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Integrating Sustainability and Users' Demands in the Retrofit of a University Campus in China

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Abstract: Green retrofit is essential for the sustainable development of Chinese Higher Education Institutions (HEIs). Limited by time and cost, a campus retrofit plan needs to consider both sustainability principles and usage demands to set feasible priorities. By integrating usage demands with sustainability principles, this paper aims to observe the relationship between the sustainability assessment tool (SAT) indicators of campus retrofit and users' needs in this process. The Chinese official SAT for campuses was combined with the campus environment components from six investigated HEIs, and then processed by a group of 15 members to establish an implementable framework of retrofit objectives. Taking the Weijin Campus of Tianjin University as an example, feedback from 432 users on the sample environment was analyzed according to our framework. The results show the difference between the users' perspective and sustainability indicators, emphasizing the importance of the sustainable development of HEIs and leading to the implementation of measures to improve sustainability awareness and guide a retrofit.

Keywords: university campus; green retrofit; sustainability; usage demand; retrofit programming; green campus

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1. Introduction

Environmental and health problems caused by rapid urbanization are causing countries to turn to sustainable development in social and economic aspects [1]. As a carrier of educational and research activities, HEIs, such as universities, consume a large number of resources and could have more responsibility in ensuring sustainability [2,3]. Many countries have developed and implemented SATs for campuses, which have increased diversity in campus construction [4]. China also updated its own national SATs for campuses in 2019 (GB/T 51356-2019). These SATs reflect the consensus normative framework [5] and priorities [6] of HEIs' sustainable development adopted in different contexts. They represent the hardware standards of a sustainable campus and the supporting resources to help a campus realize sustainability [7]. Through these tools, HEIs can measure their degrees of sustainability, increase their sense of sustainability, develop strategies, disseminate best practices [8], and guide organizations toward sustainability [9].

At the environmental level, the SATs also mark the evaluation content and boundary of the sustainability principles of campus construction under different backgrounds [1]. This usually includes site, water, materials, energy, indoor environmental quality (IEQ), and other factors [10].

Many studies reported the efforts of HEIs in these aspects, including the realization of campus energy conservation [11,12], sustainable resource usage [13,14], environment performance [15], etc. More up-to-date research covers carbon neutralization [16,17] and near-zero energy consumption [18,19] renovation in HEI campus.

On the other hand, adapting to users' demands is also one of the motivations for campus retrofit in many HEIs. In addition to the topics of safety [20,21], space model development [22,23], and historical elements [24], previous studies discussed the decision-making mode [25] and social elements in campus retrofit design [26].

The sustainability of the campus environment is connected to users' demands. For example, the relationship between energy consumption and environmental performance has been taken into account more in the multi-objective optimization of sustainable campus retrofit [27,28]. Other researchers discussed the link between sustainability indicators and users' needs, such as the impact of IEQ and the outdoor space on usage [29,30], and there remains a discussion of students' views toward HEIs' sustainability [31,32]. However, studies that simultaneously consider the relationship between sustainability and usage demands as a whole in campus retrofit are limited, whereas some green buildings studies have shown a possible discrepancy between pursuing sustainability indicators and meeting usage demands [33,34]. However, at the HEI campus level, there is still a lack of corresponding evidence and recognition. In China, a sustainable campus is also called a 'Green campus'. China's first green university campuses were introduced at the end of the last century. In recent decades, Chinese researchers and designers have worked on the energy-saving design of campus buildings [35,36], SATs of campuses [37,38], new campus construction projects [39], and other green campus technical strategies [40]. Since new campus construction of HEIs in China has gradually entered a stable development period, the problems of sustainable development in old campuses have recently received more attention from researchers.

Compared with the simple overlay of various types of retrofit projects, it is vital to use the whole campus as the object of green retrofit projects [41,42]. This requires the examination of multiple aspects, including planning, architecture, and the landscape [18,43]. In China, the drivers of campus retrofit construction in universities still focus on meeting usage needs [44]. Meanwhile, under the constraint of resources, campus renovation should set feasible priorities [45,46]. This makes it more realistic to discuss usage demands in the green renovation of Chinese university campuses at a holistic level. However, the state of matching between evaluation criteria-oriented construction indicators and the specific issues of campus planning, the transportation system, landscape layout, building use, and other aspects is still unclear. Considering the diversity of China's climate and geography, as well as the uneven development between campuses, we believe that it would be beneficial to develop a regional matching assistant tool for campus green retrofit. This tool needs to focus on the integration of campuses in the context of sustainability indicators and allow for cross-institutional assessments with similar conditions in the same region.

Therefore, this study aims to develop a framework for the campus retrofit of HEIs based on integrating sustainability indicators with usage demands, and examine the characteristics of the relationship between usage demands and sustainability indicators in retrofit using sample campuses.

To fulfill this aim, this study investigates the usage status of several selected HEI campuses in the Tianjin region and integrates them with national campus SAT indicators to establish a retrofit tool. Then, based on the tool application in a case study, an explanation of the gap between usage demand and sustainability principles in university campus retrofit is provided and suggestions are made in the conclusions.

2. Materials and Methods

Mixed methods research (MMR) was used in this study. First, the Chinese Assessment Standard for Green Campus (GB/T 51356-2019, ASGC) was integrated with the usage demands of the old campus. The importance of each component of the assistant tool for campus green retrofit was identified by a team of 15 experts through the Analytic Hierarchy Process (AHP). The tool was then used on the Weijin Road Campus of Tianjin University in order to comprehensively assess its retrofit elements. Finally, the priority of each retrofit point was calculated, and suggestions for campus retrofit were developed.

2.1. Tool Development

2.1.1. Framework and Indicators

- Users' demands

The Tianjin region was used as the background for tool development. This region, located in northern China, has 56 HEIs with more than 583,400 students. These campuses cover 1756 hectares, and their size has remained relatively stable in recent years (Figure 1).

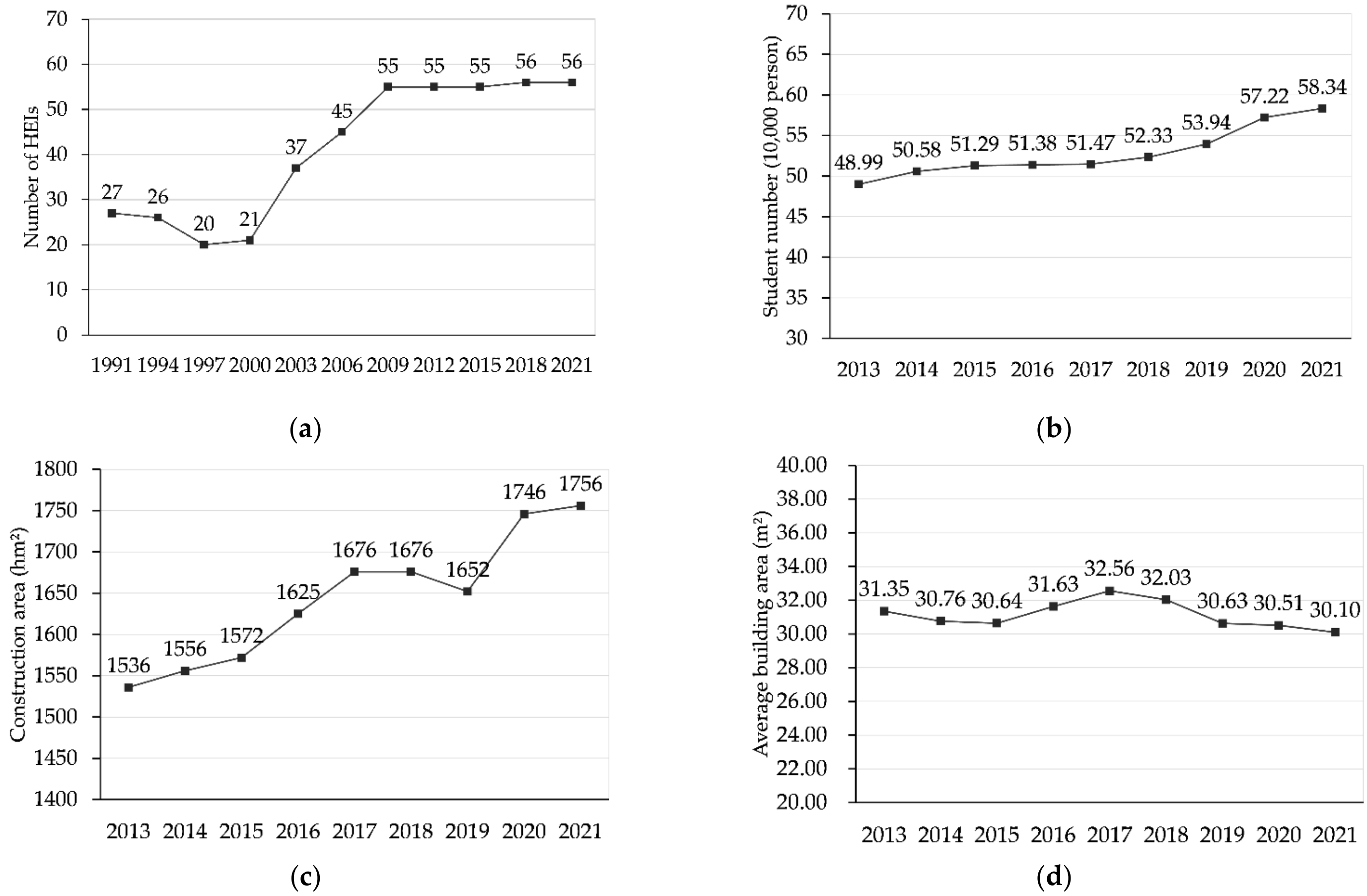
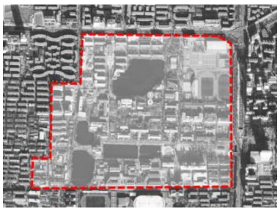
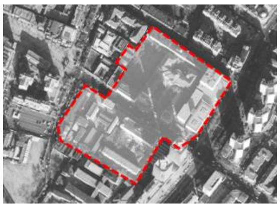


Figure 1. Overview of the HEIs in Tianjin: (**a**) number of HEIs; (**b**) student number of HEIs (10,000 person); (**c**) construction area of HEIs (hm^2); (**d**) average building area of HEIs (m^2).

We investigated 6 university campuses from a possible 56 universities in the Tianjin area. The oldest of these campuses is the Hongqiao Campus of Hebei University of Technology, built in 1903, and the newest is the Weijin Road Campus of Tianjin University, built in 1952. All of the investigated campuses have been in operation for more than 70 years (Table 1). The feedback from the users of these campuses and their fieldwork reveals some typical conditions of old local university campuses.

Structured and semi-structured interviews were conducted to assess the needs of different people on campus to improve campus space usage [47]. Those surveyed included: (a) campus administrators, mainly from the campus administration, and (b) campus user groups, consisting of faculties, staff, and students. We also conducted fieldwork to identify these demands, and categorized the recorded and identified demand points.

Table 1. Overall situation of the investigated campuses.

Name	Campus Plan	Build Year	Enrollment	Land Covered (hm^2)	Area Covered (hm^2)	Plot Ratio	Per-Student Area (m^2)
TJU, Weijin Road Campus		1952	19,000	182.00	142.50	0.78	74.96
NKU, Balitai Campus		1923	11,000	122.50	124.20	1.01	112.90
TMU, Qixiangtai Campus		1951	10,100	18.58	15.20	0.82	49.70
TFSU, Machangdao Campus		1926	10,747	12.80	11.90	0.93	49.58
TAFA, Tianweilu Campus		1906	2400	5.19	6.94	1.33	34.70
HEBUT, Hongqiao Campus		1903	28,665	199.90	90.38	0.45	31.53

As shown in Figure 2, the feedback of the users' demands was summarized into usage issues, such as campus planning, architecture, and landscape, and connected with relevant retrofit measures. The retrofit measures were divided into 8 different categories. This process refers to the structure of HEI campus SATs [10,48] in order to be able to integrate the contents of the SAT with subsequent stages. It includes common contents in campus SATs, such as 'Campus planning', 'Energy', and 'Water ', but also content topics based on usage, such as 'Building facade and function' and 'Campus safety'.

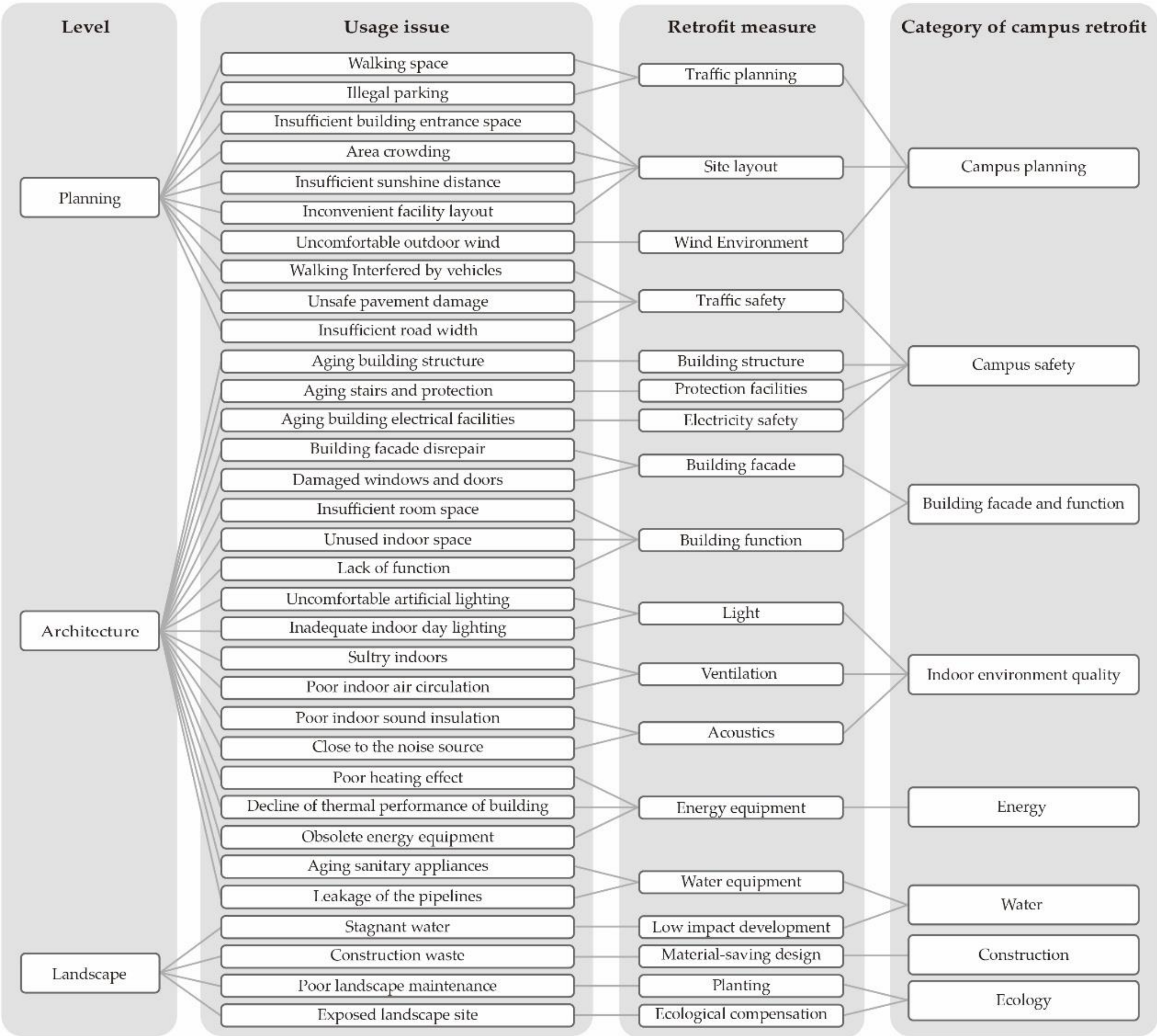


Figure 2. Identifying usage issues toward retrofit.

- Sustainable Criteria of Green Campus

A variety of SATs for HEIs have been developed (Table 2), which reflect the sustainable development of universities from concept to practice. There are calls for using a tool to evaluate global HEIs with the same criterion [9,49]. However, in practice, most SATs act more applicability in their original region [50].

As a guideline for the sustainable environmental construction of university campuses in China, ASGC is the national SAT for campus construction promulgated by the Ministry of Housing and Urban–Rural Development of China (MoHURD). The content of ASGC is divided into two sections for elementary and higher education institutions. Each section consists of 'Planning and Ecology', 'Energy and Resources', 'Environment and Health', 'Operation and Management', and 'Education and Publicity'. Among them, 28 indicators are related to campus retrofit and are distributed in three sections: 'Planning and Ecology', 'Energy and Resources', and 'Environment and Health' (Table 3).

Table 2. Overview of major sustainable campus assessment systems by country.

Name	Country	Categories	Rating Results
LEED for school	US	Location and Transportation; Sustainable Site; Water Efficiency; Energy and Atmosphere; Materials and Resources; Indoor Environmental Quality; Innovation in Design.	Platinum; Gold; Silver; Certified.
STARS	US	Academics; Engagement; Operations; Planning and Administration; Innovation and Leadership.	Platinum; Gold; Silver; Bronze; Reporter.
BREEAM Education	UK	Management; Health and Well Being; Energy; Transport; Water; Material; Waste; Land Use and Ecology; Pollution.	Outstanding; Excellent; Very Good; Good; Pass.
DGNB	Germany	Ecological Quality; Economic Quality; Technical Quality; Process Quality; Site Quality.	Platinum; Gold; Silver; Bronze.
Green Star Education	Australia	Management; IEQ; Energy; Transport; Water; Material; Land Use and Ecology; Emissions; Innovation.	World Leadership; Best Practice; Australia Excellence.
UI GreenMetric	Indonesia	Setting and Infrastructure; Energy and Climate Change; Waste; Water; Transportation; Education and Research.	Global Ranking.
CASBEE	Japan	Q1: Indoor Environment; Q2: Quality of Service; Q3: Outdoor Environment on Site; LR1: Energy; LR2: Resources and Materials; LR3: Off-site Environment.	S; A; B+; B−; C.
ASGC	China	Planning and Ecology; Energy and Resources; Environment and Health; Operation and Management; Education and Publicity.	Three-star; Two-star; One-star.

Table 3. Indicators related to retrofit in ASGC.

Tier 1 Indicators	Tier 2 Indicators
Planning and Ecology	Increase green areas; Underground space development; Comprehensive safety planning; Outdoor wind environment improvement; Vegetation protection and ecological compensation; Green infrastructure for rainwater; Campus buses; Parking lots.
Energy and Resources	Energy-saving equipment; Resources planning; Reduction in energy consumption; High-standard energy-saving design; Renewable energy utilization; Waste heat utilization; Energy efficiency optimization; Reduction in the leakage rate of the pipe network; Reduction in water consumption; Water-saving irrigation; Rainwater recycling and utilization; Reclaimed water utilization system.
Environment and Health	Prefabricated building; Indoor acoustical environment; Indoor daylight; Indoor air quality testing; Surface water quality; Reduction in heat island intensity; Campus greening.

- Integration

Addressing usage demands remains a driving force for university campus retrofit in China. In order to show a balance between sustainability goals and usage demands, we integrated the contents of Table 3 into Figure 2. The principle of integration is to merge indicators with the same retrofit content and retain indicators that will lead to different retrofit measures on both sides. This ensures that as many features of usage demands and sustainability principles as possible are covered in the framework of the tool.

As a result, we developed a framework of 8 primary indicators, 36 secondary indicators, and 66 tertiary indicators to support decision-making in green campus retrofit. These indicators include both the principles of sustainable campuses and the practical problems with the use of old campuses. (Table 4).

2.1.2. AHP

Next, an online questionnaire was organized to identify the weights of the indicators in the framework. The questionnaire for the pairwise comparison of indicators was developed according to AHP. AHP is a well-known structured, quantitative analysis method that was introduced by Saaty in the 1980s [51]. It has been widely used for the criteria weight-calculation of assessment tools [52,53]. AHP follows simple operating procedures, has high accuracy and the ability to manage complex factors, and is considered a successful technology for the research of evaluation systems [54]. The application of AHP has the following advantages: (a) As with most problems, campus retrofit can be fundamentally regarded as a combination of different hierarchical structures. (b) The hierarchical structure can match and describe the framework and content of the campus retrofit system in this study. (c) With pairwise comparisons, it is easy for researchers to judge various elements of complex campus retrofits.

Table 4. Retrofit framework integrating usage and sustainability principles.

Tier 1 Indicators	Tier 2 Indicators	Tier 3 Indicators		Source
B1. Campus planning	C1. Facility layout	D1	Area of outdoor space	Usage
		D2	Facility function layout	Usage
	C2. Underground space			ASGC
	C3. Wind environment	D3	Wind environment in winter	ASGC/Usage
		D4	Wind environment in summer	ASGC
	C4. Public transportation	D5	Site connected to public transport	ASGC
		D6	Minimum of public transport within walking distance	ASGC
		D7	Pavement connected to public transport	ASGC
	C5. Parking design	D8	Shaded and rain-proof bicycle parking lot	ASGC/Usage
		D9	Motor vehicle parking lot	ASGC/Usage
		D10	Utilization of the remaining space	ASGC
	C6. Social cooperation	D11	Public facilities open to the community	ASGC
		D12	Outdoor space open to the community	ASGC
B2. Architecture aesthetics and function	C7. Architectural aesthetics	D13	Old building facade retrofit	Usage
		D14	Old building facade style update	Usage
	C8. Building functions	D15	Adjustment of room functions	Usage
		D16	Area of functional room	Usage
		D17	Building flow	Usage
B3. Campus safety	C9. Safety site planning	D18	Emergency evacuation system	ASGC
		D19	Guiding signage system	ASGC
	C10. Traffic safety	D20	Separation of pedestrians and vehicles	Usage
		D21	Barrier-free design of pedestrian passages	ASGC/Usage
		D22	Accessible sidewalk	ASGC/Usage
	C11. Building structure	D23	Building structure reinforcement	Usage
		D24	Building roof renovation	Usage
	C12. Safety protection measures	D25	Evacuation flow	Usage
		D26	Handrails and other protection measures	Usage
	C13. Electricity safety	D27	Safety of old electrical pipelines	Usage
		D28	Safety of old electrical equipment	Usage
B4. Energy	C14. Reduction in average energy consumption			ASGC
	C15. Energy efficiency			ASGC
	C16. Renewable energy utilization	D29	Domestic hot water supplied by renewable energy	ASGC
		D30	Powered by renewable energy	ASGC
		D31	Cooling and heating by renewable energy	ASGC
	C17. Waste heat utilization			ASGC
	C18. Equipment energy-efficiency optimization	D32	Heating efficiency	ASGC/Usage
		D33	Hot water efficiency	ASGC/Usage
		D34	Equipment efficiency	ASGC/Usage
	C19. Building irregular shape			ASGC
B5. Water	C20. Water-saving irrigation			ASGC
	C21. Separate metering			ASGC
	C22. Utilization of recycled water			ASGC
	C23. Water equipment	D35	Water-saving sanitary appliances	Usage
		D36	Water supply network and equipment	ASGC
	C24. Green infrastructure for rainwater	D37	Rainwater collection rate	ASGC/Usage
		D38	Site rainwater infiltration measures	ASGC/Usage
		D39	Rainwater recycling and utilization	ASGC/Usage
		D40	Bioretention and preliminary rainwater purification	ASGC/Usage
		D41	Flood storage and peak regulation facilities	ASGC/Usage
		D42	Volume capture ratio of annual rainfall of the site	ASGC/Usage
	C25. Surface water quality			ASGC

Table 4. *Cont.*

Tier 1 Indicators	Tier 2 Indicators	Tier 3 Indicators		Source
B6. Indoor environmental quality	C26. Indoor acoustical environment	D43	Indoor noise	ASGC/Usage
		D44	Air-borne sound insulation performance between the members and the adjacent rooms	ASGC/Usage
		D45	Impact sound insulation performance of floor slabs	ASGC/Usage
		D46	Indoor reverberation time of ordinary classrooms	ASGC/Usage
		D47	Indoor reverberation time of other rooms	ASGC/Usage
	C27. Daylighting	D48	More than 80% of the classrooms meet the requirements of daylighting	ASGC/Usage
		D49	Administrative offices meet the requirements of daylighting	ASGC/Usage
		D50	More than 75% of student dormitory rooms meet the requirements of daylighting	ASGC/Usage
	C28. Indoor thermal	D51	Thermal comfort of classrooms	ASGC/Usage
		D52	Thermal comfort of administrative offices	ASGC/Usage
		D53	Thermal comfort of student dormitories	ASGC/Usage
	C29. Indoor air quality	D54	Linkage of carbon oxide concentration monitoring and ventilation	ASGC/Usage
		D55	Linkage of indoor pollutant exceedance warning and ventilation	ASGC/Usage
B7. Ecology	C30. Reduction in heat island intensity	D56	Ratio of the outdoor shadow area	ASGC
		D57	Reflected solar radiation of roofs and roads	ASGC
	C31. Greening planting	D58	Local plants	ASGC/Usage
		D59	Configuration density of trees	ASGC/Usage
		D60	Vertical and roof greening	ASGC/Usage
	C32. Vegetation protection and ecological compensation			Usage
	C33. Green space	D61	Green space rate	ASGC/Usage
		D62	Per-capita green space	ASGC/Usage
		D63	Public open campus green space	Usage
B8. Construction	C34. Building-material-saving design			ASGC
	C35. Green building materials and local building materials	D64	Usage of green building materials	ASGC
		D65	Usage of local building materials	ASGC
		D66	Usage of renewable and recyclable materials	ASGC
	C36. Prefabricated building			ASGC

In use, AHP is based on a hierarchical structure of a pairwise comparison of experts' judgments on both more- and less-important factors, and the steps that were used are shown in Figure 3. To quantify the relative importance among the elements, a one-way hierarchical scale of 1–9 was used for measurement [55] (Table 5) and forms a pairwise comparison matrix-like Formula (1).

$$X_{n*n} = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & \cdots & a_{1n} \\ a_{21} & 1 & a_{23} & \cdots & \cdots & a_{2n} \\ a_{31} & a_{32} & 1 & \cdots & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & \cdots & 1 \end{bmatrix} \tag{1}$$

where a_{ij} represents the relative importance of x_i element relative to x_j element among n elements from the X level. The X_{n*n} matrix satisfies the following: (a) For any x_i and x_j, a_{ij}>0. (b) When $i = j$, $a_{ij} = 1$. (c) For the mutual comparison of x_i and x_j, $a_{ij} = 1/a_{ji}$.

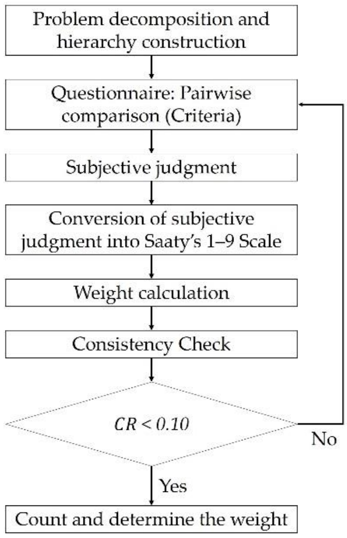


Figure 3. AHP process in this study.

Table 5. Linguistic terms and numbers.

Linguistic Term	Number
Equally important	1
Equally to moderately important	2
Moderately important	3
Moderately to strongly important	4
Strongly important	5
Strongly to very strongly important	6
Very strongly important	7
Very strongly to extremely important	8
Extremely important	9

On this basis, the geometric mean (GM) of all comparison results in X_{n*n} is calculated, which is G_i in Formula (2). Additionally, the weight result w_i of Formula (3) is obtained by normalizing GM.

$$G_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \tag{2}$$

$$w_i = \frac{G_i}{\sum_{j=1}^{n} G_i} \tag{3}$$

This process helps to determine the relative importance of indicators, but the response of expert knowledge and perception may also be inconsistent. This means that the consistency of the judgment results must be evaluated through the validation mechanism. In the AHP, the consistency of the pairwise comparison matrix is calculated using the consistency ratio (CR).

$$CR = \frac{CI}{RI} \tag{4}$$

where $CI = (\lambda_{\max} - n)/(n-1)$, and $\lambda_{\max}$ represents the largest eigenvalues. RI is the random consistency index of the 1–9-dimension judgment matrix. According to Saaty [55], if the CR value is greater than 0.1, the pairwise comparison should be repeated.

In April 2020, we invited 19 experts working in urban planning, architecture, and campus management in Tianjin, and received 15 positive responses. As a result, we assembled a team of 15 local experts to undertake an online questionnaire (Table 6), all of whom had previous experience in old campus retrofit or new green campus construction. The questionnaire was sent by email and the responses were verified for consistency. All experts were informed about the risk of having to fill out the questionnaire again in case of inconsistency ($CR < 0.1$).

Table 6. The team of experts.

Number of Years in Researching or Working in Campus Retrofit	HEIs N	HEIs (%)	Research and Design Institutes N	Research and Design Institutes (%)
1–5 years	1	12.5%	0	-
6–10 years	4	50.0%	4	57.1%
11–15 years	2	25.0%	3	42.9%
More than 20 years	1	12.5%	0	-
Total	8	100%	7	100%

After two rounds of questionnaire surveys conducted in July, 15 valid questionnaires were finally obtained, calculated, and counted.

2.2. Tool Application

2.2.1. User Survey

We applied the assistant tool to determine the willingness to retrofit the Weijin Road Campus of Tianjin University. This university is one of the oldest modern universities in China. As the basis for a green campus, the university obtained an energy-saving campus certification from the MoHURD and the Ministry of Education (MoE) [56] and participated in the demonstration application of the campus energy management system (CEMS) [57]. It is a good sample for investigating the transition of Chinese HEIs from energy-saving campuses to a green campuses. Moreover, in 2018, Weijin Road Campus was selected by the MoHURD as the national green campus construction demonstration project to test the typical situation of sustainable development in the campuses of old HEIs [58,59]. Therefore, this is the most realistic campus to choose for a case study.

The response of users on campus was examined by using a tool that integrates demand and sustainability principles. Due to the influence of COVID-19, the Weijin Road campus was closed to the public by a smart access control system that recorded the attendance on campus and posted it to the campus mobile APP.

Accommodation and activities for students varied widely on campus during the pandemic. Based on the APP records from 7–11 September 2020, we calculated the average attendance distribution on campus between 06:00 and 24:00 on weekdays (Figure 4), and found the attendance number on campus peaks to be between 12:00 and 14:00. In order to cover more campus users, 12:00–14:00 was selected as the time for the survey.

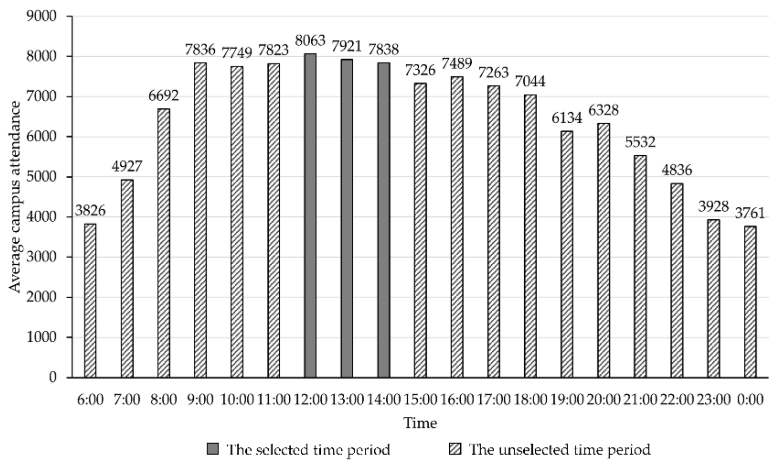


Figure 4. Average attendance number on campus.

The next 5 working days were used for the investigation. A sample size of approximately 1% of the average campus attendance at that time was collected each day through random sampling in multiple fixed scenarios. The locations for data collection included restaurants, gardens, dormitories, and teaching buildings on campus. The sample groups surveyed comprised several different campus users, including (a) students, (b) teachers, (c) staff, and (d) other personnel (campus visitors, non-university staff, etc.). Respondents were asked to provide basic information to avoid repeated collection.

In the research, we created electronic and paper versions of the questionnaire based on the same question system, constructed the logic of the questions and answers in the interview, and adopted various collection strategies according to the respondents. We used positive statements to describe the issues in the form of 'In the current situation of X-level at Weijin Road Campus, I am satisfied with the x_i-aspect', and used Likert scales (1 = strongly disagree to 5 = strongly agree) to process the feedback. This made the users' scores proportional to their satisfaction.

In addition, some tier 3 indicators in the framework were not easily understood by the respondents. Therefore, these indicators were consolidated and replaced with their parent indicators in the form of questions. These made the collected feedback from the users of Tianjin University's Weijin Road Campus more accurate, and reduced the distortion of respondents' feedback due to the collection form.

Finally, 432 valid samples were recovered, and the basic information of the respondents is shown in Table 7.

Table 7. Baseline characteristics of the respondents.

	Total n = 432	**Percentage**
Age		
<18	6	1.39%
18–25	158	36.57%
25–30	96	22.22%
30–40	64	14.81%
40–50	48	11.11%
50–60	46	10.65%
>60	14	3.24%
Identity		
Student	258	59.72%
Teacher	86	19.91%
Staff	76	17.59%
Others	12	2.78%
Gender		
Female	136	31.48%
Male	296	68.52%
Accommodation		
Boarding at school	284	65.74%
Boarding outside school	148	34.26%

2.2.2. Calculation of Results

The arithmetic mean of satisfaction was used to initially quantify the results of feedback. In order to compare the relative values of different data, the following formula was used to normalize the indicators' weights and average satisfaction:

$$S = (x_i - x_{min}) / (x_{max} - x_{min}) \tag{5}$$

where S is the synthetical weight or satisfaction index; x_i is the absolute value of the weight or average satisfaction; and x_{max} and x_{min} represent the maximum and minimum values in the corresponding data. This makes the data from the two different dimensions more comparable. The results comprise the absolute and relative values of the indicators in the overall level of campus retrofit under the two main orientations of sustainability principles and usage demands.

3. Results

3.1. Weights

The mathematical function of the weight calculations is to show the degree of importance of each element of the corresponding indicator. Appendix A shows the weight of each element calculated in the framework of the assistant tool. In the calculation of the primary indicators, the elements with the highest weights are 'Energy' and 'Campus safety', followed by 'Indoor environmental quality', 'Water', and 'Campus planning'. The weights of these five elements were significantly higher than those of the next three elements: 'Architectural aesthetics and function', 'Ecology', and 'Construction'. This indicates that the performance of campus safety and energy efficiency are the most sensitive and affected issues in established campus retrofit.

By determining the synthetical weight (Appendix B), the secondary indicators, which provide strong guidance and functions for the relevant design strategies, can be broadly divided into three groups (Table 8): an emphasis on indicators with *S* values higher than 0.6, a relative emphasis on *S* of 0.3 to 0.6, and general indicators with a synthetical weight below 0.3. In addition to 'Green building materials', the secondary indicators with the highest weight in each category were related to usage demands. The highest percentage of important indicators was found in 'Indoor environmental quality', 'Water', and 'Energy'. This result shows that experts have a higher perception of specific issues under the relevant topics during retrofit. The weights of the primary indicators of 'Ecology' and 'Construction' were low. After further communication with the respondents, since existing campus landscapes have formed certain styles and usage habits over the course of their long-term development, universities regularly maintain and improve their campuses, while campus retrofit mainly focuses on small-scale construction, so these indicator weights are lower.

3.2. Satisfaction

The overall average satisfaction score of Tianjin University Weijin Road Campus was 3.53 (Appendix A), the score rate was 70.68%, and the sample satisfaction rate was 87.28%. These data indicate that users' feedback regarding the campus was generally positive, but there was still room for optimization and improvement.

As with the weights, the synthetical satisfaction results (Appendix B) could be grouped into three similar categories (Table 9). They included satisfactory issues with an *S* value greater than 0.6, relatively satisfactory issues with an *S* value between 0.3 and 0.6, and less satisfactory issues with an *S* value below 0.3. Regarding the primary indicators, 'Ecology' contained the most satisfactory indicators. Compared with dissatisfactory issues, 'Campus safety' and 'Indoor environmental quality' contained more satisfactory indicators. The scores of 'Construction', 'Architecture aesthetics and function', 'Campus planning', and 'Water' were average, and the score of 'Energy' was low. Regarding the secondary and tertiary indicators, users gave positive feedback regarding the architectural style of the campus, safety of the building structure, safety protection measures in the building, number of irregular buildings on campuses, greening irrigation, quality of surface water, quality of indoor air, heat island intensity, green planting, vegetation protection, etc. The issues that received negative comments were mainly associated with usage demands. Users gave negative feedback regarding the underground space on campuses, electricity safety, waste heat utilization, equipment energy efficiency, green rainwater infrastructure, etc.

Table 8. Synthetical weights of the indicators in the framework.

Tier 1 Indicators	*S* of Tier 2 Indicators							
	S < 0.3	(%)	*S* Within 0.3–0.6	(%)	*S* > 0.6	(%)	Highest *S*	Resource
B1. Campus planning	3	50.00%	3	50.00%	0	0.00%	C1. Facility layout	Usage
B2. Architecture aesthetics and function	0	0.00%	2	100.00%	0	0.00%	C8. Building functions	Usage
B3. Campus safety	1	20.00%	4	80.00%	0	0.00%	C13. Electricity Safety	Usage
B4. Energy	2	33.33%	3	50.00%	1	16.67%	C18. Equipment energy efficiency	ASGC/Usage
B5. Water	4	66.67%	0	0.00%	2	33.33%	C24. Green infrastructure for rainwater	ASGC/Usage
B6. Indoor environmental quality	0	0.00%	2	50.00%	2	50.00%	C26. Indoor acoustical environment	ASGC/Usage
B7. Ecology	4	100.00%	0	0.00%	0	0.00%	C31. Greening planting	ASGC/Usage
B8. Construction	3	100.00%	0	0.00%	0	0.00%	C35. Green building materials	ASGC

Table 9. Synthetical satisfaction of indicators in the framework.

Tier 1 Indicators	*S* of Tier 2 Indicators							
	S < 0.3	(%)	*S* Within 0.3–0.6	(%)	*S* > 0.6	(%)	Lowest *S*	Resource
B1. Campus planning	2	33.33%	3	50.00%	1	16.67%	C2. Underground space	ASGC
B2. Architecture aesthetics and function	1	50.00%	0	0.00%	1	50.00%	C8. Building functions	Usage
B3. Campus safety	1	20.00%	2	40.00%	2	40.00%	C13. Electricity safety	Usage
B4. Energy	5	83.33%	0	0.00%	1	16.67%	C18. Equipment energy efficiency	ASGC
B5. Water	2	33.33%	2	33.33%	2	33.33%	C24. Green infrastructure for rainwater	ASGC/Usage
B6. Indoor environmental quality	0	0.00%	3	75.00%	1	25.00%	C28. Indoor thermal	ASGC/Usage
B7. Ecology	0	0.00%	1	25.00%	3	75.00%	C33. Green space	ASGC/Usage
B8. Construction	0	0.00%	3	100.00%	0	0.00%	C36. Prefabricated building	ASGC

The satisfaction results essentially reflected the actual perception of users on campuses. The green space ratio of Weijin Road Campus is 36%. Additionally, the campus is adjacent to the city's water body, and there are four small artificial lakes on the campus. The rich ecological resources of the campus are essential for the 'Begonia Festival' and other landscape cultural activities. From a biological perspective, this explains the users' positive comments regarding campus ecology [60]. Campus users made positive comments regarding campus ecology. Tianjin University invests nearly CNY 300 million each year in the retrofit of the existing buildings and campuses to improve their overall appearance and function. The previous forms of campus retrofit were mainly fragmentary and gradual, avoiding the disturbance to normal teaching and living activities due to the overall retrofit.

Meanwhile, the Weijin Road campus was built in the 1950s, 76.14% of the buildings were built more than 20 years ago, and 31.25% of the buildings were built before 1970. It is difficult to improve the use of underground space through general retrofit and repair due to the limitations of the built environment. The overall score of campus safety was high, but some of the old buildings on campus, such as the former Liulitai Student Dormitory (which has been gradually renovated) and Qilitai Student Dormitory, have aging electrical facilities and poor electrical safety. Some of the old buildings that have not been retrofitted have aging heating equipment and leaking pipelines. While some of the old buildings that have been retrofitted excessively focus on reducing energy consumption, and due to the subjective differences [61] in some users' perceptions of the indoor thermal environment in the winter, the feedback regarding energy was generally negative. Old buildings and limited retrofit also reduced some positive comments on indoor environmental quality. Meanwhile, the drainage of rainwater and sewage pipes in some areas of the campuses are poor, and water accumulation is more serious in the rainy season.

4. Discussion

This study constructed a comprehensive campus retrofit auxiliary tool that integrates usage demands and sustainability indicators, and examined users' feedback on the sample campus based on this tool. It can be found from the results that: (a) There are differences in the content between users' demands and sustainability indicators in the setting of HEI campus retrofit issues. (b) Retrofit issues related to usage account for a higher proportion of the more sensitive content in each category. (c) The users' feedback from the sample campus is more based on the perceivable characteristics of the campus.

As mentioned, previous studies emphasized the importance of usage perspective in buildings [33,34]. The application of green assessment systems does not entirely imply the satisfaction of users' demands [62]. This provides the basis for similar discussions about HEI campuses. By integrating usage demands in retrofitting, along with the Chinese official green campus assessment standard from a whole-campus level, this study suggests a new perspective for observing the difference between campus users' demands in the context of a sustainability assessment system for higher education.

The combination of results from previous studies with the development of sustainability assessment systems can be understood in two ways. One aspect is the difference between the contents. Although some previous studies described some common characteristics of both campus sustainability indicators and users' needs [63,64], evidence suggests that there is a difference [62]. Our findings provide more evidence for this view from the perspective of user needs in the context of HEI. Some issues of usage demands, such as the layout of campus facilities, building functions, building structural safety, and campus architectural appearance, have not been included in the ASGC, while, for the aspect of commonality, the results of weights and feedback explain more important retrofit issues from the perspective of demand. For instance, although energy indicators had a high weight in the framework, users provided more feedback based on comfort, and little feedback involved concerns about energy consumption and carbon emissions in use. The sustainability principles that users were concerned about were also more oriented toward the health and comfort aspects of use, such as poor heating in winter and indoor noise.

Furthermore, the update of ASGC also explained this difference, to some extent. Unlike STARS and UI GreenMetric, ASGC is closely related to China's Assessment Standard for Green Buildings (ASGB). Green building assessment tools, including ASGB, pay more attention to economic and environmental factors in the early stage [65,66], while neglecting end users [67]. The first vision of ASGC (CSUSGBC 04-2013) promulgated in 2013 adopted the model structure of 'Land conservation', 'Water conservation', 'Material conservation', and 'Energy conservation' from ASGB (GB/T 50378-2006). In recent years, user-side indicators, such as comfort and psychological experience, are constantly being included in various green building assessment systems [63]. ASGB also changed its structure in the 2019 update based on users' feedback from the application. The updated ASGC in the same year synchronized this approach, adopting a more comprehensive framework and incorporating more user-related indicators. However, the economy and environment remain important themes. Their importance in sustainability principles cannot be overstated, but the question remains of how to associate this factor with the demands of campus users [68]. Relevant studies have underlined the role of users' awareness [69–71]. In the practice of raising awareness, improving the clarity of information regarding campus energy consumption is seen as an effective method [72–74]. The improvement of energy awareness can increase users' enthusiasm for campus energy-saving retrofitting, change some retrofit demands from the perspective of comfort, and raise the awareness of users of energy saving.

Another aspect is reflected in the meticulous expressions of the content of sustainable campus evaluation indicators and users' demands. Compared with the ASGC, which has two tiers, users tend to express their specific needs from a more practical perspective and are more likely to provide clear retrofit suggestions [75,76]. This difference explains, to some extent, demand orientation dominating the retrofitting of university campuses in China. A college campus can be viewed as a more streamlined model of a city [77], including a community, workplaces, natural landscapes, and complex social and economic aspects. This makes it easier to implement repairs based on actual demand. rather than systematic green retrofits, since corrections to usage problems allow us to more easily find paradigm solutions. Similarly, some cities have introduced guidelines for green retrofit in urban areas to reduce the trial costs of retrofitting large-scale urban areas [78,79]. This may provide a good reference for the green retrofitting of local university campuses; however, the specificity of universities in terms of educational attributes and population needs to be considered.

5. Conclusions

This study aimed to inspect the difference between sustainability principles and users' demands in campus retrofitting through the construction of the assistance tool for the green retrofitting of established university campuses. To achieve this goal, six selected university campuses were investigated to determine typical campus usage issues. We identified the indicators involved in campus retrofit using the Green Campus Evaluation Criteria, and established the scope and characteristics of green campus retrofit through integration with users' demands. By calculating the weight assignments and case satisfaction, the difference between users' demands for campus retrofit and the sustainability principles was explained. This difference is reflected in the content and clarity. The differences in content may stem from the different orientations between the concepts and the awareness of users. This reflects the resistance to the green retrofit of established university campuses due to complexity. We recommend improving the clarity of information regarding campus energy and developing different local guidelines to promote the improvement of users' awareness and reduce the cost of trial.

- Limitation

University campuses are also considered important places of activity for residents from the surrounding communities [80]. However, due to the impact of the epidemic, local universities have adopted closed management during study, which means that the campuses were inaccessible to city residents other than students, faculty, and staff. Therefore, this study only considered the use demand of the institutional users and their views on campus retrofit. We hope to expand the research scope of this assistant tool in the future to analyze the users' demands in campus retrofit from a more comprehensive perspective.

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Appendix A

Table A1. Weight and average satisfaction.

Tier 1	Weight	Satisfaction	Tier 2	Weight	Satisfaction	Tier 3	Weight	Satisfaction
B1	0.153	3.694	C1	0.038	3.727	D1	0.016	3.322
						D2	0.022	4.032
			C2	0.011	3.182			
			C3	0.028	3.655	D3	0.015	3.192
						D4	0.012	4.22
			C4	0.02	3.606	D5	0.007	3.325
						D6	0.006	4.328
						D7	0.007	3.235
			C5	0.035	3.513	D8	0.013	3.624
						D9	0.022	3.445
			C6	0.021	4.319	D10	0.018	3.323
						D11	0.005	3.192
						D12	0.005	2.983
B2	0.07	3.832	C7	0.029	4.234	D13	0.016	4.321
						D14	0.013	4.123
			C8	0.041	3.541	D15	0.014	3.987
						D16	0.016	2.972
						D17	0.011	3.835
B3	0.187	3.976	C9	0.022	3.875	D18	0.015	4.128
						D19	0.008	3.383
			C10	0.039	3.735	D20	0.016	3.358
						D21	0.014	3.774
						D22	0.01	4.283
			C11	0.041	4.492	D23	0.026	4.567
						D24	0.015	4.358
			C12	0.043	4.324	D25	0.024	3.994
						D26	0.019	4.728
			C13	0.041	3.38	D27	0.014	3.127
						D28	0.027	3.516
B4	0.188	3.48	C14	0.017	3.512			
			C15	0.036	3.528			
			C16	0.034	3.342	D29	0.012	3.432
						D30	0.009	3.343
						D31	0.013	3.256
			C17	0.03	3.312			
			C18	0.058	3.212	D32	0.023	2.832
						D33	0.016	3.583
						D34	0.019	3.368
			C19	0.015	4.58			
B5	0.166	3.632	C20	0.012	4.328			
			C21	0.01	3.526			
			C22	0.008	3.987			
			C23	0.045	3.853	D35	0.028	3.674
						D36	0.017	4.152
			C24	0.071	3.04	D37	0.019	3.178
						D38	0.016	2.923
						D39	0.006	3.282
						D40	0.004	3.328
						D41	0.013	3.128
						D42	0.014	2.728
			C25	0.02	4.757			
B6	0.167	3.775	C26	0.052	3.641	D43	0.015	3.128
						D44	0.01	3.738
						D45	0.009	3.682
						D46	0.011	4.125
						D47	0.006	3.728
			C27	0.037	3.746	D48	0.015	4.125
						D49	0.009	3.973
						D50	0.013	3.152
			C28	0.05	3.593	D51	0.018	3.452
						D52	0.013	4.127
						D53	0.02	3.383
			C29	0.028	4.378	D54	0.01	
						D55	0.019	

Table A1. *Cont.*

Tier 1	Weight	Satisfaction	Tier 2	Weight	Satisfaction	Tier 3	Weight	Satisfaction
						D56	0.005	
			C30	0.01	4.782	D57	0.005	
						D58	0.006	4.343
			C31	0.017	4.312	D59	0.007	4.578
B7	0.048	4.216				D60	0.004	3.777
			C32	0.006	4.156			
						D61	0.007	3.988
			C33	0.015	3.764	D62	0.005	3.158
						D63	0.003	4.384
			C34	0.003	3.752			
						D64	0.007	
B8	0.021	3.929	C35	0.015	4.027	D65	0.003	
						D66	0.005	
			C36	0.003	3.592			

Appendix B

Table A2. Synthetical results of weight (Sw) and satisfaction (Ss).

Tier 1	Tier 2	Sw	Ss
B1. Campus Planning	C1. Facility layout	0.5164	0.3944
	C2. Underground space	0.1163	0.0815
	C3. Wind environment	0.3608	0.3530
	C4. Public transportation	0.2497	0.3249
	C5. Parking design	0.4719	0.2715
	C6. Social cooperation	0.2719	0.7342
B2. Architecture aesthetics and function	C7. Architectural aesthetics	0.3880	0.6854
	C8. Building functions	0.5508	0.2876
B3. Campus Safety	C9. Safety site planning	0.2868	0.4793
	C10. Traffic Safety	0.5314	0.3990
	C11. Building structure	0.5586	0.8335
	C12. Safety protection measures	0.5857	0.7371
	C13. Electricity Safety	0.5586	0.1952
B4. Energy	C14. Reduction in average energy consumption	0.2072	0.2710
	C15. Energy efficiency	0.4812	0.2801
	C16. Renewable energy utilization	0.4538	0.1734
	C17. Waste heat utilization	0.3990	0.1561
	C18. Equipment energy efficiency	0.8099	0.0987
	C19. Building irregular shape	0.1799	0.8840
B5. Water	C20. Water-saving irrigation	0.1299	0.7394
	C21. Separate metering	0.1058	0.2790
	C22. Utilization of recycled water	0.0816	0.5436
	C23. Water equipment	0.6135	0.4667
	C24. Green infrastructure for rainwater	1.0000	0.0000
	C25. Surface water quality	0.2508	0.9856
B6. Indoor environmental quality	C26. Indoor acoustical environment	0.7143	0.3450
	C27. Daylighting	0.4955	0.4053
	C28. Indoor thermal	0.6900	0.3175
	C29. Indoor air quality	0.3739	0.7681
B7. Ecology	C30. Reduction in heat island intensity	0.1016	1.0000
	C31. Greening planting	0.2143	0.7302
	C32. Vegetation protection and ecological compensation	0.0523	0.6406
	C33. Green space	0.1791	0.4156
B8. Construction	C34. Building-material-saving design	0.0066	0.4087
	C35. Green building materials and local building materials	0.1808	0.5666
	C36. Prefabricated building	0.0004	0.3169

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