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An assessment model of classroom acoustical environment based on fuzzy comprehensive evaluation method

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Abstract

In this paper, an assessment model based on multi-layer fuzzy comprehensive evaluation method (FCE) of classroom acoustical environment is proposed. The model classifies five major factors affecting overall assessment model into several subsets alternatives. The weightings of these main criteria and alternatives were collected through questionnaires among students based on analytic hierarchy process methodology (AHP). An evaluation score was calculated from the proposed model with the weightings generated from AHP method. In this paper, classrooms in the Hong Kong Polytechnic University were used to develop the assessment model. The result shows that the evaluation score of PolyU classrooms is about 87.2, which refers to “Good” evaluation set. It indicates that classrooms in PolyU needs to be improved. The weightings generated from AHP method can be considered for the importance of each alternatives. The assessment model can provide proper recommendation to universities for acoustic treatment so as to increase the acoustic quality of the educational environment.

Keywords: assessment model; acoustical environment; fuzzy comprehensive evaluation; analytic hierarchy process

1. Introduction

The education of every citizen is essential to all modern societies. The most formal education takes place in the classroom, where the learning process involves intensive verbal communication between teachers and students [1]. Evidence shows that poor room acoustics, such as excessive noise and reverberation, reduces the speech intelligibility in a classroom and interrupts the verbal communication between teachers and students [2]. In rooms intended for speech communication, good acoustical design is particularly important. Room size and shape, ambient noise level and amount and location of sound-absorbing materials all affect how well such a room fulfils its purpose [3]. Han and Mak [4] reported that increasing the absorption coefficient at the back wall could increase the speech intelligibility to the largest extent in the classroom. To achieve good acoustical environment from the beginning is to identify acoustical problems that can be found inside or outside the classrooms. In order to overcome the existing classroom acoustics problems and enhance the speech intelligibility, classroom acoustic treatment is an effective way to improve the learning quality and learning outcomes. Besides, interactive teaching in the classroom is another main source of noise that can affect the educational quality in classrooms. It is therefore essential to have appropriate and accurate methods for assessing the acoustical environment in buildings. Mak and Wang [5] reported several assessment models used in building acoustics includes analytical models, empirical models and numerical models.

Many researchers evaluated some assessment of acoustic quality. Zannin et.al [6] evaluated reverberation time, sound insulation index, background noise and assessment of speech transmission index. Subjective assessment of audio quality were conducted by

Hoeg et.al [7]. Astolfi and Pellerey [8] conducted a subjective assessment and an objective assessment of acoustical and overall environmental quality of vernacular classrooms and modern classrooms. Madbouly et al. [9] proposed an assessment model of classroom acoustics criteria based on analytic hierarchy process (AHP) for enhancing speech intelligibility. The model consisted of five main criteria that include classroom specifications, noise sources inside and outside the classroom, teaching style, and vocal effort. These five criteria covered twenty-eight alternatives that were considered the main factors influenced the classroom acoustics. AHP method can evaluate the priorities of the alternatives by conducting a number of pairwise comparisons. Mak et al. [10] presented an approach to sustainable noise control system design using AHP method to evaluate various noise control systems. However, the AHP cannot take into account uncertainty when assessing and tackling a problem effectively. Therefore, the combination of fuzzy set of AHP method can effectively tackle fuzziness or vague decision-making problem. Zadeh [11] first introduced fuzzy sets in 1965, which is a class of objects with a continuum of grades of membership. The fuzzy sets were pointed out because of the availability and uncertainty of information as well as the vagueness of human feeling and recognition, it is relatively difficult to provide exact numerical values for the criteria, make an exact evaluation and convey the feeling and recognition of objects for decision makers. Fuzzy set theory has been applied in many systems in the latter scientific research [12-17]. Fuzzy comprehensive evaluation method (FCE) is a multilayer comprehensive evaluation index system based Fuzzy mathematics. Researchers presented many evaluation systems using FCE method. In a multi-criteria decision-making problem, FCE method has been used to trace the trend of urban development [18]. In an assessment of Korean national competitiveness in the hydrogen sector, researchers conducted the hydrogen technology sectors of 30 nations, using fuzzy AHP relative weightings garners triangular fuzzy numbers. The studies mentioned above are all related to assessment model based on fuzzy evaluation models.

In this paper, a new multi-criteria assessment model of classroom acoustics criteria is developed based on fuzzy comprehensive evaluation method (FCE). Analytic hierarchy process (AHP) method is used to calculate the weightings of secondary layer index. Multi-criteria FCE method combines with the weightings from AHP method.

2. Criteria and alternatives

An assessment model of the classroom acoustic criteria is established in Fig.1.

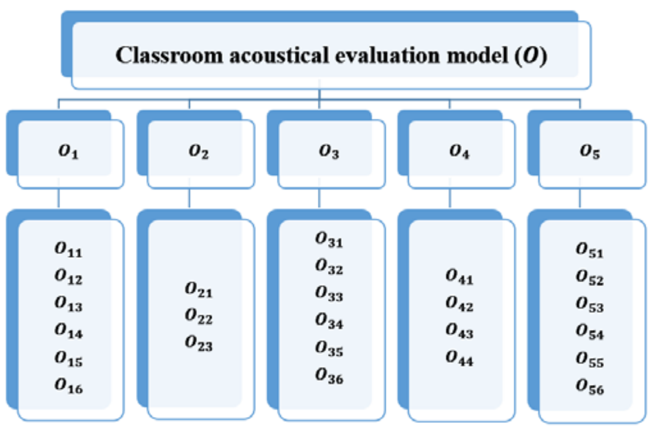

Fig.1 An assessment model for assessing acoustical criteria and alternatives

Refer to previous studies [9, 19], the assessment model should consist of five main criteria. Each of these criterions is made up of some independent indexes. Therefore, a three-layer comprehensive evaluation index system is proposed. The index system consider the overall classroom acoustical criteria comprehensive evaluation score (O) determined by five main evaluation indexes: the classroom facility(O_1), inside classroom noise(O_2), outside classroom noise(O_3), Interactive teaching(O_4), and vocal effort(O_5).

O_1 represents classroom facility which influence the education quality. This criterion include six sub-factors named $O_{11} to$ O_{16}.

Acoustical properties (O_{11}): such as the acoustical design of walls and ceilings which are used as preserve reverberation time and keep ambient noise less. Lighting (O_{12}): both low lights level and too much lighting are problems for inside classroom education. Equipment (O_{13}): facilities includes data projector, projection screen, teacher's computer and network connection for students' computer and laptops. Ventilation (O_{14}): proper ventilation in classroom will promote optimum conditions for students in study, listening, reading and interaction. Classroom specification (O_{15}): this criterion is mainly refer to the classroom size. Insufficient classroom space may influence students on daily education. Classroom architecture (O_{16}): such as shape and style of the classroom, the location of the classroom. All of these are important factors that affect students learning process and education quality.

O_2 is further determined by three alternatives. Heating ventilation and Air condition (HVAC) system (O_{21}) are the main sources of noise inside classroom. The system includes air handlers and fans, acoustical treatment of ducts, returns and diffusers. Besides, students' activity and interacting (O_{22}) can increase the noise level inside the classrooms. In addition, another factor contributed to the noise inside classroom is the lighting system (O_{23}).

Corresponding toO_2, noise sources outside the classroom (O_3) is another important criterion of the classroom acoustics. O_3 is further considered by the following six criteria: traffic noise (O_{31}), noise generated from neighbouring classroom (O_{32}), noise from corridor, hallway, and lobby (O_{33}), noise coming from surrounding playgrounds (O_{34}), mechanical equipment noise (O_{35}), noise generated from nearby building (O_{36}).

Universities aim to increase effectiveness of teaching students so that the teaching methods and styles (O_4) play an important role in the classroom education. These teaching methods and styles mainly include practice work (O_{41}), group work (O_{42}), blackboard teaching (O_{43}) and multimedia techniques (O_{44}). Different ways of the communication between students and speakers affect different learning experience.

Traunm$\ddot{u}$llera and Eriksson [20] defined "Vocal effort" as the communication distance estimated by a group of listeners for each utterance. Therefore, vocal effort (O_5) becomes the fifth criterion of classroom acoustical assessment model. Six alternatives are included in O_5 as follows: acoustical treatment (O_{51}), sound reinforcement system (O_{52}), classroom size (O_{53}), position of students inside classroom (O_{54}), lecturer position inside the classroom (O_{55}) and the numbers of students (O_{56}).

3. Fuzzy multi-layer evaluation methodology

In the real world, precise data pertaining to measurement indicators is very hard to extract from human judgments. This is because human preferences encompass a degree of uncertainly, and decision makers may very well be reluctant or unable to assign crisp numerical values to comparison judgements. Decision makers also prefer natural language expressions over exact numbers when assessing criteria and alternatives. Fuzzy set theory deals with ambiguous or not well-defined situations. The AHP leads from simple pairwise comparison judgements to priorities arranged within a hierarchy. The AHP cannot take into account uncertainly when assessing and tackling a problem effectively. However, the fuzzy comprehensive evaluation method can tackle fuzziness or the problem of vague decision-making more efficiently by using fuzzy scales with lower, median and upper values. This can be contrasted with the AHP's crisp 9-point scale and synthesis of the relative weights using fuzzy sets, membership functions and fuzzy members.

Fuzzy multi-layer assessment model generally classify those major factors affecting overall assessment model into several subsets alternatives. Assuming the set of evaluation criteria $O = [O_1, O_2, \ldots O_n,]$. Since $O_i(i \in [1,2 \ldots n])$ is composed of n_i sub-criteria,

$O_i = [O_{i1}, O_{i2}, \ldots O_{in}]$. The evaluation index set V is composed of all evaluation indexes. V is divided into k subsets, i.e., $V = [V_1, V_2, \ldots V_k]$ which satisfy the following:

$$\cup_{i=1}^{k} V_i = V, V_i \cap V_j = \emptyset,\ i, j \in [1,2 \ldots n].$$

Next, assuming that the evaluation index set $V = [V_1, V_2, \ldots V_k]$ has n_i evaluation indexes, the eigenvalue of n_i evaluation matrix R_i can be represented as follows,

$$R_i = \left\{ \begin{matrix} r_{11}^{(i)} & r_{12}^{(i)} & \cdots & r_{1m}^{(i)} \\ r_{21}^{(i)} & r_{22}^{(i)} & \cdots & r_{2m}^{(i)} \\ \vdots & \vdots & \vdots & \vdots \\ r_{ni1}^{(i)} & r_{ni2}^{(i)} & \cdots & r_{nim}^{(i)} \end{matrix} \right\}$$

Assuming that $A_i = [{a_1}^{(i)}, {a_2}^{(i)}, \ldots, {a_{n_i}}^{(i)}]$ is the weighting coefficient evaluation matrix.

The result set of comprehensive evaluation is as follows,

$$B = A \circ R = (b_1, b_2, \ldots, b_m),$$

where ° represent a kind of fuzzy operation symbol, computational formula is

$$b_j = \sum_{i=1}^{n} (a_i r_{ij}).$$

4. Model evaluation

Refer to the multi-criteria assessment model, the combination of AHP method and FCE method are needed to calculate the model. The AHP enables decision makers to structure complex problems in a simple hierarchical form, and to evaluate a large number of quantitative and qualitative factors in a systematic manner despite the presence of multiple conflicting criteria. In order to collect information about classroom acoustical properties, a set of survey questionnaires was conducted in the Hong Kong Polytechnic University (PolyU). Twenty students (both undergraduates and postgraduates are included) participated in the survey. They were asked to compare each two factors of one main criterion and to give scale according to the importance. Besides, participants were asked about the quality of acoustical environment in PolyU. In terms of each criteria, students can choose evaluation score from the assessment system. They were told to answer each questions independently. They were arranged to complete the questionnaires in prescript classrooms. These classrooms were selected in different building in PolyU. This condition aimed to coverage the whole university.

Table 1
Pairwise comparisons among classroom facilities alternatives.

	$\mathbf{O_{11}}$	$\mathbf{O_{12}}$	$\mathbf{O_{13}}$	$\mathbf{O_{14}}$	$\mathbf{O_{15}}$	$\mathbf{O_{16}}$	**weighting**
$\mathbf{O_{11}}$	1.00	3.58	5.66	2.21	4.80	5.12	41.44%
$\mathbf{O_{12}}$	0.28	1.00	0.50	0.26	1.12	2.05	7.83%
$\mathbf{O_{13}}$	0.18	2.00	1.00	0.45	4.06	4.60	14.98%
$\mathbf{O_{14}}$	0.45	3.85	2.22	1.00	3.54	6.80	25.21%
$\mathbf{O_{15}}$	0.21	0.89	0.25	0.28	1.00	1.20	6.00%
$\mathbf{O_{16}}$	0.20	0.49	0.22	0.15	0.83	1.00	4.54%

Table 2
Pairwise comparisons among inside classroom noise alternatives.

	$\mathbf{O_{21}}$	$\mathbf{O_{22}}$	$\mathbf{O_{23}}$	**weighting**
$\mathbf{O_{21}}$	1.00	0.40	0.67	19.66%
$\mathbf{O_{22}}$	2.50	1.00	2.10	53.01%
$\mathbf{O_{23}}$	1.50	0.48	1.00	27.33%

Table 3
Pairwise comparisons among outside classroom noise alternatives.

	$\mathbf{O_{31}}$	$\mathbf{O_{32}}$	$\mathbf{O_{33}}$	$\mathbf{O_{34}}$	$\mathbf{O_{35}}$	$\mathbf{O_{36}}$	**weighting**
$\mathbf{O_{31}}$	1.00	0.28	0.40	0.58	1.15	1.88	10.71%
$\mathbf{O_{32}}$	3.57	1.00	0.62	2.86	2.12	2.04	26.53%
$\mathbf{O_{33}}$	2.50	1.61	1.00	2.16	2.96	1.91	28.03%
$\mathbf{O_{34}}$	1.72	0.35	0.46	1.00	3.32	1.85	16.34%
$\mathbf{O_{35}}$	0.87	0.47	0.34	0.30	1.00	0.67	8.14%
$\mathbf{O_{36}}$	0.53	0.49	0.52	0.54	1.50	1.00	10.25%

Table 4
Pairwise comparisons among interactive teaching alternatives.

	$\mathbf{O_{41}}$	$\mathbf{O_{42}}$	$\mathbf{O_{43}}$	$\mathbf{O_{44}}$	**weighting**
$\mathbf{O_{41}}$	1.00	0.36	4.21	1.98	25.35%
$\mathbf{O_{42}}$	2.78	1.00	4.56	4.13	52.72%
$\mathbf{O_{43}}$	0.24	0.22	1.00	0.38	7.44%
$\mathbf{O_{44}}$	0.51	0.24	2.63	1.00	14.49%

Table 5
Pairwise comparisons among vocal effort alternatives.

	$\mathbf{O_{51}}$	$\mathbf{O_{52}}$	$\mathbf{O_{53}}$	$\mathbf{O_{54}}$	$\mathbf{O_{55}}$	$\mathbf{O_{56}}$	**weighting**
$\mathbf{O_{51}}$	1.00	2.05	4.22	5.02	2.86	3.69	37.47%
$\mathbf{O_{52}}$	0.49	1.00	3.06	2.88	1.66	2.92	22.91%
$\mathbf{O_{53}}$	0.24	0.33	1.00	2.14	3.06	0.88	12.55%
$\mathbf{O_{54}}$	0.20	0.35	0.47	1.00	1.08	2.00	9.14%
$\mathbf{O_{55}}$	0.35	0.60	0.33	0.93	1.00	0.41	7.77%
$\mathbf{O_{56}}$	0.27	0.34	1.14	0.50	2.44	1.00	10.16%

Table 6
Pairwise comparisons among five major criteria.

	O_1	O_2	O_3	O_4	O_5	weighting
O_1	1.00	1.21	1.67	1.58	2.15	28.11%
O_2	0.83	1.00	1.34	1.63	2.08	24.87%
O_3	0.60	0.75	1.00	1.16	1.80	18.87%
O_4	0.63	0.61	0.86	1.00	1.42	16.40%
O_5	0.47	0.48	0.56	0.70	1.00	11.76%

Assuming that the evaluation index set:

$V = [V_1, V_2, V_3, V_4, V_5] = ["Excellent", "Good", "Medium", "Poor", "Very\ Poor"]$,

where "Excellent" refers to score more than 90, "Good" refers to score between 80 and 90, "Medium" refers to score from 70 to 80, "Poor" refers to score from 60 to 70 and "Very Poor" refers to score up to 60.

Table 7
The results of classroom acoustic quality from students

Main Criteria	Sub-criteria	Excellent V_1	Good V_2	Medium V_3	Poor V_4	Very Poor V_5
The classroom facility (O_1)	Acoustical properties (O_{11})	12	6	2	0	0
	Lighting (O_{12})	8	8	3	1	0
	Equipment (O_{13})	4	6	5	4	1
	Ventilation (O_{14})	6	6	4	3	1
	Classroom specification (O_{15})	2	8	8	2	0
	Classroom architecture (O_{16})	4	12	3	1	0
Inside classroom noise (O_2)	HVAC system (O_{21})	8	8	2	2	0
	Students' activity and interacting (O_{22})	14	5	1	0	0
	lighting system (O_{23})	12	5	2	0	1
Outside classroom noise (O_3)	Traffic noise (O_{31})	8	4	7	1	0
	Noise generated from neighbouring classroom (O_{32})	14	6	0	0	0

	Noise from corridor, hallway, and lobby (O_{33})	10	8	2	0	0
	Noise coming from surrounding playgrounds (O_{34})	16	1	2	1	0
	Mechanical equipment noise (O_{35})	10	4	4	1	1
	Noise generated from nearby building (O_{36})	8	8	2	1	1
Interactive teaching (O_4)	Practice work (O_{41})	10	4	4	1	1
	Group work (O_{42})	8	6	4	2	0
	Blackboard teaching (O_{43})	4	8	4	4	0
	Multimedia techniques (O_{44})	9	5	5	1	0
Vocal effort (O_5)	Acoustical treatment (O_{51})	15	4	1	0	0
	Sound reinforcement system (O_{52})	12	3	2	1	2
	Classroom size (O_{53})	8	8	4	0	0
	Position of students inside classroom (O_{54})	14	2	2	2	1
	Lecturer position inside the classroom (O_{55})	12	4	3	1	0
	The numbers of students (O_{56})	10	6	3	1	0

From the survey results, the sub-criteria evaluation matrix is:

$$R_{11} = [0.6, 0.3,0.1,0,0] \qquad R_{12} = [0.4, 0.4,0.15,0.05,0]$$

$$R_{13} = [0.2, 0.3,0.25,0.2,0.05] \qquad R_{14} = [0.3, 0.3,0.2,0.15,0.05]$$

$$R_{15} = [0.1,0.5,0.4,0.1, 0] \qquad R_{16} = [0.2,0.6,0.15,0.05, 0]$$

The second hierarchy evaluation matrix is:

$$R_1 = \begin{bmatrix} 0.6, 0.3, 0.1, 0, 0 \\ 0.4, 0.4,0.15,0.05,0 \\ 0.2, 0.3,0.25,0.2,0.05 \\ 0.3,0.3,0.2,0.15,0.05 \\ 0.1, 0.5, 0.4, 0.1, 0 \\ 0.2,0.6,0.15,0.05, 0 \end{bmatrix}$$

$A_1 = [0.4144, 0.0783, 0.1498, 0.2521, 0.006, 0.0454]$ is the weighting coefficient evaluation matrix calculated from AHP method.

The result set of second hierarchy comprehensive evaluation is as follows,

$B_1 = A_1 \circ R_1$= [0.3952, 0.3064, 0.1503, 0.0746, 0.0201]

Similarly,

$$B_2 = [0.6737,0.2795,0.0735,0.0197,0.0137]$$

$$B_3 = [0.5811,0.2786,0.1084,0.0227,0.0092]$$

$$B_4 = [0.4177,0.2748,0.2072,0.0875,0.0127]$$

$$B_5 = [0.6301,0.2147,0.1028,0.0296,0.0229]$$

$$B = \begin{Bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{Bmatrix} = \begin{Bmatrix} 0.3952,0.3064,0.1503,0.0746,0.0201 \\ 0.6737,0.2795,0.0735,0.0197,0.0137 \\ 0.5811,0.2786,0.1084,0.0227,0.0092 \\ 0.4177,0.2748,0.2072,0.0875,0.0127 \\ 0.6301,0.2147,0.1028,0.0296,0.0229 \end{Bmatrix}$$

According to Table 6, the weighting coefficient evaluation of main criteria

$$A = [0.2811,0.2487,0.1887,0.1640,0.1176]$$

The first hierarchy comprehensive evaluation Y is

$$Y = A \circ B = [0.5309,0.2785,0.1271,0.0480,0.0156]$$

Assuming that the evaluation index set V:

$$V = [V_1, V_2, V_3, V_4, V_5] = ["Excellent", "Good", "Medium", "Poor", "Very\ Poor"],$$

where “Excellent” refers to score more than 90, “Good” refers to score between 80 and 90, “Medium” refers to score from 70 to 80, “Poor” refers to score from 60 to 70 and “Very Poor” refers to score up to 60. In order to calculate the value of the overall assessment of the classroom environment. “Excellent” refers to score 95, “Good” refers to score 85, “Medium” refers to score 75, “Poor” refers to score 65, and “Very Poor” refers to score 30. Therefore, the evaluation index value set N defines:

$$N = [N_1, N_2, N_3, N_4, N_5] = ["Excellent", "Good", "Medium", "Poor", "Very\ Poor"$$

$$N = [95,85,75,65,30]$$

The overall assessment score of the classrooms environment F is:

$$F = Y * N' = [0.5309,0.2785,0.1271,0.0480,0.0156]\begin{bmatrix}95\\85\\75\\65\\30\end{bmatrix} = 87.2251$$

Therefore, the overall assessment score in PolyU classrooms is 87.2251, which refers to “Good”.

5. Findings and discussions

Tables 1-5 show pairwise comparisons among each major criteria based on AHP method. The weightings column represents the significant proportion of each alternatives. Table 1 shows Acoustical properties (O_{11}), Ventilation (O_{14}), Equipment (O_{13}) are the main classroom facilities avoid classroom acoustical environment. Table 2 shows those students’ activity and interacting (O_{22}) generates most noise inside classroom. Table 3 shows that noise from corridor, hallway, and lobby (O_{33}), noise generated from neighboring classroom (O_{32}), noise coming from surrounding playgrounds (O_{34}) are the main noise sources outside the classroom. Table 4 shows group work (O_{42}) in interactive teaching generates most noise. As for vocal effort, Table 5 shows that acoustical treatment (O_{51}), sound reinforcement system (O_{52}) are the main source of noise.

As shown in Table 6, five main criteria can be ranked from O_1-O_5 based on the weights calculated from AHP method. The FCE assessment model input the weightings based on AHP and finally output the evaluation score. This evaluation score can intuitively show the quality of the classroom acoustical environment. The FCE assessment model not only can assess the acoustical condition in classroom, but also can give the weightings of each alternatives. Besides, the model can give proper recommendations to universities. In the evaluation survey as shown in Table 7, some students choose “poor” or “very poor” option to evaluate the objective alternatives. For example, there are three students considering that ventilation system (O_{14}) in PolyU generates poor acoustical environment, even one student choose “very poor”. Universities are suggested to reduce the noise generated from the ventilation system in order to improve the acoustical environment. For our case study, the evaluation score of PolyU is 87.2, which refers to “Good” educational environment. In order to increase the evaluation score, university authority may consider improving the following alternatives based on the FCE assessment model. First is the noise from the equipment and facilities that include data projector, projection screen, teacher’s computer and network connection for students’ computer and laptops. Second is the noise from the ventilation system. Third is the seating of the students inside the classroom and the sound reinforcement system. Fourth is the mechanical equipment noise and the noise generated from nearby building.

6. Conclusion

The work in this paper proposed an assessment model of classroom acoustical environment. The model based on Fuzzy comprehensive evaluation method and applied in

PolyU classrooms. The data is collected from students in the university. The weighting coefficient was calculated from Analytic hierarchy process method. The model is a combination of qualitative and quantitative, which is more accurate and reliable. It can be used in other universities and schools' assessment. It can help universities comprehend the experience of students about the acoustical environment. Besides, it can help manage the proper treatment and improve acoustical facilities in a proper way.

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