through Dynamo.

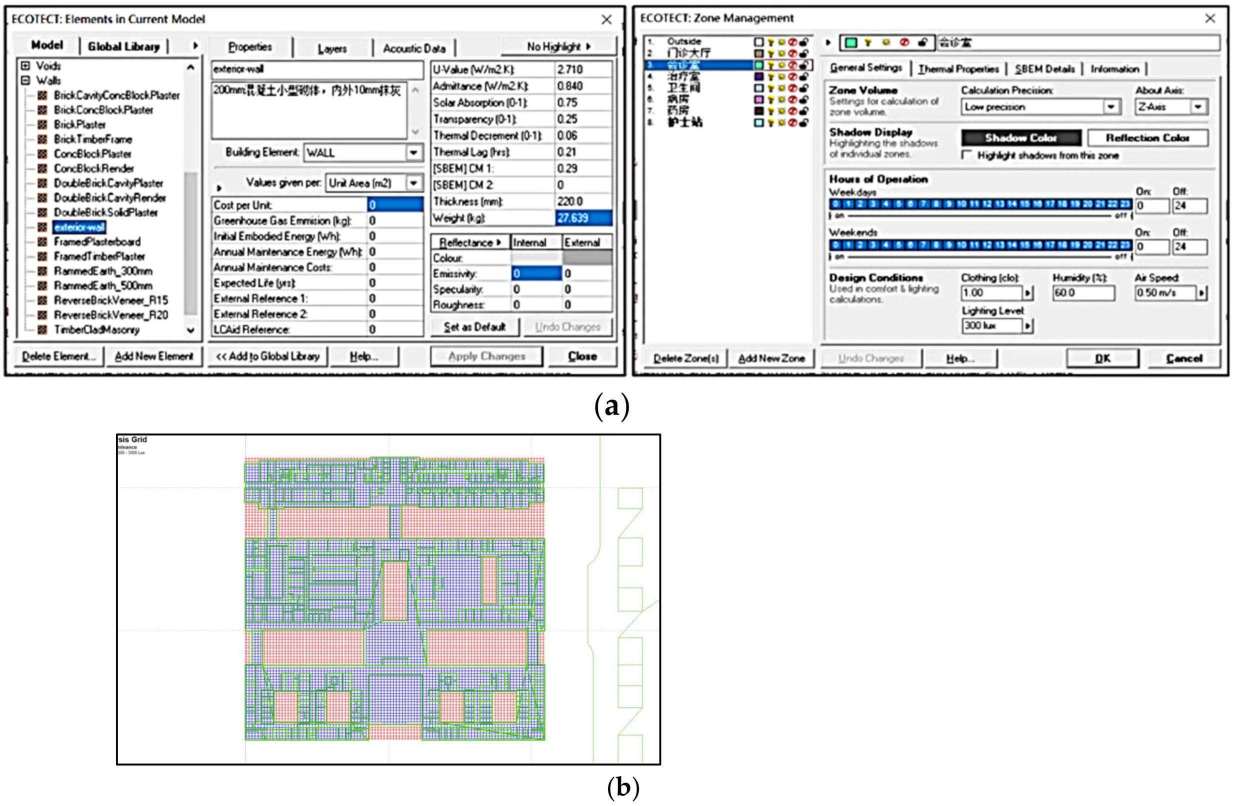


Figure 2. Screenshots of related settings in Ecotest for green building performance simulation: (**a**) thermal environment simulation parameters setting; (**b**) grid drawing of indoor light environment simulation.

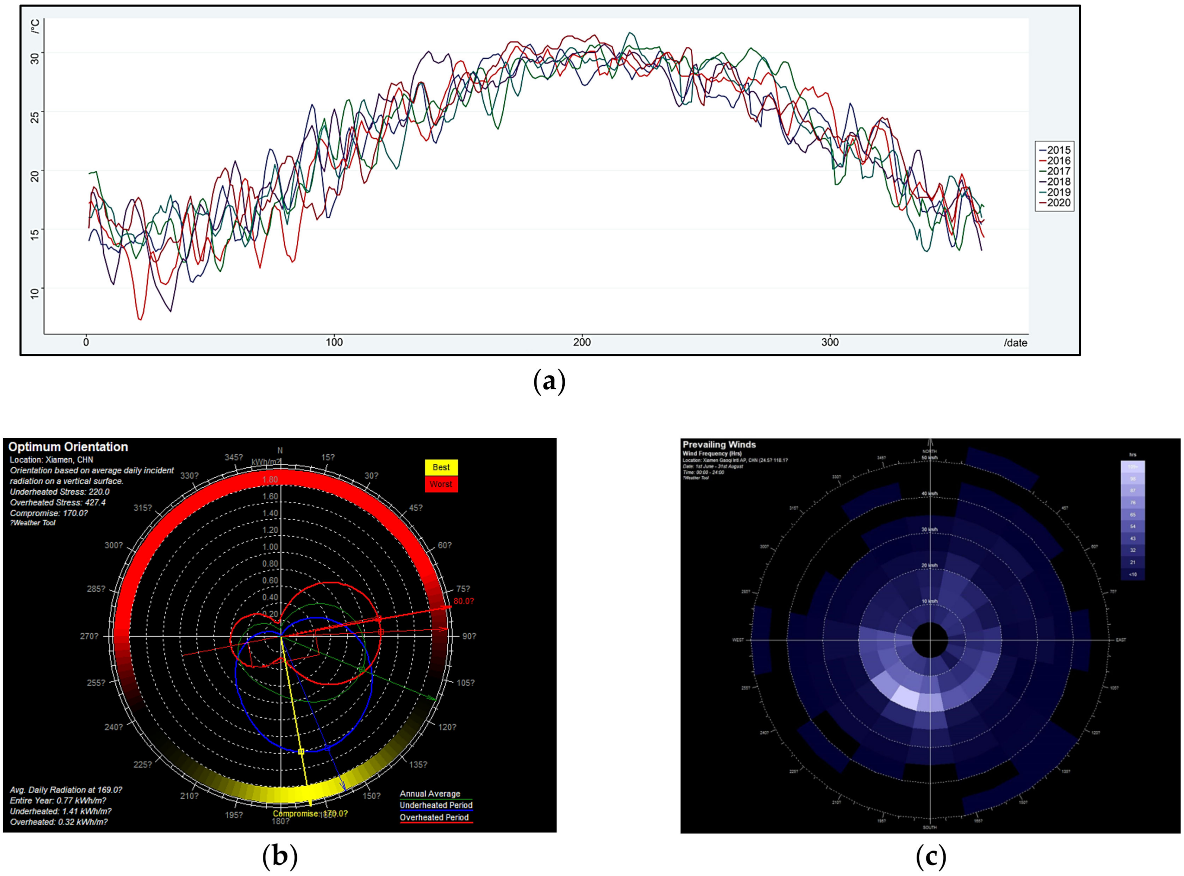


Figure 3. Wind environment simulation parameters setting: (**a**) five-day sliding temperature; (**b**) building optimum orientation; (**c**) wind rose.

3.3.2. Performance Evaluation

Based on evaluation rules, the indicators' scores will be obtained after the building performance simulation. Then, the membership degree will be calculated by the Cloud Matter–Element Theory.

(Ex, En, He) is used to replace the representation of object features to construct a cloud matter–element model where expectation *(Ex)* represents the classification of green hospital building pre-evaluation indicators. Entropy *(En)* describes the fuzziness of the pre-evaluation grade division of hospital building performance and the randomness of obtaining evaluation samples. Hyper-entropy *(He)* indicates the dispersion degree of the pre-evaluation sample of green hospital building performance. Specifically, the larger *He* is, the more discrete the sample is. The Cloud Matter–Element model is expressed as follows.

$$R = \begin{bmatrix} N_j & c_1 & (Ex_1, En_1, He_1) \\ & c_2 & (Ex_2, En_2, He_2) \\ & \vdots & \vdots \\ & c_n & (Ex_n, Enn, He_n) \end{bmatrix} \quad (1)$$

The interval division of index level is determined by *Ex*, *En* and *He* in the Cloud Matter–Element Theory. As presented in the following Equations, expected value *Ex* is calculated by the average value of the interval, and then the position of the cloud model is fixed. Entropy *En* is calculated by the "*3En*" rule that indicates almost all cloud droplets located in *[Ex − 3En, Ex + 3En]* and the left side can be neglected [55]. Taking the pre-evaluation model of green hospital building performance and the characteristics of the hospital building into consideration, each evaluation index is divided. Assuming that the grade interval of each index is (C_{min}, C_{max}), Ex, En and He in the cloud model are represented, respectively, as follows [56,57]:

$$Ex = \frac{C_{min} + C_{max}}{2} \quad (2)$$

$$Ex = \frac{C_{max} - C_{min}}{6} \quad (3)$$

$$He = s \quad (4)$$

where S is a constant, which is determined according to expert experience or practical situation.

Moreover, by selecting the normal cloud generator to calculate x, we obtain $x = Ex \pm 1.774En$. Then, set x as the boundary value of a fixed interval, and it can be defined as follows.

$$En = \frac{C_{max} - C_{min}}{2.3584} \quad (5)$$

He is an uncertain value, which determines the thickness of the cloud. The smaller the value is, the thinner the cloud is and the fuzzier the correlation coefficient is. The larger the value is, the opposite is true.

x is any cloud droplet in the cloud map. The membership function is used to calculate the correlation degree between cloud droplet and evaluation grade to finally determine the green grade of the evaluation object. The membership function expression is as follows:

$$F(x) = \exp\left[-\frac{(x - Ex)^2}{2En'^2}\right] \quad (6)$$

where En' is a normal random number generated by expected value Ex and variance He.

(1) The membership degree of secondary indicators determination

Firstly, the membership degree of the i-th evaluation index corresponding to Vp to each green grade was calculated by Matlab programming. Secondly, the membership degree of Vp to each green grade was calculated by weighting the following:

$$K_j(M_p) = \sum_{i=1}^{n} w_{pi} K_j(V_{pi}) \quad (7)$$

where $K_j(M_p)$ is the membership degree of p-th criterion matter–element to j-th green grade (j = 0,1,2,3); W_{pi} is the weight of the i-th index to the p-th criterion matter–element; and $K_j(V_{pi})$ is the measured value of the i-th indicator in the matter element of the p-th to the membership degree of the j-th green grade.

(2) The membership degree of first-level indicators determination

After obtaining the membership degree of secondary indicators, the membership degree of the first level index is weighted with second-level indexes by Equation (8).

$$K_j(M) = \sum_{p=1}^{3} w_p K_j(V_p) \quad (8)$$

(3) Green grade determination

According to the principle of maximum membership degree, the green grade of second-level indicators, first-level indicators and the matter element to be evaluated is defined as follows.

$$K(R) = maxK_j(R) \quad (9)$$

Finally, green hospital building performance grades could be divided into four categories according to calculation results: basic level, 1 star, 2 star and 3 star. The specific classification is shown in Table 3.

Table 3. Classification of green hospital building performance pre-evaluation grades.

Total		Score Classification			
		Basic level	First level	Second level	Third level
120	Graded specific gravity	40%	50%	62.5%	80%
	Range of grades	[48,60]	[60,75]	[75,95]	[95,120]

3.3.3. Performance Optimization Measures

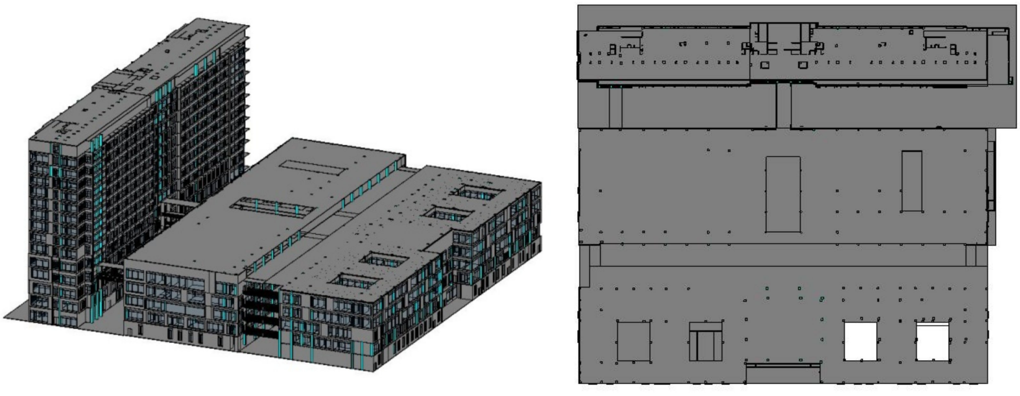
According to the evaluation results, the optimization measures of green hospital building performance can be obtained. This paper determines three aspects of green hospital building performance evaluation and optimization. Following the evaluation, score values of the first-level and second-level indices are determined, then some optimization measures will be put forward after analyzing the cause of the low score items.

4. Case Study

4.1. Case Background

In order to verify the scientificity and validity of the proposed system, the Maluan Bay Hospital is selected as an example for the application of this system. The Maluan Bay Hospital is located in Xiamen and aims to be a Class 3A hospital (the top level hospital classification in the Chinese Mainland). The selected hospital intends to construct a gross floor area of around 310,960 square meters, including 136,000 square meters and 174,960 square meters (gross floor) above and under the ground level perspectively. The performance of the hospital building will be evaluated, which contains six floors of the outpatient building and the medical building and fourteen floors of the inpatient building. The rendering of the target hospital building is presented in Figure 4, and the Revit model is presented in Figure 5.

Figure 4. The rendering of the Maluan Bay Hospital. (The picture source is from the BIM team of the Maluan Bay Hospital Tefang Company.)



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

Figure 5. Revit model of the Maluan Bay Hospital: (**a**) elevation view; (**b**) plan view.

4.2. Building Performance Simulation

The existing Revit model of the Maluan Bay Hospital can be imported into the Ecotest directly by using the gbXML standard to conduct simulations. In the indoor lighting simulation example, the sky condition is set as the CIE on a complete cloud for avoiding the influence of other factors so that only natural lighting is considered for this simulation. Moreover, the third floor is chosen to conduct a simulation to obtain the daylight factor and the daylight compliance rate. The daylight compliance rate of the outpatient building, the medical building and the ward building are 85%, 60% and 99%, respectively. Figure 6 presents the indoor daylight factor.

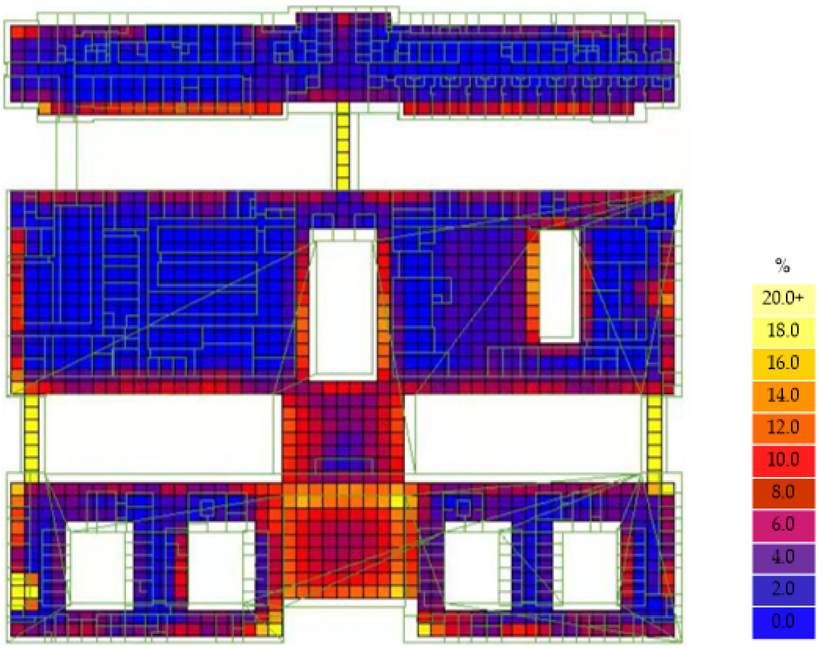


Figure 6. Simulation of the indoor daylight factor.

Wind environment simulation uses statistics of five-day sliding temperature, wind speed and wind direction in Xiamen from 2015 to 2020 to determine simulation parameters and conditions. The results of the statistics show that the average daily temperature of Xiamen is above 10 °C; there is no winter; and summer can last for 217 days per year. Thus, the transition season will be taken to replace winter for simulation. In addition, the detail parameters can be set by analyzing the wind environment: (1) wind direction: south wind in summer and northeast wind in the transition season; (2) wind speed: 4 m/s in summer and transition season. After simulation, the quantitative airflow rate and qualitative indoor airflow organization can be acquired. Figure 7 depicts indoor wind environment simulation results, and wind speed is roughly 0–1.4 m/s. The wind speed is pleasant, and the wind vector is reasonable. Furthermore, wind environment simulation can be used to simulate the wind environment outside.

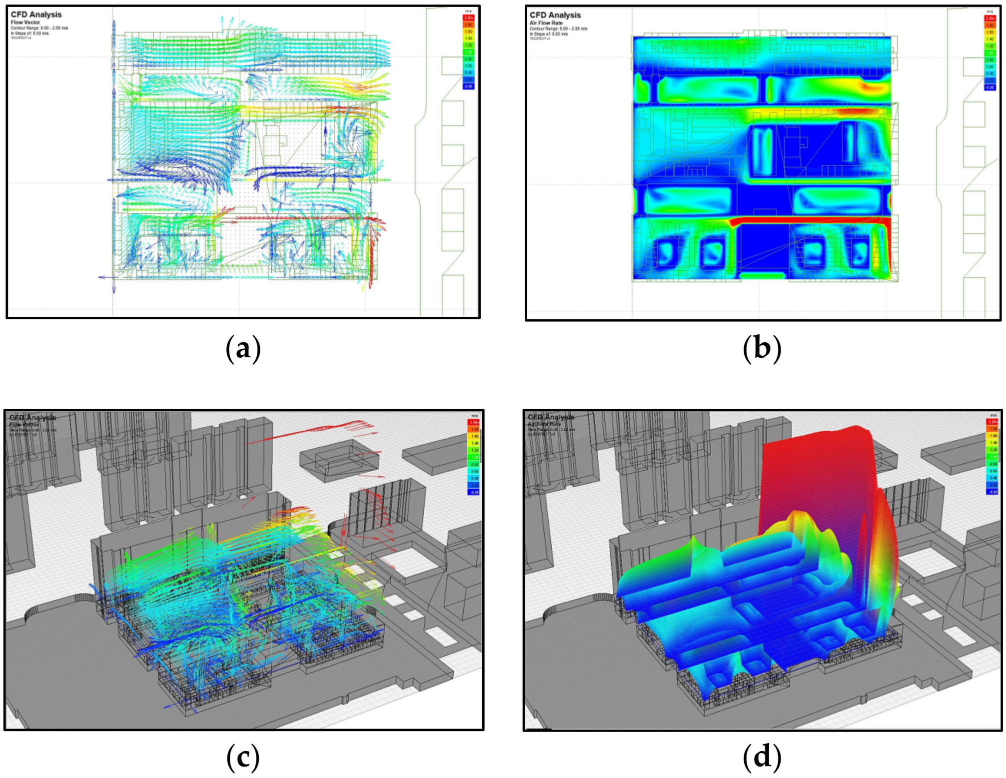


Figure 7. Simulation of the indoor wind environment: (**a**) indoor wind direction; (**b**) indoor wind speed; (**c**,**d**) 3D renderings of indoor wind direction and wind speed correspondingly.

The envelope's thermal performance is determined by simulating the thermal environment of the building. The relevant parameters need to be set before simulation, and the physical parameters of the envelope layer of the hospital are demonstrated in Table 4. Figure 8 (the fabric gains) shows that the building receives more heat from June to September, and the maximum heat is obtained from 12:00 to 18:00. The maximum heat is lost from 23:00 to 8:00 in January and December. The indoor hourly temperature curve can depict indoor temperature changes quantitatively and reflects the envelope's thermal insulation ability when subjected to the effects of the outside environment. As presented in Figure 9, the black line is the inside hourly temperature change curve, and the blue line is the outdoor hourly temperature change curve. The temperature values of the two lines are nearly identical so that the enclosure is adequately insulated. The gains breakdown indicates the day-to-day heat shift from various sources. The simulation results demonstrate heat conduction accounts for 64.1 percent, indicating that heat or cold is mostly transmitted through heat conduction forms of the envelope. The amount of heat removed by ventilation is 24.2 percent, showing that the wind speed near the building is relatively high, and airtightness needs to be strengthened. In addition, 40.4 percent of heat is obtained by solar radiation (Figure 10).

Table 4. Physical parameters of envelope layer.

Structure		Thickness (mm)	Thermal Conductivity Coefficient (W/m·k)	Thermal Storage Coefficient (W/m·k^2)	Thermal Resistance (m·k^2/W)	Thermal Inertia Index
roof	Fine aggregate concrete	40	1.74	17.20	0.023	0.395
	Composite mortar	10	0.87	10.75	0.011	0.124
	Extruded polystyrene plate	35	0.03	0.31	0.972	0.365
	Cement mortar	20	0.93	11.37	0.022	0.245
	Lightweight aggregate concrete pouring and tamping	30	0.98	11.10	0.034	0.374
	Reinforced concrete	120	1.74	17.20	0.069	1.186
Sum of layers		255			1.131	2.689
The solar radiation absorption coefficient of the outer surface				0.50		
Thermal transfer coefficient				0.78		
Outer wall	Cement mortar	15	0.93	11.37	0.016	0.183
	Sintered gangue porous brick	200	0.40	5.55	0.50	2.775
	Thermal insulation mortar	10	0.07	1.20	0.143	0.171
	Anti-crack Mortar	5	0.93	11.37	0.005	0.061
Sum of layers		230			0.664	3.191
The solar radiation absorption coefficient of the outer surface				0.12		
Thermal transfer coefficient				1.21		

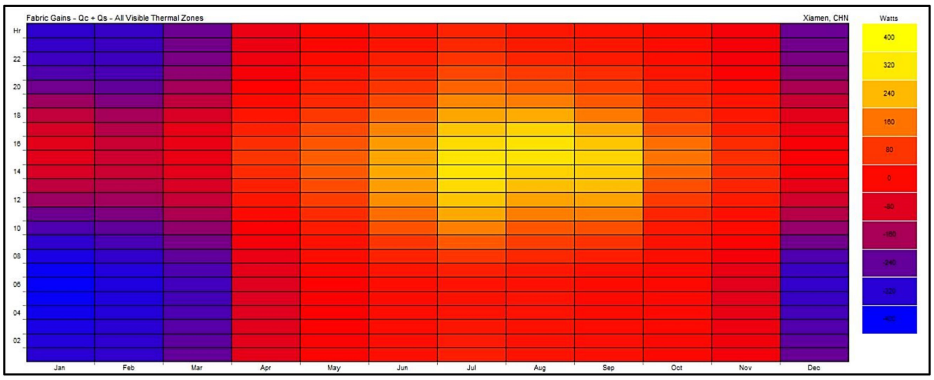


Figure 8. Simulation of the fabric gains.

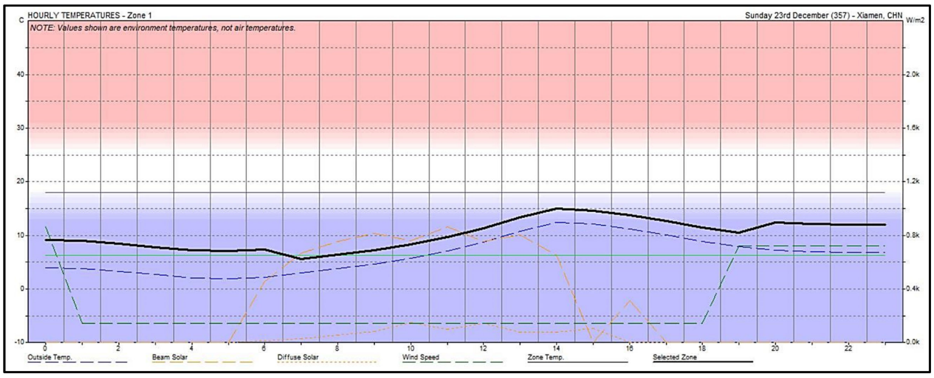


Figure 9. Simulation of the indoor hourly temperature curve.

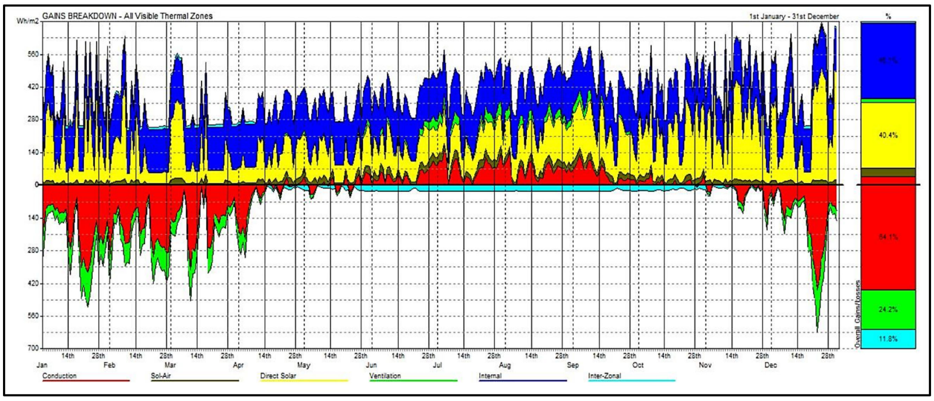


Figure 10. Simulation of the gains breakdown.

4.3. Building Performance Evaluation

By conducting the above simulations, the scores of all secondary indicators are acquired. Combined with the built evaluation model, MATLAB is used to calculate the membership degree and the green grade of the hospital to be evaluated.

(1) Project Score

Based on the actual situation of the hospital, building performance simulation is operated to obtain the pre-evaluation index data by using the BIM. Due to space constraints, indoor comfort is taken as an example to analyze the scores of each index, as shown in Table 5.

Table 5. Evaluation criteria and project scores.

Evaluation Standard	Description	Project Case	Score
U1	The department layout is reasonable and the treatment process is a sample; information network is used to improve the convenience of the treatment process.	Informationization registration services are provided, and the departments are relatively easy to reach.	6
U2	Hospitals require a high-quality indoor background noise environment to meet the current national standards.	The sound insulation performance of the component meets the high current national standard, and the impact performance of the floor meets the low standard.	7
U3	The daylight factor of main functional rooms in hospitals conforms to the current national standard <GB/T 50033-2013>.	The daylight compliance rate of the ward building, outpatient building and medical building is 99%, 85% and 60%, respectively.	6
U4	Indoor ventilation airflow organization is reasonable, and the airflow rate should be kept 0–1.4 m/s to ensure comfort.	The indoor airflow rate is 0–1.4 m/s, and the airflow vector is reasonable.	10

(2) Project green level

The scores of the second-level indexes are obtained when the simulations are completed. The first-level indexes should then be computed as a result of the suggested model. To begin, Equations can be used to find the matter–element to be evaluated:

$$R = \begin{bmatrix} N_j & M_1 & c_1 & (Ex_1, En_1, He_1) \\ & M_2 & c_2 & (Ex_2, En_2, He_2) \\ & M_3 & \vdots & \vdots \\ & & c_{12} & (Ex_{12}, En_{12}, He_{12}) \end{bmatrix}$$

where N_j (j = 0,1,2,3) is the green grade, M_p (p = 1,2,3) is the first-level index and C_i (I = 1,2,3, . . . ,12) is the second-level index.

According to the theory of matter–element extension, the classical domain is determined, wherein the basic level, 1-star, 2-star and 3-star of green hospital building grades are represented by R_1, R_2, R_3 and R_4, respectively, as follows.

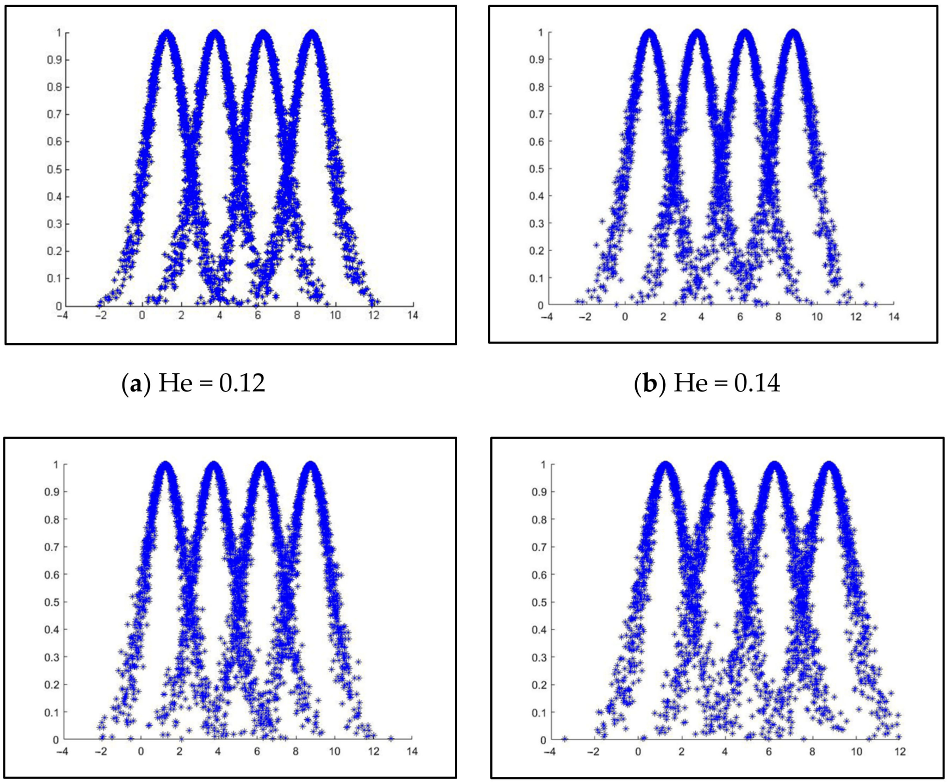
$$R_1 = (N_1, C_i, V_{ij}) = \begin{bmatrix} N_1 & c_1 & (0, 2.5) \\ & c_2 & (0, 2.5) \\ & \vdots & \vdots \\ & c_{12} & (0, 2.5) \end{bmatrix} \quad R_2 = (N_2, C_i, V_{ij}) = \begin{bmatrix} N_2 & c_1 & (2.5, 5.0) \\ & c_2 & (2.5, 5.0) \\ & \vdots & \vdots \\ & c_{12} & (2.5, 5.0) \end{bmatrix}$$

$$R_3 = (N_3, C_i, V_{ij}) = \begin{bmatrix} N_3 & c_1 & (5.0, 7.5) \\ & c_2 & (5.0, 7.5) \\ & \vdots & \vdots \\ & c_{12} & (5.0, 7.5) \end{bmatrix} \quad R_4 = (N_4, C_i, V_{ij}) = \begin{bmatrix} N_4 & c_1 & (7.5, 10.0) \\ & c_2 & (7.5, 10.0) \\ & \vdots & \vdots \\ & c_{12} & (7.5, 10.0) \end{bmatrix}$$

The node domain is the sum of all classical domain ranges, the node domain range is (0,10), and the node domain is expressed as follows.

$$R_p = (N_p, C_i, V_{ip}) = \begin{bmatrix} N_p & c_1 & (0, 10) \\ & c_2 & (0, 10) \\ & \vdots & \vdots \\ & c_{12} & (0, 10) \end{bmatrix}$$

After classical and nodal domains are obtained by the theory of matter–element extension, *Ex* and *En* in the cloud model are obtained by the preceding formulas. MATLAB programming is used to create the evaluation cloud map of *He* under the conditions of 0.10, 0.12, 0.14 and 0.16, as shown in Figure 11. The prerequisites for a cloud image are fuzziness and unpredictability. The Cloud Model has good qualities when *He* = 0.14 and may be used to calculate the precise membership degree. According to the constructed pre-evaluation model, the membership degree of second-level indicators is calculated using MATLAB, and the membership degree of first-level indicators and green grade are eventually produced. Table 6 describes pre-evaluation outcomes.



(**a**) He = 0.12 (**b**) He = 0.14

(**c**) He = 0.16 (**d**) He = 0.18

Figure 11. Cloud map with different values of *He*.

Table 6. Indicator membership degree and green grade.

Second-Level Indicator	Degree of Membership				Green Rating
	Basic Level	First Level	Second Level	Third Level	
U1: Patient visit process	0	0.1052	0.9726	0.0346	Second level
U2: Indoor background noise	0	0.0091	0.7785	0.0346	Second level
U3: Indoor natural lighting	0	0.1052	0.9726	0.0346	Second level
U4: Indoor natural ventilation	0	0	0.0019	0.4989	Third level
E1: Outdoor wind environment	0	0.0091	0.7785	0.0346	Second level
E2: Hospital humanized design	0	0	0.2561	0.7786	Third level
E3: Sunshine environment in inpatient wards	0	0	0.0346	0.9726	Third level
E4: Greening rate of the hospital park	0	0	0.0019	0.4989	Third level
E5: Smart medical services	0.019	0.4988	0.4989	0.1088	Second level
R1: Hospital parkland use	0	0	0.0019	0.4989	Third level
R2: Save materials	0	0.1052	0.9726	0.0346	Second level
R3: Thermal performance of envelope structure	0	0.0091	0.7785	0.0346	Second level

Table 6. *Cont.*

Second-Level Indicator	Degree of Membership				Green Rating	
	Basic Level	First Level	Second Level	Third Level		
First-level indicator					max $K_j(R)$	
Indoor comfort	0	0.0236	0.2901	0.0469	0.2901	Second level
Hospital environment	0	0.0546	0.0973	0.1347	0.1347	Third level
Resource utilization	0	0.0103	0.1743	0.0502	0.1743	Second level
Project Green Grade	0	0.0297	0.1949	0.0760	0.1949	Second level

The results indicate that the green level of the Maluan Bay Hospital is 2-star, and the trend of developing to 3-star is not obvious. The results are analyzed as follows:

(1) Five second-level indicators arrive at the 3-star standard, including U4, E2, E3, E4, R1 and the first-level indicator of E also meets the 3-star standard. The result demonstrates that the hospital has an excellent environment.
(2) The second-level indicators are mostly the 2-star level. Among those indicators, E5's degree is close to the 1-star and 2-star, for which their trends to 3-star is the worst. Therefore, it should be optimized and improved based on the calculation results of membership degrees.
(3) U and R both reached the 2-star level, which is consistent with the comprehensive green level of the hospital. However, it can be observed that the index of indoor comfort has the worst tendency to develop to the 3-star level, which should be optimized and improved accordingly.

4.4. Building Performance Optimization

The pre-evaluation aims to evaluate completed drawings to find the existing problems that can be optimized and provides dynamic feedback to improve the expected performance of the building. According to the performance pre-evaluation results of Maluan Bay Hospital, some optimization measures are summarized to improve its level.

(1) Improve the level of hospital intelligence

Smart medicine enables medical staff to improve their work efficiency and provides patients with convenient medical services. Thus, the following areas can be optimized: (1) Remote consultation is developed with 5G technology; (2) smart energy management platform can help to save energy during the operation stage; and (3) the utilization of big data, 5G and computer technology can improve the operation efficiency of hospitals.

(2) Reduce the opening area of the outer window

The membership degree calculation results show that indoor natural ventilation reaches the 3-star level. Moreoveer, the thermal performances of the envelope structure and indoor background noise are both 2-star level, with a trend to 3-star development. Therefore, it is possible to reduce indoor background noise and improve the envelope's thermal performance by reducing the opening area of the outer window by satisfying indoor natural ventilation.

(3) Improve the convenience of the medical treatment process

Among the first-level indicators, indoor comfort has the least obvious trend of developing to a 3-star level, and the patient treatment process is the index with the largest weight. As a result, it should be optimized to improve the convenience of medical treatment by adjusting the distribution of departments, the layout of buildings, and the use of intelligent medical treatment.

5. Discussion

This study introduced an approach integrated BIM and BIM-related tools for green hospital building performance pre-evaluation. An innovative performance pre-evaluation index system is established from a theoretical aspect to overcome the weakness of measure indicators. Moreover, extra factors that aim to improve patient satisfaction are included for green hospital performance pre-evaluation in addition to the general function. For example, hospital humanized design refers to the privacy of patients and medical staff, and smart medical services will promote treatment efficiency. Compared with previous studies that largely concern individual indicators [25–28], this study proposed a complete system to demonstrate the systematicity and scientificity of green buildings. Additionally, rating methods, such as LEED, BREEAM, HKBEAM and GB/T 51153-2015, which serve as guides for determining the green hospital building performance pre-evaluation score standard, should consider regional characteristics to achieve compatibility. After that, a BIM-based green hospital building performance pre-evaluation model is built. The hospital building's assessment is more complicated due to its special structure. Thus, a specialized performance pre-evaluation model can ensure that green hospital buildings are evaluated smoothly.

The case is taken to test the performance of the proposed assessment method. It also benefits for promoting the application of pre-evaluation and further promotes the development of green hospital buildings. Revit, a 3D model integrated project information, is built to be transferred to BIM-related information exchange and collaboration tools. Green hospital building performance simulations and evaluations are undertaken with Ecotect and MATLAB, and some optimization measures can be gained according to the index score. In addition, simulation can be repeated by resetting relevant parameters to find optimal allocation. Thus, further optimization can be conducted with BIM and BIM-related tools in the future. Although some scholars have started to evaluate performance indices by using simulation software, these studies are limited to residences, schools and commercial buildings [35] and hardly involve hospital buildings.

However, there are still some limitations. Although the proposed approach has proven to efficiently apply in the green hospital field, smart medical is not explicitly mentioned. Smart medical is a significant shift in the medical industry that must be incorporated in detail. The built green hospital building performance pre-evaluation focuses mostly on performance indicators that can be quantified and simulated. However, smart medical lack the performance indicators' properties; thus, it is difficult to apply. In addition, the pre-evaluation index screening of green hospital building performance depends on the expert consultation method. In the future, it can be improved for novel methods such as Big Data. Further work should focus on solving shortcomings and developing a more intelligent evaluation system.

6. Conclusions

In order to optimize the performance of green hospital buildings and promote sustainable development, this study constructed a BIM-based performance pre-evaluation system of the green hospital. The performance pre-evaluation index system is established by theoretical research and weight model construction, and performance simulations are guaranteed by BIM and BIM-based tools, gaining indicators' scores and green levels. Then, the Maluan Bay Hospital is taken to test the effectiveness and scientificity of the proposed method.

In this study, inpatient satisfaction was regarded as an important indicator, because some indicators involving inpatient satisfaction account for relatively large weight. Thus, the evaluation results will be more scientific and reasonable when considering inpatient satisfaction. In addition, a BIM and BIM-based pre-evaluation model is integrated, which focuses on the efficiency and accuracy of the assessment. A green hospital building can improve performance by simulation and feedback. However, there are also some limitations. Among this index system, smart medical devices are relatively important but were underappreciated. Thus, some more details about smart medical should be absorbed into the index system in the future.

Author Contributions: Z.Z., conceptualization, methodology, validation, formal analysis, data curation, writing—review and editing, visualization, project administration and funding acquisition; W.X., methodology, software, validation, formal analysis, data curation, writing—original draft preparation, writing—review and editing and project administration; L.X., methodology, software, investigation, writing—original draft preparation, visualization and project administration; X.Q., conceptualization, investigation; W.S., conceptualization and investigation; C.W., investigation, visualization and supervision; Z.H., writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: The authors are grateful for financial support from the Fujian Provincial Department of Science and Technology through grants number 2021R0056.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are openly available in (Historical weather) at (http://www.tianqihoubao.com/, accessed on 6 December 2020).

Acknowledgments: Maluan Bay Hospital Tefang Company is acknowledged for its support.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Background of 21 experts in step 2 of Section 3.1.

Item	Category	Frequency	Proportion
Employer	China Academy of Building Research	7	33.33%
	Hospital Infrastructure Department	5	23.81%
	Architecture Design Institute	9	42.86%
Working hours (year)	<5	2	9.52%
	5–10	6	28.57%
	10–15	8	38.10%
	15–20	3	14.29%
	>20	3	14.29%
Education background	Junior College	3	14.29%
	College	9	42.86%
	Master	7	33.33%
	Doctor	2	9.52%
Seniority	Primary	5	23.81%
	Intermediate	13	61.90%
	Senior	3	14.29%

References

1. Zhong, S.; Zhao, J.; Li, W.; Li, H.; Deng, S.; Li, Y.; Hussain, S.; Wang, X.; Zhu, J. Quantitative analysis of information interaction in building energy systems based on mutual information. *Energy* **2021**, *214*, 118867. [CrossRef]
2. Liu, X.; Ding, Y.; Tang, H.; Xiao, F. A data mining-based framework for the identification of daily electricity usage patterns and anomaly detection in building electricity consumption data. *Energy Build.* **2021**, *231*, 110601. [CrossRef]
3. Yazdani, M.; Kabirifar, K.; Frimpong, B.E.; Shariati, M.; Mirmozaffari, M.; Boskabadi, A. Improving construction and demolition waste collection service in an urban area using a simheuristic approach: A case study in Sydney, Australia. *J. Clean. Prod.* **2021**, *280*, 124138. [CrossRef]
4. Energy Information Administration, Department of Energy. 2018 Commercial Buildings Energy Consumption Survey. Available online: www.eia.gov/consumption/commercial (accessed on 4 January 2022).
5. Bharara, T.; Gur, R.; Duggal, S.D.; Jena, P.; Khatri, S.; Sharma, P. Green Hospital Initiative by a North Delhi Tertiary Care Hospital: Current Scenario and Future Prospects. *J. Clin. Diagn. Res.* **2018**, *12*, DC10–DC14. [CrossRef]

6. Taseli, B.K.; Kilkis, B. Ecological sanitation, organic animal farm, and cogeneration: Closing the loop in achieving sustainable development—A concept study with on-site biogas fueled trigeneration retrofit in a 900-bed university hospital. *Energy Build.* **2016**, *129*, 102–119. [CrossRef]
7. Ji, R.; Qu, S. Investigation and Evaluation of Energy Consumption Performance for Hospital Buildings in China. *Sustainability* **2019**, *11*, 1724. [CrossRef]
8. Li, Y.; Pan, X.; Han, Y.; Taylor, J.E. Sustainable Healthcare Facilities: A Scoping Review. *J. Constr. Eng. Manag.* **2021**, *147*, 03121007. [CrossRef]
9. Hossain, M.F. Green science: Advanced building design technology to mitigate energy and environment. *Renew. Sustain. Energy Rev.* **2018**, *81*, 3051–3060. [CrossRef]
10. Chi, B.; Lu, W.; Ye, M.; Bao, Z.; Zhang, X. Construction waste minimization in green building: A comparative analysis of LEED-NC 2009 certified projects in the US and China. *J. Clean. Prod.* **2020**, *256*, 120749. [CrossRef]
11. Keller, R.L.; Muir, K.; Roth, F.; Jattke, M.; Stucki, M. From bandages to buildings: Identifying the environmental hotspots of hospitals. *J. Clean. Prod.* **2021**, *319*, 128479. [CrossRef]
12. Gomes, M.G.; Rodrigues, A.M.; Natividade, F. Thermal and energy performance of medical offices of a heritage hospital building. *J. Build. Eng.* **2021**, *40*, 102349. [CrossRef]
13. Nimlyat, P.S.; Kandar, M.Z. Appraisal of indoor environmental quality (IEQ) in healthcare facilities: A literature review. *Sustain. Cities Soc.* **2015**, *17*, 61–68. [CrossRef]
14. Nilashi, M.; Zakaria, R.; Ibrahim, O.; Majid, M.Z.A.; Mohamad Zin, R.; Chugtai, M.W.; Zainal Abidin, N.I.; Sahamir, S.R.; Aminu Yakubu, D. A knowledge-based expert system for assessing the performance level of green buildings. *Knowl.-Based Syst.* **2015**, *86*, 194–209. [CrossRef]
15. Kim, S.; Osmond, P. Analyzing green building rating tools for healthcare buildings from the building user's perspective. *Indoor Built Environ.* **2013**, *23*, 757–766. [CrossRef]
16. Andrés, S.; Solar, P.d.; Peña, A.d.l.; Vivas, M.D. Implementation of BIM in Spanish construction industry = Implementación BIM en la industria española de la construcción. *Build. Manag.* **2017**, *1*, 1–8. [CrossRef]
17. Jiang, S.; Wang, N.; Wu, J. Combining BIM and Ontology to Facilitate Intelligent Green Building Evaluation. *J. Comput. Civ. Eng.* **2018**, *32*, 04018039. [CrossRef]
18. Mustaffa, N.K.; Mat Isa, C.M.; Che Ibrahim, C.K.I. Top-down bottom-up strategic green building development framework: Case studies in Malaysia. *Build. Environ.* **2021**, *203*, 108052. [CrossRef]
19. Chen, L.; Chan, A.P.C.; Owusu, E.K.; Darko, A.; Gao, X. Critical success factors for green building promotion: A systematic review and meta-analysis. *Build. Environ.* **2022**, *207*, 108452. [CrossRef]
20. Ryan-Fogarty, Y.; O'Regan, B.; Moles, R. Greening healthcare: Systematic implementation of environmental programmes in a university teaching hospital. *J. Clean. Prod.* **2016**, *126*, 248–259. [CrossRef]
21. Candaş, A.B.; Tokdemir, O.B. A unified approach to evaluate green hospitals' certification criteria. *J. Constr. Eng. Manag. Innov.* **2019**, *2*, 157–166. [CrossRef]
22. Ferrari, S.; Zoghi, M.; Blázquez, T.; Dall'O', G. New Level(s) framework: Assessing the affinity between the main international Green Building Rating Systems and the european scheme. *Renew. Sustain. Energy Rev.* **2022**, *155*, 111924. [CrossRef]
23. Licina, D.; Langer, S. Indoor air quality investigation before and after relocation to WELL-certified office buildings. *Build. Environ.* **2021**, *204*, 108182. [CrossRef]
24. Licina, D.; Yildirim, S. Occupant satisfaction with indoor environmental quality, sick building syndrome (SBS) symptoms and self-reported productivity before and after relocation into WELL-certified office buildings. *Build. Environ.* **2021**, *204*, 108183. [CrossRef]
25. Chamseddine, A.; Alameddine, I.; Hatzopoulou, M.; El-Fadel, M. Seasonal variation of air quality in hospitals with indoor–outdoor correlations. *Build. Environ.* **2019**, *148*, 689–700. [CrossRef]
26. Shi, Y.; Yan, Z.; Li, C.; Li, C. Energy consumption and building layouts of public hospital buildings: A survey of 30 buildings in the cold region of China. *Sustain. Cities Soc.* **2021**, *74*, 103247. [CrossRef]
27. Alzoubi, H.H.; Attia, A.S. Assessment of the acoustical standards in patient care units in Jordanian National Hospitals in light of the international criteria: Case of King Abdullah University Hospital. *Alex. Eng. J.* **2019**, *58*, 1205–1213. [CrossRef]
28. Leccese, F.; Montagnani, C.; Iaia, S.; Rocca, M.; Salvadori, G. Quality of Lighting in Hospital Environments: A Wide Survey Through in Situ Measurements. *J. Light Vis. Environ.* **2017**, *40*, 52–65. [CrossRef]
29. Si, B.; Wang, J.; Yao, X.; Shi, X.; Jin, X.; Zhou, X. Multi-objective optimization design of a complex building based on an artificial neural network and performance evaluation of algorithms. *Adv. Eng. Inform.* **2019**, *40*, 93–109. [CrossRef]
30. Liu, Q.; Ren, J. Research on the building energy efficiency design strategy of Chinese universities based on green performance analysis. *Energy Build.* **2020**, *224*, 110242. [CrossRef]
31. Jia, M.; Srinivasan, R. Building Performance Evaluation Using Coupled Simulation of EnergyPlus™ and an Occupant Behavior Model. *Sustainability* **2020**, *12*, 4086. [CrossRef]
32. Gerrish, T.; Ruikar, K.; Cook, M.; Johnson, M.; Phillip, M.; Lowry, C. BIM application to building energy performance visualization and management: Challenges and potential. *Energy Build.* **2017**, *144*, 218–228. [CrossRef]
33. Zhuang, D.; Zhang, X.; Lu, Y.; Wang, C.; Jin, X.; Zhou, X.; Shi, X. A performance data integrated BIM framework for building life-cycle energy efficiency and environmental optimization design. *Autom. Constr.* **2021**, *127*, 103712. [CrossRef]

34. Ansah, M.K.; Chen, X.; Yang, H.; Lu, L.; Lam, P.T.I. Developing an automated BIM-based life cycle assessment approach for modularly designed high-rise buildings. *Environ. Impact Assess. Rev.* **2021**, *90*, 106618. [CrossRef]
35. Guo, K.; Li, Q.; Zhang, L.; Wu, X. BIM-based green building evaluation and optimization: A case study. *J. Clean. Prod.* **2021**, *320*, 128824. [CrossRef]
36. Zhou, Z.-y.; Kizil, M.; Chen, Z.-w.; Chen, J.-h. A new approach for selecting best development face ventilation mode based on G1-coefficient of variation method. *J. Cent. South Univ.* **2018**, *25*, 2462–2471. [CrossRef]
37. Liu, J.; Li, Y.; Lu, Y.; Yan, S. Study on coupling optimization model of node enterprises for energy storage-involved photovoltaic value chain in China. *Energy Rep.* **2020**, *6*, 69–81. [CrossRef]
38. Zhong, C.; Yang, Q.; Liang, J.; Ma, H. Fuzzy comprehensive evaluation with AHP and entropy methods and health risk assessment of groundwater in Yinchuan Basin, northwest China. *Environ. Res.* **2022**, *204*, 111956. [CrossRef]
39. Yin, Y.; Zhang, Y. Environmental Pollution Evaluation of Urban Rail Transit Construction Based on Entropy Weight Method. *Nat. Environ. Pollut. Technol.* **2021**, *20*, 819–824. [CrossRef]
40. Jin, M.; Zhang, J.; Cui, S.; Kang, M.; Xiao, Y.; Xiang, R.; Yan, Z. Research on comprehensive evaluation of data link based on G1 method and entropy weight method. *J. Phys. Conf. Ser.* **2021**, *1820*, 012115. [CrossRef]
41. Sun, J.; Hu, G.; Ma, J.; Chen, Y.; Wu, L.; Liu, Q.; Hu, J.; Livoti, C.; Jiang, Y.; Liu, Y. Consumer satisfaction with tertiary healthcare in China: Findings from the 2015 China National Patient Survey. *Int. J. Qual. Health Care* **2017**, *29*, 213–221. [CrossRef]
42. Giao, H.N.K.; Thy, N.T.A.; Vuong, B.N.; Kiet, T.V.; Lien, L.T.P. Outpatient Satisfaction at Private General Hospitals in Ho Chi Minh City, Vietnam. *J. Asian Financ. Econ. Bus.* **2020**, *7*, 323–334. [CrossRef]
43. Zhou, F.; Xu, C.; Sun, Y.; Meng, X. Influencing Factors of Outpatients' Satisfaction in China a Cross-Sectional Study of 16 Public Tertiary Hospitals. *Patient Prefer. Adherence* **2021**, *15*, 1243–1258. [CrossRef]
44. Mazaheri Habibi, M.R.; Abadi, F.M.; Tabesh, H.; Vakili-Arki, H.; Abu-Hanna, A.; Eslami, S. Evaluation of patient satisfaction of the status of appointment scheduling systems in outpatient clinics: Identifying patients' needs. *J. Adv. Pharm. Technol. Res.* **2018**, *9*, 51–55. [CrossRef]
45. Wang, N.; Xu, H.; Song, X.; Lun, Z. Doctor Visiting Process Based on Information Technology. In Proceedings of the 2019 3rd International Conference on Data Science and Business Analytics (ICDSBA), Istanbul, Turkey, 11–12 October 2019; pp. 225–226.
46. Sadatsafavi, H.; Walewski, J.; Taborn, M. Patient experience with hospital care—Comparison of a sample of green hospitals and non-green hospitals. *J. Green Build.* **2015**, *10*, 169–185. [CrossRef]
47. Nimlyat, P.S. Indoor environmental quality performance and occupants' satisfaction [IEQPOS] as assessment criteria for green healthcare building rating. *Build. Environ.* **2018**, *144*, 598–610. [CrossRef]
48. Jamshidi, S.; Parker, J.S.; Hashemi, S. The effects of environmental factors on the patient outcomes in hospital environments: A review of literature. *Front. Archit. Res.* **2020**, *9*, 249–263. [CrossRef]
49. Enache-Pommer, E.; Horman, M.J.; Messner, J.I.; Riley, D. A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles and BIM. In Proceedings of the Construction Research Congress 2010, Banff, AB, Canada, 8–10 May 2010.
50. Wood, L.C.; Wang, C.; Abdul-Rahman, H.; Abdul-Nasir, N.S.J. Green Hospital Design: Integrating Quality Function Deployment and End-user Demands. *J. Clean. Prod.* **2016**, *112*, 903–913. [CrossRef]
51. Buonomano, A.; Calise, F.; Ferruzzi, G.; Palombo, A. Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings. *Energy* **2014**, *78*, 555–572. [CrossRef]
52. Kim, E.; Yoo, S.; Hee, H.; Park, H.; Kim, G.; Ha, S. Patient satisfaction in a context-aware hospital guidance system. *Stud. Health Technol. Inf.* **2012**, *180*, 1177–1179. [CrossRef]
53. Shen, J.; Zhang, J.; He, Q.; Pan, H.; Wu, Z.; Nie, L.; Zhang, H.; Liu, S.; Sun, Y.; Du, Y.; et al. "Without the need for a second visit" initiative improves patient satisfaction with updated services of outpatient clinics in China. *BMC Health Serv. Res.* **2021**, *21*, 267. [CrossRef]
54. Shi, Z.; Lv, K. Green highway evaluation based on Big Data GIS and BIM technology. *Arab. J. Geosci.* **2021**, *14*, 1022. [CrossRef]
55. Cao, Y.; Bian, Y. Improving the ecological environmental performance to achieve carbon neutrality: The application of DPSIR-Improved matter-element extension cloud model. *J. Environ. Manag.* **2021**, *293*, 112887. [CrossRef]
56. Dong, J.; Wang, D.; Liu, D.; Ainiwaer, P.; Nie, L. Operation Health Assessment of Power Market Based on Improved Matter-Element Extension Cloud Model. *Sustainability* **2019**, *11*, 5470. [CrossRef]
57. Wang, Y.; Zhang, X.; Wu, Y. Eutrophication Assessment Based on the Cloud Matter Element Model. *Int. J. Environ. Res. Public Health* **2020**, *17*, 334. [CrossRef]