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Delphi and Analytical Hierarchy Process Fuzzy Model for Auxiliary Decision-making for Cross-field Learning in Landscape Design

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Landscape design plays an important role in community building, residential buildings, and urban planning. Landscape design education requires multidisciplinary teaching of construction, management, ecology, and environmental protection as it requires the understanding of planting design, green energy, water resources, culture, and history. Therefore, it is necessary to establish an appropriate curriculum to educate students to be landscape designers. To find which courses are appropriate for such a curriculum, we defined the important teaching courses in landscape design education by integrating the results of the Delphi, analytical hierarchy process (AHP), and fuzzy logic theory (FLT) model as a DA fuzzy model, which provided a multi-attribute decision-making model. The DA Fuzzy model evaluates individual courses and selects the best plan with multiple courses. Three factors were defined to be important for landscape design education: professional skills, professional practice, and interdisciplinary collaboration. Each factor has three subfactors: hand-drawing ability, 3D drawing ability, and eco-friendly design (professional skills); project simulation, project practice, and humanistic value and responsibility (professional practice); interdisciplinary communication, Internet interdisciplinary course, and collaborative design (interdisciplinary collaboration). The highest relative weight was found for professional skills, followed by professional practice and interdisciplinary collaboration. Eco-friendly design, project practice, collaborative design, simulation project, and 3D drawing ability were found important as subfactors. The result indicates that project practice and collaborative design illustrate the importance of multidisciplinary knowledge and collaboration with various industries along with the consideration of the environment.

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1. Introduction

At the UN climate change conference UK 2021 (COP26), China proposed the ecological civilization for ecological priority and green and low-carbon development. China announced the achievement of carbon neutrality by 2060 as the priority for green environmental protection in urban development. On the basis of the policy, the sustainability of cities becomes important in urban planning. In urban development with ecological protection,(1) low-carbon cities are inevitable for reducing greenhouse gas emissions.(2) At present, China's industrial structure has experienced rapid transformation. In the past, industries consumed excessive energy and emitted a huge amount of pollutants. However, as the use of fossil fuels has been limited and with the development of new technologies such as 5G mobile networks,(3) big data, and artificial intelligence (AI), smart and high-tech industries are favored by the government. Such industries have a low dependence on energy and even provide technologies for energy saving and emission reduction. This leads to changes in the urban economy, which affects urban residents. Changes in the quality of life due to the development of the urban economy demand increasing public and living spaces even with carbon emission reduction.(4,5) As the number of highly educated urban residents increases in the urban population, the demand for improving the quality of life is increasing faster than ever.

Rapid urbanization has led to more public attention on urban public landscapes than before. Thus, landscape designers become more aware of their increasing responsibilities. In the past, the requirements for urban public landscapes were only based on aesthetics and functionality. However, nowadays, urban residents require more humanistic, historical, futuristic, and technological designs, which influence the design aesthetics.(6) The popularity of Internet use, at the same time, has also changed residents' concepts in environmental aesthetics.(7) People now compare the distinctive and impressive urban landscapes in different cities through the Internet with those in their cities, which pushes landscape designers to improve their design capabilities to meet the expectations of the public.

Landscape design is closely related to serving society. The number of graduates who major in landscape design increases every year, so their competitiveness directly affects their employment. Therefore, universities need to provide students with an appropriate education so that the students cultivate competitiveness for the fast-changing urban environment. It is also necessary for universities to revise and adjust curricula to offer appropriate courses for the current environment. In recent landscape design education, the main topics to be dealt with include several aspects: (1) how to achieve a seamless connection between students and workplaces, (2) how to enable students to learn professional knowledge and skills with recent technology, and (3) how to relate the norms and standards of universities with onsite working. The rapid development of technology directly affects the daily life of people and the landscape design of cities. The previous design concept is no longer applicable to the current living conditions of urban residents. Therefore, landscape design education needs to offer new education methods by adopting 5G networks, big data, AI, and multimedia technology that must harmonize with low-carbon policy,(8) sustainable development,(9) and cities' histories and identities.

Recently, such technologies have been combined and used for machine learning that needs computing algorithms to improve learning by themselves. As training with previous data is critical, machine learning requires collecting data for training and improving its algorithms. In many cases, the data are collected by and through various sensors. In landscape design, drawing ability is an important basic skill. To enhance students' capability in landscape design education, appropriate hardware including sensors is necessary to monitor and assess the drawing capability. Tablet technology is used for this purpose and requires various sensors such as gyroscopes, pressure sensors, accelerometers, temperature sensors, touch sensors, humidity sensors, and digital compasses. All the sensors are used to capture and record drawn images, which are then processed to evaluate the quality or appropriateness of the images. Other than the drawing capability, there are other factors to be considered for educating students with the mentioned technologies in landscape design.

Therefore, considering the above issues, we aim to investigate the factors that should be considered for proposing an education model of the curricula of landscape design in universities. For research, we combine the Delphi method, analytical hierarchy process (AHP), and fuzzy logic theory (FLT) for providing a multi-attribute decision-making process. The result provides a way to effectively integrate technology and various concepts and implement them into education, which satisfies the urgent needs of current landscape design education.

2. Background

Landscape design education involves a wide range of knowledge for the development of professional competence. Thus, the curriculum focuses on the development of professional design skills, professional design practice capabilities, professional general knowledge development, and cross-professional platform cooperation capabilities, all of which contribute to professional core competence. The content of the development is summarized as follows.

2.1 Development of professional design skills

The course for teaching hand-drawing ability mainly guides perspective, proportion, scale, material, color, space, atmosphere, and so on to cultivate students' spatial perception. In the course, students learn how to integrate environmental and outdoor spaces into the design. The expression of thinking connects thoughts and drawings to train students to carry out complex design projects in the future.

2D computer-aided design (CAD) mainly cultivates students' ability to carry out standardized tasks in accordance with the industry requirement and standards. 3D CAD allows students to construct detailed effects on the space with a computer and further refine the design plan. At the same time, CAD is used for the simulation of a plan to demonstrate their designs as mimicking the real environment. For example, CAD enables students to look at a design in the view of real pedestrians and to design planting trees according to various types of weather and climate.[10] Such experience allows students to design green spaces in a landscape design with different plants in a certain environment.

Community and environmental planning is based on the concept of community building and allows students to design functional zoning, streamline design, functional facilities, and recreational facilities based on the investigation of residents' living behavior. Urban and rural landscape planning is based on the city's green energy and ecologically sustainable development goals, which promotes the spatial transformation and revitalization of old industrial areas, commercial districts, communities, and villages and streets in urban environments. Current cultural cognition is also the basis of landscape design, as cultural values and emotions effectively stimulate residents' intrinsic motivation for low-carbon consumption and help them participate in low-carbon practices.(11)

2.2 Professional design practice ability

The goal of professional design practice is to allow students to adapt to working based on traditional learning. Through project analysis, students experience the whole process of a complete design project, understand the division of labor, and understand how to fill vacancies. This enables students to gradually make up for missing knowledge and have self-learning ability in the follow-up learning process. Project simulation exercise strengthens students' design skills and increases their professional self-confidence, allowing them to find their strengths and positioning from their project roles and to clarify their career paths in the future learning process. Professional internship has laid the necessary foundation. In addition, professional design practice further provides the cross-disciplinary workshop.(12)

The term workshop first appeared in the field of education and psychology. Lawrence Harplin, an American scholar, introduced the concept of the workshop to the design of urban landscape space in the 1960s. Soon, it provided people in different positions with different cultural backgrounds with the opportunities to think, discuss, and communicate. When discussing urban landscape space design or community environmental issues, participants are encouraged to find innovative solutions. After the workshop, questionnaire surveys are usually carried out through interviews, field surveys, observation, and so on. Experience, practice, and reflection enable participants to deepen knowledge and skills.

As the graduates who have majored in landscape design mostly work for landscape design firms, it is necessary for them to have internships before employment. The internship allows students to understand the implementation and development of projects and enables them to pragmatically consider the design process. Industry training allows students to have a comprehensive and accurate grasp of current industry standards and technical specifications.

2.3 Cultivation of professional knowledge

Landscape design education aims at cultivating designers to have humanistic and scientific rationale. Therefore, students learn the necessary values such as environmental protection, green energy, ecological design, sustainable development, and human-oriented concepts. These are important in shaping designer philosophy that has a profound impact on urban landscape design. The landscape designer's ethics are also important. It reflects the designer's professionalism that must not be altered. Design plagiarism occurs owing to the lack of ethics. Thus, design ethics need to be included in the compulsory courses of landscape design education. Landscape designers are required to equip themselves with altruistic values,(13) personal and social norms, situation awareness, as well as scientific knowledge on low-carbon development.(14)

2.4 Multidisciplinary cooperation

The advancement of technology such as the 5G network has changed people's lives tremendously. Therefore, in landscape design, the impact of the Internet era needs to be considered to adapt it to the current life pattern and construct a livable urban space. For example, the popular behaviors of taking and sharing photos can be reflected in urban landscape design in addition to functionality, comfort, and expectation, which requires the designer's elaboration for the visual importance of space. The urban landscape is appreciated by the residents and by online viewers on the Internet.

Traditional landscape design only showed its conceptual model as miniatures. However, present multimedia technology creates images in virtual reality. Digitized architectures can be seen by interactive multimedia technology that has changed the way of showing the urban landscape. In the era of big data, local governments have successively launched "smart city" construction plans based on big data and AI in recent years. At present, Guangdong, Zhejiang, Shandong, Guizhou, Fujian, Jilin Province, Henan, Jiangxi, and Guangxi Zhuang Autonomous Region, Inner Mongolia Autonomous Region, Chongqing City, Shanghai have established their big data management institutions. With this, the urban public landscape has become important for the realization of smart cities where new technologies are used. This is important for improving the level of refining management and improving social governance. The urban landscape based on big data AI technology has various operations in terms of landscaping, management, law enforcement, lighting, transportation, waste treatment, water supply, and sewage treatment. The safety of facilities, such as power grids, gas pipelines, and constructions such as bridges, is also included in the operation.

At the same time, with the development goal of "cultural self-confidence", cities have begun to explore local history and cultural heritage that have cultural connotations. Cultural and historical legacy reveals self-identity and urban cohesion and allows a city to develop tourism and other green economic industries. Sometimes, the archaeological excavation of a city affects the shaping of its image and landscape. Therefore, for landscape design, humanities and history play important roles in research, design, and practice. In addition to the improvement of the cultural level of cities, the artistic and aesthetic standards of urban landscapes are also improving. Traditional urban landscape design is far from meeting the requirements of the residents. Public art based on materials, installations, and shapes has recently become an important means for the vitality of the city, shaping the city's image. Thus, cities need to have the necessary conditions to create communities as the country wants more public art to develop and proliferate into urban planning and development. This is another reason why the cross-field and interdisciplinary development of urban landscape design is needed.

3. Methods

The Delphi method, AHP, and FLT are used for establishing and assessing a multi-attribute decision-making model in which the effect of landscape design is investigated as an interdisciplinary course.

3.1 Delphi method

The Delphi method is an anonymous group decision-making methodology. It is carried out through a questionnaire survey for experts to obtain the experts' consensus. The flow chart of the Delphi questionnaire survey in this study is shown in Fig. 1.[15] Currently, the Delphi method is widely used in various studies. Several examples include determining the potential of Fintech,[16] decision-making in pharmacy education,[17] the evaluation of low-carbon tourism,[18] the validation of a wetland ecosystem,[19] and landscape architecture.[20]

3.2 AHP

AHP was proposed for decision-making based on multi-attributes with the assessment of uncertainty. Relative weights are applied to impact factors that are the basis for evaluation and decision-making. An AHP evaluation model first confirms the evaluation factors and then establishes the hierarchical structure of the factors to calculate the relative impact weight of each factor according to the calculation equation. AHP enables systematic and quantitative decision-making based on qualitative and quantitative analyses. AHP also has been used in various fields including waste treatment,[21] contract analysis,[22] process mining,[23] logistics analysis,[24] corporate social responsibility analysis,[25] and environmental protection policy-making.[26]

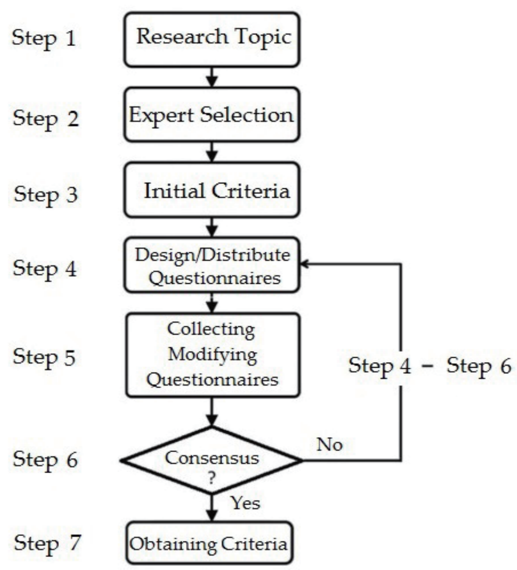


Fig. 1. Delphi questionnaire survey flow chart.

3.3 FLT

FLT is a multi-attribute decision-making model that is often used to construct quantitative evaluation models. It is used to analyze vague semantics(27) by finding information from natural lingual expressions.(28) Complex and inaccurate semantics are converted through quantitative analysis. As FLT is used with AI, building an FLT model needs the construction of the fuzzy logic inference system (FLIS). FLIS requires fuzzy sets, membership function (MF), IF-THEN rules, and the definitions of interval values for impact factors. With AI, FLIS provides inference and calculation and a quantitative function in decision-making. The inference procedure of FLIS is as follows (Fig. 2).

(1) The input status of each impact factor is confirmed.
(2) With FLIS for the input status, Fuzzifier is resolved.
(3) Fuzzifier inference engine conducts rule-based data comparison.
(4) After the rule-based inference data are compared, the defuzzifier of the input status is performed.
(5) Output values are quantified.

FLT is also widely used in various fields such as sustainable energy system development,(29) technology-enabled design education and practices,(30) fuzzy multi-criteria decision-making for energy,(31) and risk analysis in oil and gas projects. (32)

4. Results and Discussion

4.1 Delphi method

In the Delphi method, a total of 12 experts with 15 or more years of practical experience in landscape design were invited. On the basis of literature review and the survey with the experts,

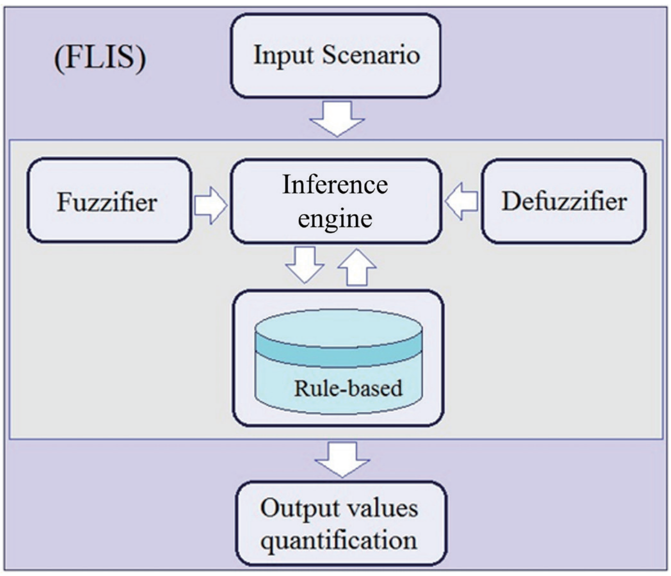


Fig. 2. (Color online) FLIS architecture diagram.

preliminary factors in the courses of landscape design education are summarized as follows. The first-level factor has three categories that have three subfactors.
(1) Professional skills: hand-drawing ability, 3D drawing ability, eco-friendly design
(2) Professional practice: project simulation, project practice, humanistic value and responsibility
(3) Interdisciplinary collaboration: interdisciplinary communication, Internet interdisciplinary course, collaborative design

4.2 AHP model

The first-and second-level factors were confirmed by the Delphi method for establishing an AHP multi-attribute decision-making model. The procedure of the AHP model to calculate the relative weight of each impact factor is as follows:
(1) establishing a hierarchical structure of the first- and second-level impact factors (Fig. 3),
(2) making and distributing the questionnaires for the comparison of pairs at each level of AHP,
(3) pairwise comparison of each factor for the magnitude comparison of its relative importance,
(4) testing the AHP model with a consistency index (*CI*) and consistency ratio (*CR*) [under $CI \leq 0.1$ and $CR \leq 0.1$ conditions, the model is considered effective ($CR = CI/RI$ (relative index))], and
(5) applying the AHP model to calculate the relative weight of each impact factor (Table 1).

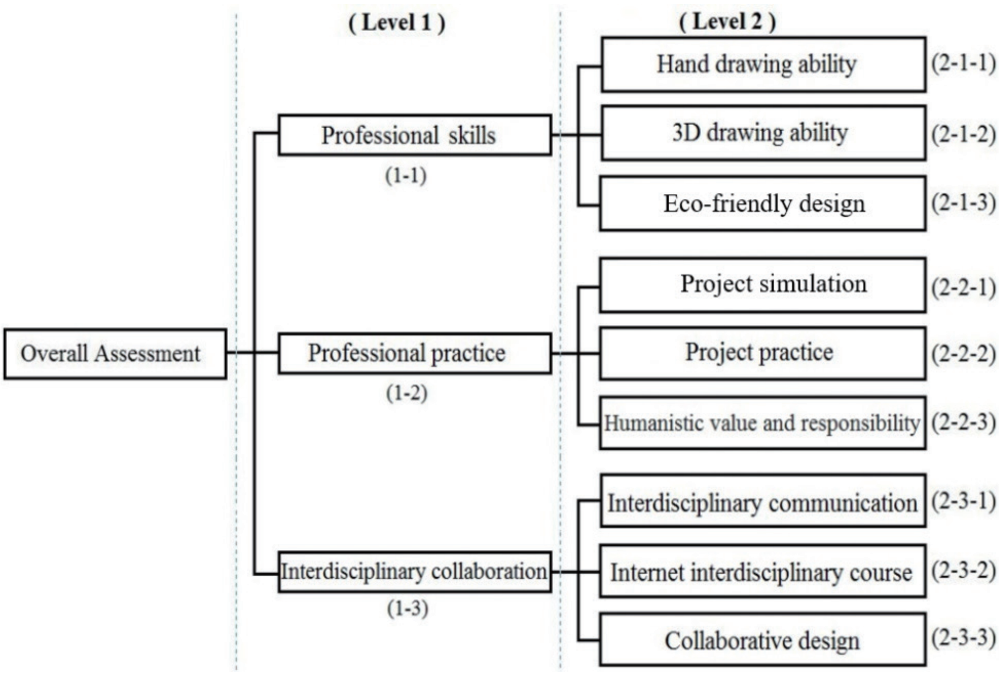


Fig. 3. Schematic diagram of AHP's hierarchical structure.

Table 1
Relative weight of each criterion.

First level (Level 1)	Second level (Level 2)	w_i	Sequence
Professional skills (1–1) (0.41)	Hand-drawing ability (2–1–1) (0.16)	0.065	6
	3D drawing ability (2–1–2) (0.19)	0.077	5
	Eco-friendly design (2–1–3) (0.66)	0.270	1
Professional practice (1–2) (0.33)	Project simulation course (2–2–1) (0.30)	0.099	4
	Project practice (2–2–2) (0.60)	0.198	2
	Humanistic value and responsibility (2–2–3) (0.10)	0.033	9
Interdisciplinary collaboration (1–3) (0.26)	Interdisciplinary communication (2–3–1) (0.17)	0.044	8
	Internet interdisciplinary course (2–3–2) (0.19)	0.049	7
	Collaborative design (2–3–3) (0.64)	0.166	3
Total weighting value (W_i)		1.001	
Remark	(1) Level 1: $CI = 0.0268$, $RI = 0.58$, $CR = CI/RI = 0.0462 \leq 0.1$; (2) Level 2–1: $CI = 0.0146$, $RI = 0.58$, $CR = CI/RI = 0.0251 \leq 0.1$; (3) Level 2–2: $CI = 0$, $RI = 0.58$, $CR = CI/RI = 0 \leq 0.1$; (4) Level 2–3: $CI = 0.0092$, $RI = 0.58$, $CR = CI/RI = 0.0158 \leq 0.1$; (5) $n = 3$, it is found that $RI = 0.58$ by looking up the AHP calculation formula.		

Table 1 shows the weights of the interdisciplinary learning effectiveness of landscape design at Levels 1 and 2, which are calculated by AHP.

(1) The factors of Levels 1 and 2 have $CR \leq 0.1$ and $CI \leq 0.1$, proving that the weights are effective.

(2) The relative weights of professional skill development, professional practice, and interdisciplinary collaboration are 0.41, 0.33, and 0.26, respectively.

(3) The relative weights of nine subfactors are eco-friendly design (0.270), project practice (0.198), collaborative design (0.166), project simulation (0.099), 3D drawing ability (0.077), hand-drawing ability (0.065), Internet interdisciplinary course (0.049), interdisciplinary communication (0.044), and humanistic value and responsibility (0.033).

4.3 FLT model

To establish the quantitative evaluation model using FLT, the parameters of various impact factors and output values were defined, including fuzzy sets, MF, and fuzzy range. Then, FLIS calculated and inferred the definitions of the parameters that were obtained by the Delphi method (Table 2). The fuzzy sets of professional skills, professional practice, and interdisciplinary collaboration have five, three, and three levels, respectively. Thus, there are 45 (5 × 3 × 3) different fuzzy sets for the evaluation. Three impact factors of Level 1 have three membership functions (Tri-MF) that are used to convert the ambiguous semantic quality belonging to

Table 2
FLIS parameters of this study.

Criteria	Fuzzy sets	Fuzzy range	Output value
Professional skills	Very Good	0–100	0–100 Very good ≥ 90 89 ≥ Good ≥ 75 74 ≥ Average ≥ 60 59 ≥ Bad ≥ 45 Very bad ≤ 44
	Good		
	Ordinary		
	Poor		
	Very Poor		
Professional practice	Ordinary	0–100	
	Poor		
	Very Poor		
Interdisciplinary collaboration	Good	0–100	
	Ordinary		
	Poor		

quantization. The fuzzy ranges of professional skills, professional practice, and interdisciplinary collaboration are 0–100. Table 2 shows the parameters of FLIS for decision-making for 45 different evaluation scenarios. The results in Fig. 4 show the 3D mapping of quantified values and the comparison of the value of professional skills with those of professional practice and interdisciplinary collaboration.

4.4 Application of DA Fuzzy multi-attribute model

By integrating the results of the Delphi method, AHP, and FLT, a multi-attribute decision-making model (DA Fuzzy model) is proposed as shown in Fig. 5. The figure illustrates the process of applying the three methods to establish multi-attribute decision-making on selecting the courses for landscape design education. The experts' opinion on the evaluation factors is obtained, which is then reflected in the hierarchical structure of AHP. AHP is used to calculate the relative weight (w_i) of each evaluation factor. FLIS is constructed on the basis of FLT and used to confirm the output value (f_i) and the overall evaluation ($w_i \times f_i$).

The result of the DA Fuzzy model is shown in Table 3 and indicates that eco-friendly design, project practice, and collaborative design are more important than other factors. This implies

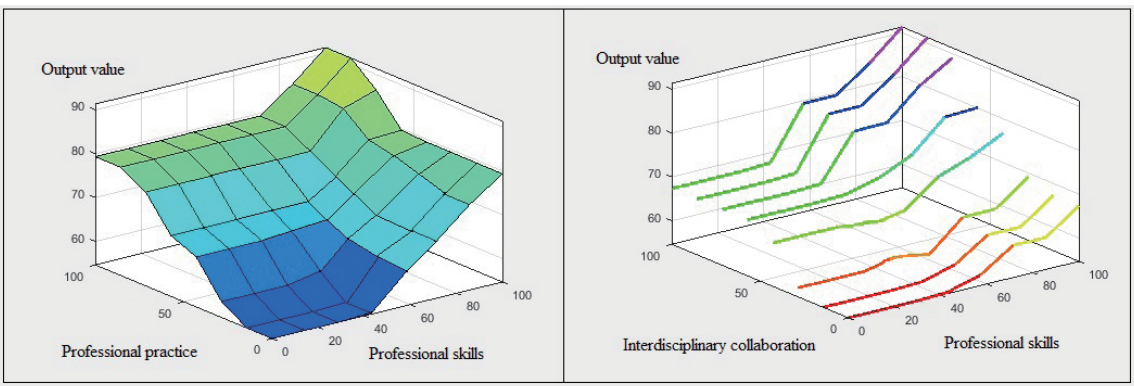


Fig. 4. (Color online) Input scenarios and 3D mapping of output quantized value.

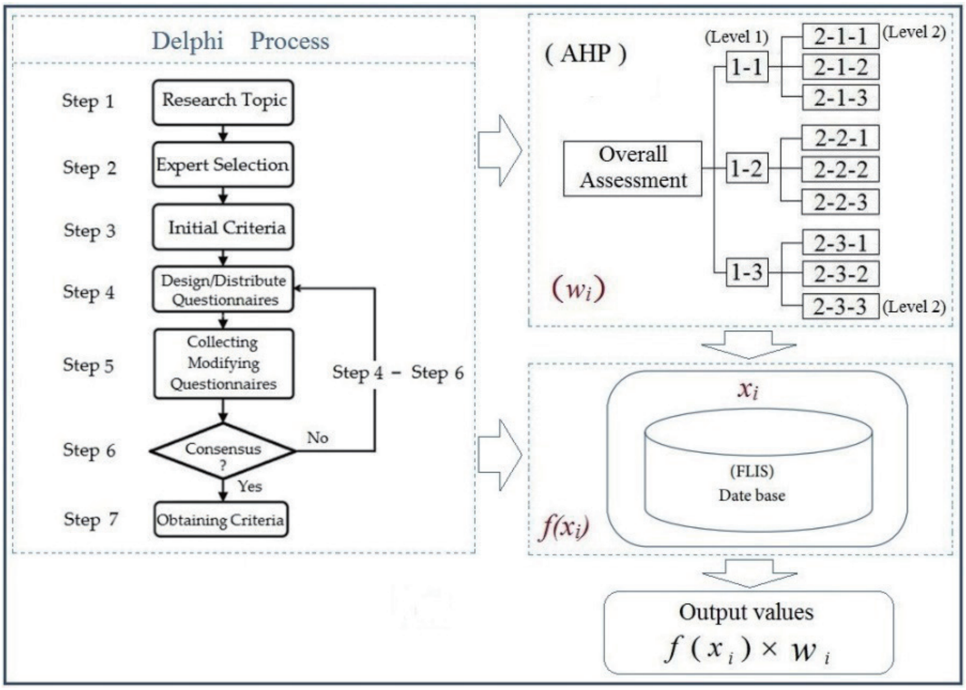
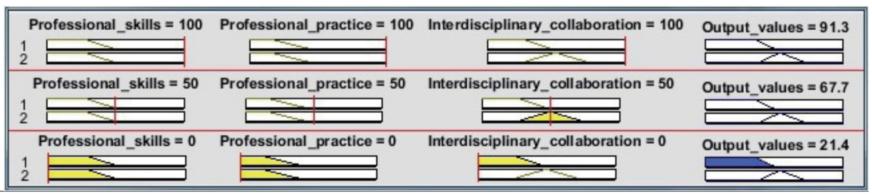


Fig. 5. (Color online) DA Fuzzy model in this study.

Table 3
(Color online) Results of DA Fuzzy model.

Factor	w_i	Best		Average		Worst	
		(f_i)	$(w_i \times f_i)$	(f_i)	$(w_i \times f_i)$	(f_i)	$(w_i \times f_i)$
Hand-drawing ability (2–1–1)	0.065		5.935		4.401		1.391
3D drawing ability (2–1–2)	0.077		7.030		5.213		1.648
Eco-friendly design (2–1–3)	0. 270		24.651		18.279		5.778
Project simulation course (2–2–1)	0.099		9.039		6.702		2.119
Project practice (2–2–2)	0.198	91.3	18.077	67.7	13.405	21.4	4.237
Humanistic value and responsibility (2–2–3)	0.033		3.013		2.234		0.706
Interdisciplinary communication (2–3–1)	0.044		4.0172		2.979		0.942
Internet interdisciplinary course (2–3–2)	0.049		4.474		3.317		1.049
Collaborative design (2–3–3)	0.166		15.156		11.238		3.552
DA Fuzzy model calculation							

that the consideration of the environment is important for landscape design, and cooperation with various organizations needs to be emphasized for inter- and multi-disciplinary education of landscape design.

5. Conclusions

Landscape design education requires multidisciplinary knowledge, and students need to pay attention to the development of professional competency. By using the Delphi, AHP, and FLT (DA Fuzzy), a multi-attribute decision-making model is proposed for defining the appropriate teaching courses in landscape design education.

The DA Fuzzy model evaluates individual courses and selects the best plan with multiple courses. Three factors were defined as Level 1 impact factors, namely, professional skills, professional practice, and interdisciplinary collaboration. Each Level 1 factor has three subfactors (Level 2 factors): hand-drawing ability, 3D drawing ability, and eco-friendly design (professional skills); project simulation, project practice, and humanistic value and responsibility (professional practice); interdisciplinary communication, Internet interdisciplinary course, and collaborative design (interdisciplinary collaboration).

The relative weights of Level 1 factors are 0.41, 0.33, and 0.26 for professional skills, professional practice, and interdisciplinary collaboration, respectively. The five important Level 2 factors are eco-friendly design (0.270), project practice (0.198), collaborative design (0.166), simulation project, (0.099), and 3D drawing ability (0.077) in the order of their weights. The relative weight of eco-friendly design (0.270) is higher than those of other Level 2 factors, which indicates that landscape design needs to improve the environment for human habitation and emphasizes the importance of green cities. Thus, a low-carbon and eco-friendly environment leads to the sustainable development of cities. The importance of project practice and collaborative design also illustrates the necessity of interdisciplinary knowledge in landscape design. To cultivate the core competency in landscape design, cooperation with organizations is required to obtain the current knowledge. In developing the ability of practical design, cooperation with various industries is also required for sustainable landscape design to educate students and enhance their abilities.

The research results are expected to be the basis for integrating technologies in land design education for assessing students' various abilities, which needs the development of algorithms and corresponding hardware with appropriate sensing technologies.

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