ISM and AHP Based Evaluation Indicators for Sustainable Community Product Service System

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Abstract—Along with the research on healthy cities, sustainable community product service system has become a new hot spot in design research and practice. Since the design of a Sustainable Community Product Service System (SCPSS, hereinafter referred to as SCPSS) involves several subsystems of society, economy, culture, and environment, and its elements are intricately related, which makes it difficult for designers to carry out the design of SCPSS. This paper constructs a structural model of SCPSS evaluation indicators by using the Interpretive Structural Model (ISM) and determines the weights of each evaluation indicator by using the Hierarchical Analysis Process (AHP) to obtain quantitative evaluation indicators of SCPSS and provides ideas for SCPSS design and practice.

Keywords-Sustainable Communities; Sustainable Product Service Systems; Evaluation Indicators; Interpretative Structural Modeling; Analytic Hierarchy Process

1 INTRODUCTION

As green design continues to extend to sustainable design, it is moving from the green design of a single physical product to the design of a Product Service System (PSS) that includes a service experience. However, while PSSs themselves have a sustainable basis due to their "immateriality," not all PSSs as a whole can be sustainable and eco-efficient [1]. Therefore, the Sustainable Product Service System (SPSS), which places more emphasis on eco-efficiency, has been proposed. Along with healthy cities becoming a hot spot for sustainable design research, the design of services for sustainable communities has become one of the important directions for research. However, the design of SCPSS involves social, economic, cultural, and other multi-system elements [2], and its relationships are intricate and complex; and the current design of sustainable design product service system mostly relies on the designer's experience and qualitative principles, and lacks quantitative indicators to guide it. Therefore, this paper attempts to use the Interpretation Structure Model (ISM) to establish the structural model of SCPSS evaluation indicators, and use the Analytic Hierarchy Process (AHP) to determine the weights of each evaluation indicator, to obtain the quantitative SCPSS evaluation indicators. The SCPSS evaluation indicators were determined by using AHP (Analytic Hierarchy Process) to obtain the quantitative SCPSS evaluation indicators to provide a method for SCPSS design practice. Analysis and construction of evaluation indicators.

ICICA 2022, December 02-04, Chongqing, People's Republic of China

DOI 10.4108/eai.2-12-2022.2328038

2 ANALYSIS AND CONSTRUCTION OF EVALUATION INDICATORS

2.1 Theoretical framework

In the SCPSS, the microsystem refers to the individuals associated with the SCPSS, which can refer to the residents of this community, the managers of this community, the staff of this community, and the people who operate in this community; the mesosystem refers to the elements that can affect individuals including culture and education, employment, social values, and health; the outer system of this SCPSS is the environment that determines the mesosystem, so in this product, The outer system of this sustainable product service system is the environment that determines the middle system. Since the macrosystem represents the imaginary system where information, matter, and energy interact with each other, this paper only extracts the assessment indexes from the three subsystems of microsystem, mesosystem, and exosystem respectively Figure 1.

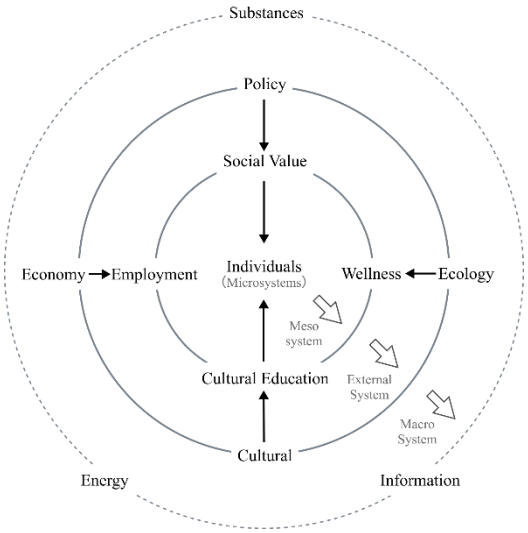

Figure 1. Framework of sustainable community product service system.

2.2 Construction of evaluation indicators

We analyzed the literature on sustainable communities, sustainable community creation, and sustainable product service systems (SCPSS) separately, and further evaluated the indicators of SCPSS by combining the current domestic and international sustainable community assessment systems and the sustainability checklist proposed by the LeNs project (an innovative research project sponsored by the European Aid Cooperation Office and the European Commission, which is mainly engaged in the design of sustainable product service systems). The SCPSS evaluation indicators were selected. At present, the British BREEAM Communities system (BC system) has achieved good evaluation results in Europe [3], so this paper mainly adopts it as a reference for foreign sustainable community evaluation systems; in China, we mainly refer to

the China Eco-settlement Assessment Manual, which is currently most widely used in domestic eco-settlements. Finally, the SCPSS evaluation index system was established from three dimensions: microsystem, mesosystem, and exosystem, and 22 indexes were finally selected, as shown in Table 1.

Table 1 Evaluation indexes of sustainable community product service system

Subsystem	Dimension	Evaluation indicators	No.
Microsystems	Wellness	Personal physical health	S1
		Personal Mental Health	S2
	Cultural Education	Sense of Community Belonging	S3
		the Understanding of this sustainable service	S4
	Income	Related management income	S5
	Social Value	The extent to which low-income people can participate	S6
		Resident participation/decision-making degree	S7
Mesosystem	Environmental Health	Amount of waste	S8
		Recyclability of materials	S9
		The use of materials toxic or toxicogenic	S10
	Cultural Education	Advocating the extent of sustainability	S11
	Employment	Share of benefits and expenses of each stakeholder	S12
	Social Value	Community co-creation forms	S13
ecosystem	Ecological Environment	Energy consumption degree	S14
		Biodiversity	S15
		Environmental healthiness	S16
	Economic Environment	Improving employment issues	S17
		Profitability of the community	S18
	Cultural Environment	Community Equity and Justice Degree	S19
		Community management's understanding of sustainability concepts	S20
	Policy Environment	Community co-creation (autonomy) degree	S21

3 ISM MODEL CONSTRUCTION

The Interpretative Structural Modeling (ISM) was proposed by John N. Warfield in the United States, and it can transform the relationship between fuzzy and messy elements into a structural model with hierarchical structure and cause-effect relationships [3]. Since SCPSS is a complex

fuzzy open system involving politics, economy, culture, and ecology, ISM is applicable to this study.

According to the above assessment indexes of SCPSS, this paper consulted five experts from Fuzhou University and South China University of Technology, and eliminated three elements, S9, S10, and S17, for the construction of the ISM model.

3.1 Build the adjacency matrix

The adjacency matrix is a matrix describing the interrelationships between the influencing elements in the system, and for the system $S = S1, S2, S3, \cdots, S22$, we have:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{122} \\ a_{21} & a_{22} & \cdots & a_{222} \\ \vdots & \vdots & \ddots & \vdots \\ a_{221} & a_{222} & \cdots & a_{2222} \end{bmatrix} \tag{1}$$

$$a_{ij} = \begin{cases} 1, & S_i \text{ has a direct effect on } S_j \\ 0, & S_i \text{ has no direct effect on } S_j \end{cases} \tag{2}$$

$$A = \begin{bmatrix}
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
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0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0 \\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0 \\
0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0 \\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
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1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\
0&0&0&0&1&0&0&0&0&1&0&0&0&0&0&0&0&0&0&1 \\
0&0&1&0&0&1&0&0&0&1&0&0&0&0&0&0&0&1&0&0 \\
0&0&0&0&0&0&0&0&1&0&0&1&1&0&0&1&0&1&1&0 \\
0&0&1&0&0&0&0&0&0&0&1&0&0&0&0&1&0&0&0&0 \\
0&0&0&1&1&0&0&0&1&0&0&1&1&0&0&0&1&0&0&0
\end{bmatrix} \tag{3}$$

3.2 Building the reachability matrix

$\boldsymbol{I}$ is the unit matrix of the above adjacency matrix $\boldsymbol{A}$. The following Boolean operation equation (2) is performed on the adjacency matrix using MATLAB 2016a until equation (3) is satisfied to obtain the reachable matrix $\boldsymbol{M}$, as follows.

$$M = (A+I)^k \tag{4}$$

$$(A+I)^{k-1} \neq (A+I)^k = (A+I)^{k+1} \tag{5}$$

$$M = \begin{bmatrix}
1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
0&0&0&1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0\\
1&1&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1\\
1&1&1&1&1&1&1&0&1&1&1&1&1&1&1&1&1&1&1&1
\end{bmatrix} \tag{6}$$

3.3 Decompose the reachable matrix and perform a hierarchy

After obtaining the reachable matrix, the reachable set $R(S_i)$ and the prior set $A(S_i)$ are constructed. The reachable set is the element Si in the reachable matrix, and the prior set is the element Si in the reachable matrix. $C(S_i)$ is the intersection of $R(S_i)$ and $A(S_i)$, as shown in Table 3. According to the calculation, the model is 4-layer as shown in Table 2.

Table 2 Breakdown table of evaluation indicators

Levels	**Evaluation Indicator** S_i
1	1,2,4
2	3,11,14,16
3	8,15
4	5,6,7,12,13, 18,19,20,21,22

3.4 Modeling the explanatory structure

According to the four levels of the decomposed reachable matrix, the reachable matrix is adjusted according to its hierarchical structure, and the adjusted reachable matrix M' is obtained.

According to the adjusted reachable matrix *M*', the explanatory structure model of the SCPSS evaluation indexes is obtained, as shown in Figure 2.

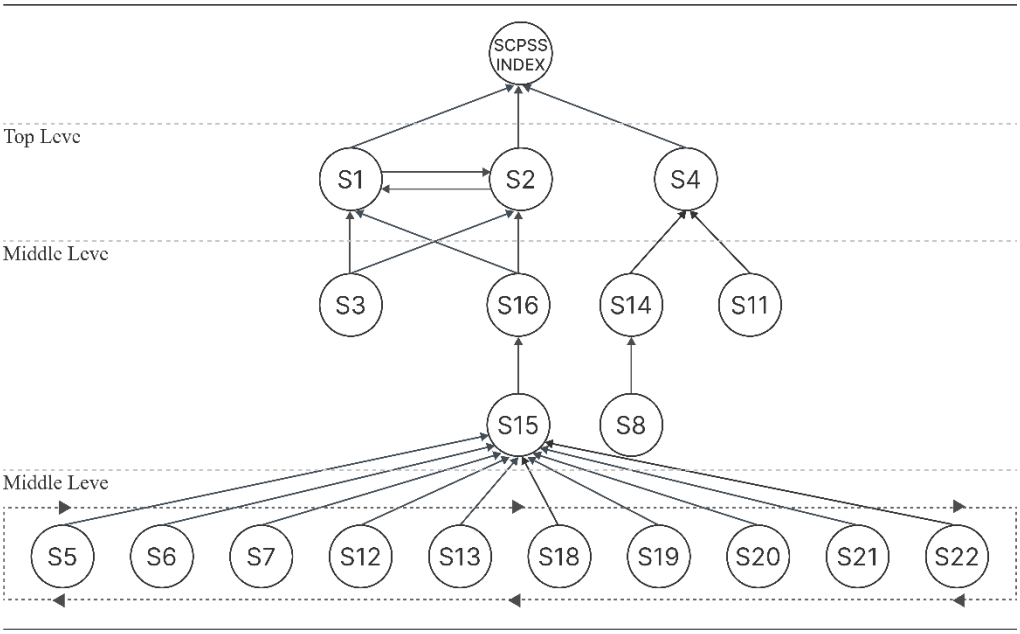

Figure 2. The IMS of the evaluation index of sustainable community product service system.

4 AHP MODEL CONSTRUCTION

Hierarchical analysis was proposed by Saaty, an American operations researcher, to systematically and hierarchically solve the problem of multi-objective decision making through qualitative and quantitative methods [4]. The ISM model established above satisfies the conditions for using hierarchical analysis, so it can be used to quantitatively calculate the weights of each evaluation index of SCPSS.

4.1 Modeling the explanatory structure

According to the AHP method, the 1-9 comparison scale method is used to indicate the importance of each evaluation index by two comparisons; 1 means equally important, 3 means slightly important, 5 means quite important, 7 means obviously important, and 9 means definitely important, where the interval value indicates the intermediate degree of adjacent judgments, $1,1/2,\cdots,1/9$ indicates the result of the above factors in turn.

4.2 Constructing judgment matrix and consistency test

By consulting five experts from Fuzhou University and South China University of Technology, the judgment matrix of evaluation indexes was constructed by comparing two by two for each tier index respectively. The geometric mean method was used in this study, and MATLAB 2016a was used to calculate the initial weights W of the evaluation indicators within each tier, while the maximum characteristic root λmax of the judgment matrix was later calculated according to equation (4), and the consistency test was performed according to equation (5)(6).

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(BW)_i}{nW_i} \tag{7}$$

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

4.3 Integrated weight calculation

After completing the initial weights W of each element in each layer mentioned above, the relative weights of each evaluation index to the highest layer are calculated; the comprehensive weights W' of each index are calculated according to the relative weights in turn to obtain the comprehensive weights of SCPSS evaluation indexes, as shown in Table 3.

Table 3 Comprehensive weight of evaluation index of sustainable community product service system

No.	Evaluation Indicators	Combined weights	Rank
S16	Environmental healthiness	0.609608287	1
S1	Personal physical health	0.466666667	2
S2	Personal Mental Health	0.466666667	2
S15	Biodiversity	0.406405525	3
S22	Investment in sustainable community creation	0.171308811	4
S3	Sense of Community Belonging	0.155781967	5
S20	Community management's understanding of sustainability concepts	0.095381014	6
S4	the Understanding of this sustainable service	0.066666667	7
S21	Community co-creation (autonomy) degree	0.03166174	8
S7	Resident participation/decision-making degree	0.028105452	9

No.	Evaluation Indicators	Combined weights	Rank
S11	Advocating the extent of sustainability	0.025115026	10
S14	Energy consumption degree	0.024856694	11
S13	Community co-creation forms	0.022895823	12
S8	Amount of waste	0.022371024	13
S19	Community Equity and Justice Degree	0.022337689	13
S12	Share of benefits and expenses of each stakeholder	0.013779604	14
S18	Profitability of the community	0.008061232	15
S5	Related management income	0.006642869	16
S6	The extent to which low-income people can participate	0.006231292	17

5 CONCLUSION

To address the complexity of SCPSS design and the lack of quantitative indicators, this paper constructs SCPSS evaluation indicators from the dimensions of four subsystems: policy, economy, culture, and environment, and decomposes the evaluation indicators into a hierarchical model of surface indicators, middle-level indicators, and deep-level indicators using the ISM model; uses AHP to determine the comprehensive weights of each evaluation indicator of SCPSS, and realizes the AHP was used to determine the comprehensive weight of each evaluation index of SCPSS and to quantify each evaluation index.

When researching the product and service systems of sustainable communities, the above indicators can be combined with an expert evaluation of an existing product and service system or the community itself or a questionnaire survey of various stakeholders.

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