that contributes to energy savings and environmental health when fully embraced and adopted by industry.

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S9-2
Determining Key Ecological Indicators for Urban Land Consolidation

Kuo-Liang Lin

Assistant Professor, Department of Civil and Ecological Engineering, I-Shou University. Taiwan. (e-mail: kllin@isu.edu.tw; phone: 886-939-058408)

ABSTRACT: Urban land consolidation, which is to reform land parcels to remove fragmentation and produce ideal blocks, is an effective means for urban renewal. Successful urban land consolidation brings out great benefits to the city officials as well as general public, such as improved city image, increased land value, and more effective land use. However, urban land consolidation can be detrimental to environment, especially in the ecological aspects, while the execution of land consolidation has been focused solely on development for the sake of human benefits. To remove negative effects of urban land consolidation to the ecological system, this paper is intended to establish a set of criteria for evaluating ecological impacts of an urban land consolidation plan. Firstly, key ecological indicators are identified using a special group decision-making process called "habitual domain analysis" and then individual weighting of each indicator is recorded by analytical hierarchy process. An urban ecological evaluation model with 4 levels and 23 indicators is thus developed.

Keywords: Ecological Evaluation, Urban Land Consolidation; Habitual Domains; Analytical Hierarchy Proces

1. BACKGROUND

Urban renewal is a process of land re-development in areas of moderate to high density urban land use. Urban renewal is usually very controversial, and typically involves the destruction of original blocks, the relocation of people, and the use of eminent domain as a legal instrument to reclaim private property for city-initiated development projects.

In Taiwan, urban land consolidation is one of the major implementing approaches for urban renewal. By reforming land parcels to remove fragmentation and produce ideal blocks, urban land consolidation brings out great benefits to the city officials as well as general public, such as improved city image, increased land value, and more effective land use.

In principle, environmental impact assessment (EIA) should be undertaken for individual projects such as a dam, highway, airport, industrial area and large urban consolidation project. The EIA procedure ensures that environmental consequences of projects are identified and assessed before authorization is given. The public can give its opinion and all results are taken into account in the authorization procedure of the project. The public is informed of the decision afterwards. With growing global warming consciousness, ecological engineering, which aims at sustainable ecosystems that integrate human society with its natural environment for the benefit of both, become a vital issue. It is mandatory to involve ecological concerns in environmental impact assessment.

However, in Taiwan EIA itself becomes a source of controversy. With no standardized process or principals to be follower, outcomes and conclusions of the EIA reports are usually deemed with prejudices that often cause further conflicts between opposite parties. Therefore, it is important to derive standard indicators so that people with different opinions could easily monitor and examine the assessment execution and achieve consensus.

This research is thus to develop an ecological evaluation model that can be included in environmental impact assessment. Using urban land consolidation as the main application area, Key Ecological Indicators are determined, and they can be used to cover the important ecological, and sustainable concerns when city officials are carrying out overall planning of urban renewal projects involving land consolidation.

2. RESEARCH METHODOLOGY

To determine the relative weighting for different indicators, Analytical Hierarchy Process (AHP) is usually used. As a multi-goals seeking approach, AHP is generally applied in those decisions comprised of multiple criteria under an uncertain scenario. A complicated system can be precisely presented by a simple and clear hierarchical factor structure categorized on a basis concluded by experts and decision-makers (Saaty 1980). Experts' and decision-makers' dedicated analysis of factor weighting by pair wise comparison will deliver a prioritized factor structure allowing best decision to be made.

Before AHP can be used for decision making, a solid hierarchical structure of factors should first be established. Delphi method, a structured process for collecting and distilling knowledge from experts by means of a series of questionnaires interspersed with controlled opinion feedback, is often used to build the hierarchy. However, when being consulted opinions on key factors, experts' thinking are easily affected by their very own bias (or Habitual Domains), and will have difficulties in carrying out a faultless conclusion. To alleviate the effects of individual bias, a special group decision making approach called Habitual Domains Analysis can be used. The Analog/Association theory from Habitual Domains developed by Dr. Yu P. L, aiming at expanding Habitual Domains, has a potential to overcome this bias constraints and make up the limitations of other human decision making process (Yu 2001, and Chen et. Al 2000). Combining fuzzy logic approach, Habitual Domains theory can become an effective tool to reinforce AHP. Therefore, this research employs AHP, with the complementation of Habitual Domains theory, to determine key ecological evaluators for urban land consolidation. This research includes the following two steps:

1. Identify Key Ecological Indicators (KEI) for urban land consolidation by Habitual Domains decision making process.
2. Determine individual weighting of each KEI by AHP.

3. HABITUAL DOMAIN ANALYSIS

Dr. Yu's Habitual Domains theory declares that Human habitual domains are comprised of four elements (Yu 1990):

1. Potential domain (*PDt*). This is the collection of all thoughts, concepts, ideas, and actions that can be potentially activated by one person or by one organization at time *t*.
2. Actual domain (*ADt*). This is the collection of all thoughts, concepts, ideas, and actions, which actually catch our attention and mind at time *t*.
3. Activation Probability (*APt*). This represents the probability that the ideas, concepts and actions in the potential domain that can be actually activated.
4. Reachable domain (*RDt*). This is the collection of thoughts, concepts, ideas, actions and operators that can be generated from initial actual domain.

Dr. Yu's research has primarily focused on how to utilize individual habitual domains to develop personal fulfillments. This research, however, applies habitual domains concepts to distill expert knowledge. A data collection and analytical process is developed to extract most critical expert knowledge, as described in the following:

Step 1. Establish Standard Attribute Set

This step summarized all ecological indicators through intensive literature survey and these indicators form the standard attribute set *Y* (Herricks 2004, Cywinsk 2001, Forman and Collonge 1997, Dramstad et. Al. 1996, Platt 1994, and Gilbert 1989) .

Y = 「Standard attribute set」

$$Y = \bigcup_{j=1}^{h} y_j$$

The derived standard attribute set (*Y*) is summarized in Table I. This standard attribute set, representing the Actual Domains of the body of knowledge in the field of BCS, provides a sufficient base of possible ecological evaluators for urban land consolidation. However, since these factors are determined through combination of various sources, many of these attributes could be inter-related with each other, and their suitability for urban land consolidation also remains uncertain.

Step 2. Establish Actual Domain of interviewed experts

Actual domain is established by using open questionnaire to consult experts' opinions in performance indicators for service industry. Assuming there are *k* experts, and then *n* attributes are referred, these form the actual domain of all experts AD*k*. In this step, our expert panel involves 10 experts, including 5 professors in the area of civil and ecological engineering, 3 government researchers, and 2 government officials experienced with ecological engineering tendering process.

AD*k* : actual domain by *K*th expert (*k*= 1,2,3,……,n, n = 10 in this case)

AD : actual domain of all experts

$$AD = \{(x, u_{AD}(x)) \mid x \in X\}$$

X

$$= \bigcup_{k=1}^{n} AD_K = U\{AD_K \mid K = 1,2,3,......., n\} = \{x1, x2, x3, \ldots\ldots, xn\}$$

Table 1 Standard attribute set (AD0)

Dimension	No	Standard Attribute Set AD0
Green Spaces	a1.1	Total Green Space Area
	a1.2	Landscape Continuity
	a1.3	Distance between Green Spaces
	a1.4	Green Space Shape
Corridors	a2.1	Corridor Continuity
	a2.2	Corridor Width
	a2.3	Space Continuity
Land Use	a3.1	Building Coverage Ratio
	a3.2	Land Use Types
Landscape Characteristics	a4.1	Vegetation Localization
	a4.2	Landscape Uniqueness
Landscape Strategic Mechanism	a5.1	Distance from Source
	a5.2	Resistance
Biodiversity	a6.1	Vegetation Structure
	a6.2	Habitat Diversity
	a6.3	Vegetation Diversity
Environmental Impacts	a7.1	Air Quality Improvement
	a7.2	Waste Reduction
Energy Use	8.1	Energy Consumption
	a8.2	Use of New Energy
Water Resource Management	a9.1	Flood Control
	a9.2	Water Quality Protection

Step3. Calculate "degree of membership" of each attribute in AD*k*

As AD*k* is derived from a fuzzy point of view of the experts, it is required to utilize fuzzy statistic to retrieve attributes with greater expert consensus, which is called degree of membership. The α-cut utilized in the research is 0.5, meaning 50% of expert consensus is required for each attribute to remain in the AD.

Probability of occurrence of A:

P(A) = No. of "ω ∈ A" ÷ n, where n is the total number of tests

Thus, degree of membership can be represented by relative frequency, that is

μAD (xi) = number of experts identifying xi in AD ÷ total experts

μAD (xi) : Attribute Xi's degree of membership in AD

According to fuzzy set theory, AD can be represented as follows:

$$AD = \sum_{j=1}^{i} \frac{\mu_{AD}(x_i)}{x_i}$$

Useα-cuts to determine AD*, that is, to retrieved qualified attribute set with degree of membership over α:

$$AD^* = AD_\alpha = \{x \in X \mid \mu_{AD}(x) > \alpha\}$$

AD* represent the attributes with Activation Probability over percentage α.

Table 2 shows the AD1 with degree of membership over α (=0.5) . AD1 represents the set of attributes with greater degree of importance proposed by interviewed experts.

Step 4. Develop Reachable Domain by analogy and/or association

To develop reachable domain, each pair of xi in AD*, and standard attribute yj is compared. Expert opinions are consulted to decide if xi can be referred to yj with analogy and/or association. A 2-round evaluation including degree of membership (α) and degree of correlation (β) is developed for this Reachable Domain analysis. Only those indicators in the Standard Attribute

Set with both sufficient degree of membership (α) and degree of correlation (β) are considered reachable domain from the experts. When an attribute in *Y* (standard attribute set) is referable and correlatable by attributes in AD1, it implies that the attribute in AD1 covers the scopes of the attribute in Y. That is, referable attributes are the reachable domain of the experts. Fuzzy statistics is again used to determine degree of membership and degree of correlation.

R= 「y referred by x with analogy and/or association」
={ (x,y) <μR (x,y) | (x,y) ∈ X×Y}………(1)

(xi, yj) =No. of experts refer and correlate xi to yi÷ No. of experts with xi in i= 1,2,3,……,t ; j=1,2,3,……,h………(2)

The domain (RD(xi)) referable from AD1 is therefore defined as the following:

$$RD(x_i)=\left\{ y_j \middle| \alpha(x_i)\geq 0.5, \beta(x_i)\geq 0.5; y_j \in Y \right\}, \forall x_i \in AD1$$

………(3)

The union set of all RD(xi) from AD* forms the total referable domain RD(AD*).

$$RD(AD1) = U\{RD(x_i) | x_i \in AD1\} \text{………(4)}$$

Step 5. Expand expert habitual domains by stimulation

Through analysis of experts' reachable domains, leading ecological indicators with explicit expert consensus are determined. However, since each expert's decision making can be limited by his own habitual domains, it is required to use some stimulation so that their habitual domains can expand and thus new ideas can be activated and generated. That is, stimulation approach should be used to allow experts to think beyond their own habitual domains. While remaining attributes in AD* and Y without sufficient consensus are beyond experts' reachable domains, these attributes are ideal igniters to stimulate experts' thinking. As the final step of HD analysis, experts were exposed to these remaining attributes, and asked to pick a few of them to supplement the original picked attributed derived in Step 4. α-cut of 0.5 is again required for these supplementary attributes to enter the key ecological indicator pool.

Table 2 Actual Domains by interviewed experts (AD1)

Dimension	No.	Actual Domain (AD1)	α
Green Space	A1.1	Total Green Space Area	0.7
	A1.2	Vegetation Combination	0.5
Corridor	A2.1	Corridor Connectivity	0.5
	A2.2	Green Corridor Width	0.6
Land Use	A3.1	Carrying Capacity	0.7
	A3.2	Land Suitability	0.5
Landscape Characteristics	A4.1	Landscape Aesthetics	0.5
	A4.2	Facility Convenience	0.7
Biodiversity	A6.1	Species Diversity	0.9
	A6.2	Habitat Diversity	0.7
Environmental Impacts	A7.1	Waste Reduction	0.7
Energy Use	A8.1	Energy Consumption	0.7
Water Resource Management	A9.1	Soil Water Content	0.7
	A9.2	Waste Water Treatment System	0.5

This research utilizes attribute set of Table I, and actual domains of experts in Table 2, and applied formula (1)~(4), using α = 0.5, β =0.5 and to determine the reachable domains of the interviewed experts , as listed in Table 3.

Table 3 Reachable Domain Analysis

No.	Actual Domain (AD1)	No.	AD0	α	β	Reachable Domain
A1.1	Total Green Space Area	a1.2	Landscape Continuity	0.8	0.55	Yes
		a1.3	Distance between Green Spaces	0.8	0.525	Yes
		a1.4	Green Area Shape	0.8	0.375	No
A1.2	Vegetation Combination	a1.2	Landscape Continuity	0.7	0.375	No
		a1.3	Distance between Green Spaces	0.7	0.3	No
		a1.4	Green Area Shape	0.4		No
A2.1	Corridor Connectivity	a2.2	Green Corridor Width	1	0.4	No
		a2.3	Space Continuity	0.9	0.5	Yes
A2.2	Green Corridor Width	a2.1	Corridor Continuity	0.9	0.375	No
		a2.3	Space Continuity	0.8	0.425	No
A3.1	Carrying Capacity	a3.1	Building Coverage Ratio	0.7	0.425	No
		a3.2	Land use types	1	0.55	Yes
A3.2	Land Suitability	a3.1	Building Coverage Ratio	0.8	0.475	No
		a3.2	Land use types	1	0.7	Yes
		a3.2	Land use types	0.9	0.625	Yes
A4.1	Landscape Aesthetics	a4.1	Vegetation Localization	0.5	0.3	No
		a4.2	Landscape Uniqueness	1	0.55	Yes
A4.2	Facility Convenience	a4.1	Building Coverage Ratio	0.4		No
		a4.2	Landscape Uniqueness	0.7	0.425	No
A5.1	Species Diversity	a6.1	Vegetation Structure	0.9	0.625	Yes
		a6.2	Habitat Diversity	1	0.75	Yes
		a6.3	Vegetation Diversity	1	0.775	Yes
A5.2	Habitat Diversity	a6.1	Vegetation Structure	0.9	0.475	No
		a6.2	Habitat Diversity	0.9	0.475	No
		a6.3	Vegetation Diversity	0.9	0.45	No
A6.1	Waste Reduction	a7.1	Air Quality Improvement	0.9	0.6	Yes
A7.1	Energy Consumption	a8.1	Use of New Energy	0.8	0.55	Yes
A8.1	Soil Water Content	a9.1	Flood Control	0.8	0.5	Yes
		a9.2	Water Quality Protection	0.7	0.475	No
A8.2	Waste Water Treatment System	a9.1	Flood Control	0.9	0.725	Yes
		a9.2	Water Quality Protection	0.9	0.6	Yes

After the expansion, 9 more attributes were picked with sufficient expert consensus. Among them, three are from the Standard Attributes Set AD0 (Green Area Shape, Space Continuity, and Building Coverage Ratio) and 5 are from some expert's habitual domain AD∗(Green Area Diversity, Natural/Urban Corridor Ratio, Strategic Point Setting, Solid Waste Reduction, and Permeable Pavement Ratio), but did not receive sufficient consensus at a earlier stag. Together with the 14 indicators in the original Actual Domain by all experts, the Habitual Domain Analysis generates a total of 23 indicators, as listed in Table 4. This has been a successful demonstration of

how Habitual Domains Analysis can expand the extent of existing expert knowledge base, and it is not easily achievable by other group decision approaches.

Table 4 23 Key Ecological Indicators After HD Expansion

NO	Key Ecological Indicator	Origin
1	Green Space Area	AD1
2	Vegetation Combination	AD1
3	Green Space Shape	AD0
4	Green Space Diversity	AD*
5	Corridor Continuity	AD1
6	Corridor Width	AD1
7	Space Continuity	AD0
8	Natural/Urban Corridor Ratio	AD*
9	Species Diversity	AD1
10	Habitat Diversity	AD1
11	Strategic Point Setting	AD*
12	Distance between Green Spaces	AD0
13	Landscape Aesthetics	AD1
14	Facility Convenience	AD1
15	Carrying Capacity	AD1
16	Land Suitability	AD1
17	Building Coverage Ratio	AD0
18	Solid Waste Reduction	AD*
19	Waste Gas Reduction	AD1
20	Energy Consumption	AD1
21	Soil Water Content	AD1
22	Waste Water Treatment System	AD1
23	Permeable Pavement Ratio	AD*

AD1: Original Experts' Actual Domain
AD0: Added from Standard Attribute Set
AD*: Add from some expert's Habitual Domain

4. ANALYTICAL HIERARCHY PROCESS

After Key Ecological Indicators are derived through HD analysis, Analytical Hierarchy Process (AHP) is then used to determine individual weighting of each Key Ecological Indicator (KEI). The procedure of AHP is described as follows:

Step 1: Setting up the hierarchy

To begin with, a hierarchy constructing the problem with several levels must first be structured. In this study, the research team intends to construct each level with at most 4 factors so that the comparison between the factors in step 2 will not be too complicated. The hierarchy is derived as in Figure 1. The first level denotes the overall goal which is to determine the KEI weighting in this study, and it is divided into 3 major categories: Ecological Concern, Human Concern, and Sustainable Concern. The third level further breaks down the second level, which breaks Ecological Concern with 4 directories (Green Space, Corridors, Biodiversity, and Landscape Strategic Mechanism), Human Concern with 2 directories(Land Use, and Design Characteristics), and Sustainable Concern with 3 directories (Waste Reduction, Energy Use, and Water Resource Management). The fourth level includes the 22 indicators derived from HD analysis in previous section.

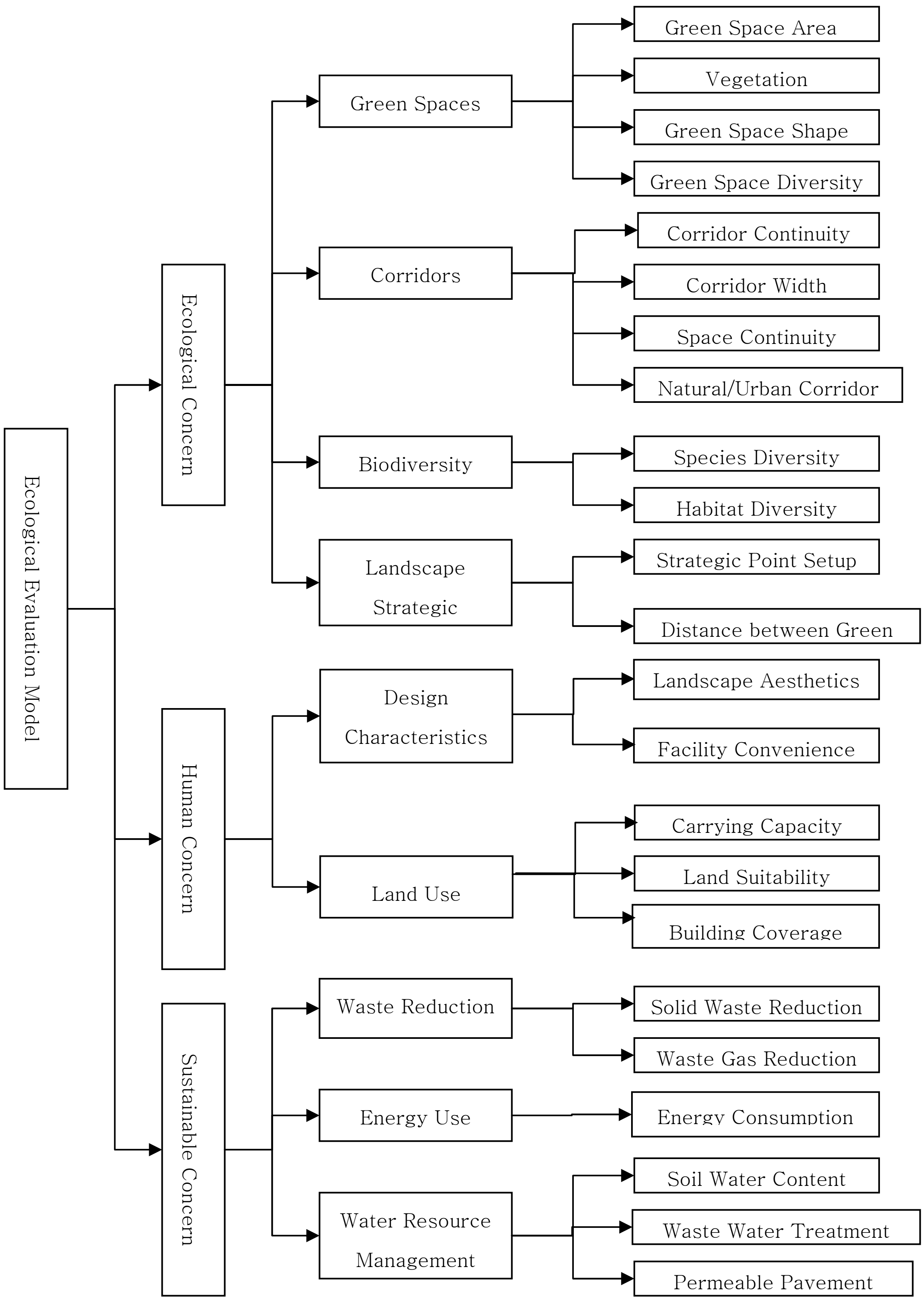

Figure 1 Ecological Evaluation Hierarchy for Urban Land Consolidation
Figure 1 Ecological Evaluation Hierarchy for Urban Land Consolidation

Step 2: Comparison of Factors in Each Level

In next step of the AHP the factors in each level of the hierarchy are compared with each other to determine the relative importance of each dimension in accomplishing the overall goal. A matrix with the factors listed at the top and on the left is prepared for the experts being surveyed. Based on individually surveyed information and the resulting informed judgment of the decision-maker, the matrix is then filled in with numerical values denoting the importance of the factor on the left relative to the importance of the factor on the top. 25 experts are involved in the survey in this research.

Step 3: Establish Priority Vector

In this step the numbers from the matrix in step 2 are used to get an overall priority value for each factor (Eigenvector). In order to do this, the evaluator calculates the sum of the values in each row of the matrix and divides each of the results by the sum of the results for all the rows. This is called eigenvector method.

Step 4: Test consistency of the matrix

Consistence Index (C.I.) and Consistence Ratio (C.R) are calculated to test if each expert's rating of factors is consistent.

C.I =(λmax – n) /n-1, where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value of average random consistency. Generally, C.R <0.1 indicates sufficient consistency. IF CR exceeds 0.1, expert judgment is reviewed and the expert is consulted so that CR can be improved.

Step 5. Test overall consistency of the hierarchy and determine relative weighting of each factor

C.R.H.(Consistency Ratio of Hierarchy) is used to determine the consistency of the overall hierarchy. Again, C.R.H <0.1 indicates sufficient consistency. If the overall consistency is acceptable, relative weighting of each individual factor can be calculated.

After these five steps, the overall weighting in the second level and the third level can be finalized. Table V summarizes the overall weights of all indicators in all dimensions.

Based on experts' decision, "Ecological Concern" is the most important aspect, accounting for 46% of the total weighting, while "Sustainable Concern" is the runner-up at 42%. "Human Concern" comes last at a mere 13%, as shown in Table 5.

Concern	Dimension	No.	Indicator
Ecological Concern(46%)	Green Spaces (0.26, 11.96%)	S1.1	Green Space Area(0.26, 3.11%)
		S1.2	Vegetation Combination(0.20, 2.39%)
		S1.3	Green Space Shape (0.18, 2.15%)
		S1.4	Green Space Diversity (0.35, 4.19%)
	Corridors(0.18, 8.28%)	S2.1	Corridor Continuity (0.30, 2.48%)
		S2.2	Corridor Width (0.21, 1.74%)
		S2.3	Space Continuity (0.27, 2.24%)
		S2.4	Natural/Urban Corridor Ratio (0.23, 1.90%)
	Biodiversity (0.37, 17.02%)	S3.1	Species Diversity (0.37, 6.30%)
		S3.2	Habitat Diversity (0.63, 10.72%)
	Landscape Strategic Mechanism (0.19, 8.74%)	S4.1	Strategic Point Setup (0.61, 5.33%)
		S4.2	Distance between Green Spaces (0.39, 3.41%)
Human Concern (13%)	Design Characteristics (0.38, 4.94%)	S5.1	Landscape Aesthetics (0.32, 1.58%)
		S5.2	Facility Convenience (0.68, 3.36%)
	Land Use (0.62, 8.06%)	S6.1	Carrying Capacity (0.37, 2.98%)
		S6.2	Land Suitability (0.36, 2.90%)
		S6.3	Building Coverage Ratio (0.27, 2.18%)
Sustainable Concern (42%)	Waste Reduction (0.41, 17.22%)	S7.1	Solid Waste Reduction (0.40, 6.89%)
		S7.2	Waste Gas Reduction (0.60, 10.33%)
	Energy Use (0.23, 9.66%)	S8.1	Energy Consumption (1.0, 9.66%)
	Water Resource Management (0.36, 15.22%)	S9.1	Soil Water Content (0.43, 6.50%)
		S9.2	Waste Water Treatment System (0.28, 4.23%)
		S9.3	Permeable Pavement Ratio (0.29, 4.38%)

On second level dimensions, "Waste Reduction" (account for 17.22%, "Biodiversity (17.02%), Water Resource Management" (15.12%), and "Green Spaces" (11.96%) are deemed as the most important ones.

In Ecological Concern, "Habitat Diversity" (10.72% overall) and "Species Diversity" (6.30%) in Biodiversity dimension are considered the most important indicators. "Habitat Diversity", at the same time, is ranked No. 1 by experts among all 23 indicators. This explicitly indicates the importance of preserving animal habitats during any urban land consideration projects. Destroying habitats for human's sake is considered disastrous from the ecological point of view.

Regarding Sustainable Concern, "Waste Gas Reduction" (10.33%), and "Energy Consumption" (9.66%) top all other indicators here, and they are also the top 2 and top 3 indicators among all, trailing only "Habitat Diversity" of Ecological Concern. Experts have demonstrated strong willpower in this result to drive sustainable considerations into the urban land consolidation development, so the idea of creating eco-city can be realized accordingly.

Regarding Human Concerns, experts pick "Facility Convenience" (3.36%) to be the most significant, but it is actually among the less important indicators (ranged only No. 12 of 23), while "Landscape Aesthetics" (1.58%) is the least important indicator of all (ranked 23). This result shows that experts' unambiguous intention to reduce the importance of human concern or human-centered preference during urban renewal, since they thought these considerations have already been the center of interests and is out of proportion in many urban land consolidation projects, and this should be discouraged to some extent.

5. CONCLUSIONS

This paper intents to establish a model for ecological evaluation of urban land consolidation. This model utilized habitual domains theory to extract Key Ecological Indicators (KEIs), and then applying AHP to determine importance weighting of each KEI. Taking advantages of habitual domains technique, this model identified key indicators in 3 aspects with the mindset of bringing more ecological and sustainable concerns into urban land consolidation. AHP then provides sufficient expert knowledge in rating the possible impact of each indicator. While this paper has proposed an innovative approach to come up with a complete evaluation model in a more comprehensive, efficient and effective way, further empirical survey and testing by using proper statistical methods should be necessary to improve the reliability and validity of this model

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