Study on Green Architecture Design Method and Evaluation Model from the Sustainable Development Perspective

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Abstract — This paper explores the green architecture design method and evaluation model. Based on the ecological thinking, we proposed the green architecture design method, that is, integration design of architecture and landscape. Integration design of architecture and landscape means to combine ecological landscape design and architecture design, synthetically considering the landscape layout, terrain, architectural form, architectural space, landscape structure, etc. For green architecture design evaluation, we introduced the weighted radar chart analysis, and establish the green architecture design evaluation index system, to carry out evaluation of four green architecture design schemes.

Keywords - Architecture ; Perspective; Ecological

I. INTRODUCTION

With the in-depth research in the green architecture and the rapid development in its practice, the definition of green architecture can no longer be limited just as a product of architecture design practice with ecological consciousness. Most of the traditional argument on this field are often confined in vague and general theoretical research as well as partial technical strategy, rather than how to systematically apply the research of green architecture design into design practice. According to current situation, this study is focused on researches on the integration design of architecture and landscape, which is positioned as one sub-topic of research on the methodology of green architecture design. And based on weighted radar chart analysis method, we construct the evaluation model of green architecture design [1-3].

II. GREEN BUILDING DESIGN METHOD

A. Ecological Thinking

Ecological thinking is the basic way of thinking of green building design, in which we consider the nature as an interrelated entirety continually generating new things, with various material systems of various organizational structures [4]. Abandoning the ancient and simple ecological thinking and modern metaphysics thinking, green building thinking has its unique characteristics [5,6].

First, it emphasizes the integrity of ecosystems. In the early twentieth century, physicists were working on microscopic anatomy of the object, but neglecting his objective integrity. While green building thinking emphasizes the integrity, since the whole ecosystem is composed of many elements, rather than mechanical accumulation of elements, without additivity. In an ecosystem, the integrity and the parts are interconnected and inseparable. The combination and structure of all elements determines the overall function and effect of the ecosystem [7].

Second, it emphasizes self-organization of ecosystems. Self-organization principle is an orderly evolution of System structure and function in time and space. As a universal system evolution process, self-organization contains three states: first is the evolution from low degree of organization to high degree of organization; second is continuous gradient, including self-adjustment, self-recombination, self-adoption; third is stable growth, which is mainly linear [8].

Third, it emphasizes dynamics of ecosystems. Since ecosystem is in the external environment, any changes in the environment will have an impact on the ecosystem. Within its adjustable range, the ecosystem will always make the corresponding adjustment in time after disturbance, to adapt to the changing environment in a dynamic equilibrium.

Forth, it emphasizes diversity of ecosystems. In design of green building, human beings abandon the old concept being the intelligent part of the universe, but should be harmonious with the environment as a member of the ecosystem [9-11].

Forth, it emphasizes complexity of ecosystems. Ecological system is not simple, but complex. That is because: the elements that constitute the ecosystem itself are a small ecosystem; the factors that affect the ecosystem are multi-dimensional, including external environment, internal structure and many other factors. In green building design, the ecosystem can be naturally formed, or man-made [12].

B. Integration Design of Architecture and Landscape

Ecological landscape design has two definitions for broad sense and narrow sense. Ecological landscape design and architecture design can be combined to carry through the integration design of indoor and outdoor space, so landscape design can be regarded as a way of thinking to legitimately deal with the relationship between artificial and natural environments, or a design organization based on the landscape. The purpose of integration design of green building is to achieve sustainable development and the optimal combination of human and nature [13, 14].

1) Overall conception

There is an inseparable connection between construction planning and landscape design, despite their difference in
In the early stages of construction planning, planning designer should establish a sense of landscape, to grasp the overall conception of landscape on the whole. First of all, determine the overall layout of the land in accordance with the characteristics of the project and the relevant economic indicators; then combined with the regional ecological and cultural characteristics, complete the preliminary selection in harmony with the landscape conception; finally, enrich the detail by using some landscape design means, so as to build a good external space environment and prospect [15].

2) Landscape layout
   For landscape layout, there are different priorities under different terrain conditions, so the landscape space created would have their unique characteristics. Taking urban landscape as an example, city is a special kind of building environment. Related studies suggest that, urban landscape space mainly includes urban road space, urban square space, urban natural space, etc. In the process of creating an urban landscape space, we can clearly see the impact of architecture planning on the entire urban landscape. If landscape factors are ignored in the early stage of architecture design, it will result in a single and rough urban landscape. If landscape factors are ignored in the early stage of architecture design, it will result in a single and rough urban landscape. Therefore, designer should focus on the interaction between architecture design and landscape layout design.

3) Integration of architectural form and terrain
   On the one hand, architectures change the topography of the region; on the other hand, architectures reshape the topography as well. One of the important purposes in green architecture design is to reduce the load on the surrounding environment.

   a) Underground construction. Underground construction appeared a long time ago, such as ancient caveman and earth building. Place the building into the ground and make arrangements for the roof, e.g. planting vegetation, to integrate the building into the surrounding environment. Such architectural form is one of the ways that produce the smallest impact on the environment, so it is widely adopted in areas with high demand for natural landscape protection.

   b) Overhead construction. In order not to destroy the original surface, building can be constructed overhead. In moist areas, overhead construction is quite effective for moisture-proof. When the building is demolished, the land can be used again. In addition, overhead building can also save space, and meanwhile enrich the expression of architecture body and create a public space at the bottom of the building. Such architectural form is commonly used base structure are as same as that of architecture, which can be summed up as point, line and plane. Architecture is an important part of the landscape, and we can regard a single building or some buildings as the point elements in landscape architecture. When the building is located in the centre of the landscape, the location, form and quantity of the building will directly affect the whole landscape structure; when the building is not the centre of the landscape, designer needs to deal with the relationship between the building and the landscape centre: the building should be coordinated with the surrounding landscape, and heighten the whole landscape centre, rather than distracting, or even destroy the whole landscape structure.

III. GREEN BUILDING EVALUATION MODEL
A. Evaluation Index System
   1) Target Layer
      The evaluation model of green building is to evaluate the overall level of green building design scheme. In addition to the factors of traditional architecture design evaluation, such as safety, economic, applicability, beauty and so on, green architecture design evaluation model also need to include environment protection, resource saving and their influence on society. Overall, our evaluation model has the following objectives:

      a) Reflect the overall economic benefits of green construction projects. The model should evaluate the overall economic benefits, respectively from the subjective and
objective aspects, taking into account the requirements for economic contribution.

b) Aim at green construction projects scheme. The fundamental purpose of green building design is to help constructer determine the best scheme of green building.

c) Measure the technical value of green construction project. In the evaluation model, the evaluation indices should embody various involved green technologies, so as to carry out the comprehensive evaluation of green technology value used in green architecture design.

(2) Criteria Layer
Criteria layer of green architecture design evaluation model includes economic C1, resource utilization and environmental impact C2, technology and management C3 and social impact C4.

Economic evaluation criteria are to evaluate resource input and benefit output of green architecture design, including benefit indices and cost indices. Resource utilization and environmental impact evaluation criteria are to measure the indices of resource saving, waste disposal, recycle and reuse, etc. Technology and management evaluation criteria mainly incorporate maturity of green technology, risk coefficient, organizational structure and management process in construction process into the evaluation system. Social impact evaluation criteria not only evaluate the technical and economic feasibility of green architecture design scheme, but also evaluate its possible social impact.

(3) Indicator Layer
From the sustainable development perspective, we set up a green architecture design evaluation system. The evaluation system is divided into three layers: target layer, criteria layer and indicator layer. There are 11 First-level indicators and 36 second-level indicators, as shown in Table 1:

<table>
<thead>
<tr>
<th>Target Layer</th>
<th>Criteria Layer</th>
<th>Indicator Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Architecture Design Evaluation</td>
<td>Economic C1</td>
<td>First-level Indicator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Life cycle cost $F_1$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operating cost $S_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incremental economic benefit $F_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incremental payment period $S_4$</td>
</tr>
<tr>
<td></td>
<td>Resource utilization and environmental impact C2</td>
<td>Land saving and outdoor environment $F_3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plot ratio $S_5$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New material usage $S_6$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Underground public area $S_7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green space ratio $S_8$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land utilization ratio $S_9$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supporting facilities $S_{10}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public transportation convenience $S_{11}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building body coefficient $S_{12}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building envelope thermal performance $S_{13}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air conditioning system energy consumption $S_{14}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lighting system energy consumption $S_{15}$</td>
</tr>
<tr>
<td></td>
<td>Technology and management C3</td>
<td>Technology application $F_4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Construction technical difficulty $S_{20}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Durability design $S_{21}$</td>
</tr>
<tr>
<td></td>
<td>Social impact C4</td>
<td>Social development impact $F_{10}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy consumption per unit of building output $S_{22}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green construction technology and product promotion rate $S_{23}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coordination of architectural modeling $S_{24}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Humanistic environment protection $S_{25}$</td>
</tr>
</tbody>
</table>
B. Weighted Radar Chart Analysis

Weighted radar chart analysis is a comparative analysis method for multi-factors. As a graphical evaluation method, it can visually reflect the comprehensive property of evaluation objective.

Traditional radar chart is drawn only according to each index value of evaluation objective, but without considering the importance of each evaluation factor. The weighted radar chart we adopt in this study is drawn by combining index evaluation value and their weights.

Specifically, first express the weight of each evaluation index as the angle between the polar axis of radar chart, and then identify the evaluation index value at the corresponding polar axis. Connect the index evaluation values on adjacent polar, and then the weighted radar chart is completed. The weighted radar chart can visually display the overall situation of the evaluation objects.

(1) Establishment of standardized decision matrix

Assume Q as collection of green building design schemes, Q={ Q1, Q2, …, Qn}; assume I as collection of evaluation indices, I={I1, I2, …, Im}. Assume xij as attribute value of scheme Qi for evaluation index Ij, then the decision matrix of scheme set Q based on evaluation indices set I is:

\[
X = \begin{bmatrix}
    x_{11} & \cdots & x_{1m} \\
    \vdots & \ddots & \vdots \\
    x_{n1} & \cdots & x_{nm}
\end{bmatrix}
\]

(1)

Carry out standardized treatment on the calculated value xij of scheme Qi for evaluation index Ij. Assume a as basic value of evaluation index, a=[min{xij}−1]; assume yij as basic input value of evaluation indices. Calculate according to 

\[
y_{ij} = x_{ij} - a,
\]

and establish the standardized decision matrix as follow:

\[
Y = \begin{bmatrix}
    y_{11} & \cdots & y_{1m} \\
    \vdots & \ddots & \vdots \\
    y_{n1} & \cdots & y_{nm}
\end{bmatrix}
\]

(2)

(2) Drawing of polar axis of weighted radar chart

The evaluation indices set contains m indicators, so we set up m polar axis in weighted radar chart. Since the angle between polar axis refers to the weight of each evaluation index, we first need to evaluate the importance of indicators according to project objectives and requirements, and obtain the weights of all the evaluation indices, and then transform the weights into radians or angle. Assume Vj as the importance score of evaluation index Ij, then calculate the weight of index importance m according to the following formula:

\[
m_j = \frac{V_j}{\sum_{j=1}^{m} V_j}
\]

(3)

And then calculate the angles of the polar axis of weighted radar chart according to the following formula:

\[
\theta_j = 2\pi n_j
\]

(4)

With the angles value, we can draw the polar axis of weighted radar chart now, as shown as Fig. (1):

Fig. (1). Polar axis of weighted radar chart

(3) Drawing of weighted radar chart

Based on the polar axis chart, mark the evaluation specification value of each index Ij on the corresponding polar axis, and then link the identification points on adjacent polar axis, forming a polygon graphics that reflects the characteristics of the object, and we complete drawing the weighted radar chart now. By observing the plumpness and roundness of the polygon graphics, we can intuitively understand the overall situation of each evaluation object. Taking an evaluation Index set containing 11 indicators as example, we draw the weighted radar chart, as shown in Fig. (2):

Fig. (2). Weighted radar chart

(4) Quantitative evaluation

In order to investigate the plumpness and roundness of the polygon graphics in weighted radar chart, we extract the area and length of the graphic, and calculate the comprehensive evaluation value of evaluation object through the evaluation function:

\[
\overline{S} = \frac{\sum_{j=1}^{m-l} \sum_{k=1}^{m} y_{jk} \sin \theta_j}{2(m-1)}
\]

(5)
In the formula, $\overline{S}$ and $\overline{P}$ are respectively average area and average perimeter of the characteristic polygon. In order to ensure the balance of the evaluation method, we introduce the average perimeter eigenvalue $E$:

$$E = \frac{\overline{S}}{\pi(\overline{P}/2\pi)^2}$$

(7)

The average perimeter eigenvalue reflects the balance of each evaluation index of the green building design scheme. The larger it is, the better the balance will be.

IV. EMPIRICAL STUDY

A. Basic Data

In this project, investors plan to build an office building, and there are four alternative design schemes. First we collect the evaluation index data according to the second-level indicators according to Table 1, and then we select the first 11 indicators for evaluation. We respectively determine the score of the 11 indicators of each design scheme, and summarize it as Table 2:

<table>
<thead>
<tr>
<th>Indicator</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>7.4</td>
<td>7.3</td>
<td>6.8</td>
<td>7.1</td>
</tr>
<tr>
<td>D2</td>
<td>7.9</td>
<td>8.2</td>
<td>7.7</td>
<td>7.8</td>
</tr>
<tr>
<td>D3</td>
<td>8.2</td>
<td>8.2</td>
<td>7.8</td>
<td>7.6</td>
</tr>
<tr>
<td>D4</td>
<td>7.2</td>
<td>8.2</td>
<td>8.0</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Assume $D$ as the collection of the four green architecture design schemes, $D = \{D_1, D_2, D_3, D_4\}$; assume $I$ as the collection of the indicators, $I = \{I_1, I_2, \cdots, I_{11}\}$. Based on the evaluation value of the indicators in Table 2, we establish the decision matrix of scheme set $D$ according to the evaluation model:

$$X = \begin{bmatrix}
7.4 & 7.9 & 8.2 & 8.3 & 7.2 & 6.6 & 8.3 & 8.2 & 7.3 & 8.2 & 7.2 \\
7.3 & 8.2 & 8.2 & 8.2 & 7.1 & 6.8 & 8.2 & 8.7 & 7.6 & 8.3 & 7.0 \\
6.8 & 7.7 & 7.8 & 7.8 & 6.6 & 7.1 & 8.0 & 9.1 & 7.9 & 8.1 & 6.8 \\
7.1 & 7.8 & 7.6 & 7.6 & 6.8 & 7.2 & 7.8 & 9.3 & 8.1 & 8.0 & 6.7
\end{bmatrix}$$

B. Comprehensive Evaluation

1) Standardized decision matrix

According to the decision matrix in formula (8), we obtain $\min \{x_{ij}\} = 6.6$, and basic value of evaluation indices $a = [\min \{x_{ij}\} - 1] = 6$; then calculate the basic input value of evaluation model $y_{ij}$, and establish the standardized decision matrix as follow:

$$X = \begin{bmatrix}
1.4 & 1.9 & 2.2 & 2.3 & 1.2 & 0.6 & 2.3 & 2.2 & 1.3 & 2.2 & 1.2 \\
1.3 & 2.2 & 2.2 & 2.2 & 1.1 & 0.8 & 2.2 & 2.7 & 1.6 & 2.3 & 1.0 \\
0.8 & 1.7 & 1.8 & 1.8 & 0.6 & 1.1 & 2.0 & 3.1 & 1.9 & 2.1 & 0.8 \\
1.1 & 1.8 & 1.6 & 1.6 & 0.8 & 1.2 & 1.8 & 3.3 & 2.1 & 2.0 & 0.7
\end{bmatrix}$$

2) Drawing of weighted radar chart

For the 11 indicators, we respectively evaluate their importance, as shown in Table 3:

<table>
<thead>
<tr>
<th>Index</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

Then calculate the weights of all the indices $m_j$:

$$m_j = (0.102, 0.091, 0.102, 0.102, 0.091, 0.091, 0.102, 0.080, 0.080, 0.080, 0.080)$$

According to the evaluation index, angles of polar axis, and link the identification points, we can draw the weighted radar charts as follow:

Figure 3 continues on next page.
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