

A livability rating system of a high-rise housing and its computer simulation

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Abstract. Aiming at the problems in housing choosing and purchasing in the high-rise residential buildings, this paper considers the factors that affect various livable degrees and analyzes the important degrees of the factors through the Analytic Hierarchy Process (AHP), quantifying the various factors by 10 point scoring system. Accordingly, this paper puts forward a habitable housing index, validating the correctness of the indicators by simulating the process of housing choosing through computer program.

1. Introduction

Due to the conflict between population and land, the construction of high-rise residential buildings in modern cities becomes very common and the housing quality is largely affected by the floor, direction, type of apartment and even apartment number, etc. The common problem for the buyer is how to choose the most desirable and livable apartment in certain unsold high-rise residential neighborhood, but there is currently no a general evaluation standard on the housing habitable degree. Based on the Analytic Hierarchy Process (AHP), the important degree of various factors on housing choice quantitative relation is calculated, thus a 10-point evaluation mechanism is put forward. Meanwhile, the process of 200 buyers selecting apartments is simulated by the computer program, verifying the agreement and integrating degree between the standard and the actual situation of housing choice, and confirming the correctness of this kind of evaluation method.

2. The establishment of the scoring rules

2.1 The application scenario for the scoring rule: the object function

This paper aims to investigate and study the livable degree of an apartment building itself, and takes into consideration the evaluation criteria by which the buyer evaluates the apartment situation in the known residential buildings, defaulting the unrelated factors such as the buyer having selected the location. Based on concerns of buyers about the apartment building itself, six factors are given, containing visual field, safety coefficient, air quality, noise, ventilation and lighting. In the study, the satisfaction degree of the housing buyer on the six factors is confirmed as that on the whole apartment. A 50-storey building with four apartments and two types of model each level is used in the validation process in this paper.

The score is given in the form of a function:



$$S = \sum_{i=1}^6 p_i X_i \quad (1)$$

P_i is an important factor in the impact factor X_i ; S means that a room has a maximum of 10 points.

2.2 The importance of influencing factors is modeled using hierarchical analysis

2.2.1. Constructing the judgment matrix. Hierarchical structure reflects the relationship between various factors, and their importance in the eyes of buyers is not the same, so the judgment matrix needs to be constructed to evaluate these factors. By the Analytic Hierarchy Process, matrices for n factors need to be set up (the two criteria layers in this paper are: $n_1=2$, $n_2=6$). Each time two factors of x_i and x_j are taken, and a_{ij} is used to represent the comparison of the relative importance of the two factors, thus the matrix can be established: $A = (a_{ij})_{n \times n}$.

Based on the questionnaire data, according to the ventilation, lighting, air quality, noise, safety coefficient, the order of the vision, the floors and the order of the apartments type, the three-scale comparison matrix is set up, and statistics are as following:

$$C_1 = \begin{bmatrix} 1 & 1 & 2 & 2 & 2 & 2 \\ 1 & 1 & 2 & 2 & 2 & 2 \\ 0 & 0 & 1 & 2 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 2 & 1 & 1 \\ 0 & 0 & 1 & 2 & 1 & 1 \end{bmatrix} \quad (i, j=1,2, \dots, 6) \quad (2)$$

2.2.2 Single hierarchy arrangement and consistency checking. Consistency indicators are defined as:

$$CI = \frac{\lambda - n}{n - 1}$$

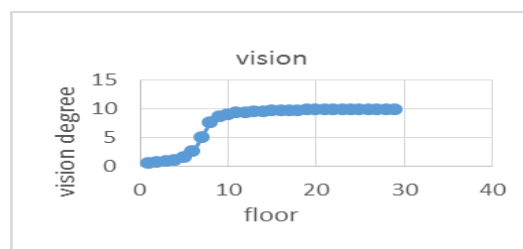
The eigenvectors are normalized: $\{0.345, 0.345, 0.092, 0.034, 0.092, 0.092\}$

The vector is the weight vector of the six requested factors. According to the example, it can be judged that the importance of the floor and the housing type are the same, and the weight vector is the weight of the six factors for the target. The substitution formula (1) is:

$$S = 0.0920X_1 + 0.0340X_2 + 0.3450X_3 + 0.3450X_4 + 0.0920X_5 + 0.0920X_6$$

2.3 The influence factors are quantified by 10-point system

2.3.1 The modeling of the influence factor x_1 - vision. The vision increases gradually as the floor increases. Questionnaire survey shows most people believe that view field on the floors 1-5 is poor, broad on 6th to 7th floor, and broader above the eighth floor, but the change is small, as shown in the figure below:



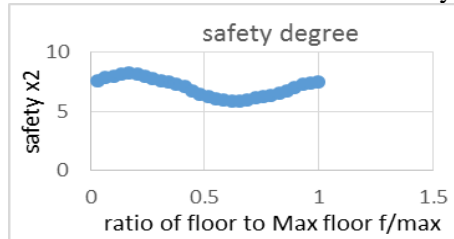
Based on this, the effect of floor f on the vision x_1 is:

$$x_1 = \frac{10}{PI} \arctan(f - 7) + 5 \quad (PI \text{ is } 3.14)$$

2.3.2 The modeling of the influence factor x_2 -safety. The results of the survey show that it is easier for residents on the first floor to escape in disaster such as fire or earthquake, but easier to be threatened by theft and other security threats. It has the advantage of easy escape on the 2-4 floors, while the threat of theft is reduced to the highest level of safety. It is easier for residents on the top floors near

the roof to escape to the roof of the building in fire, so the top floor is safer than the middle floor.

A function of the ratio of the floor to the maximum floor for safety is shown below:



Using the excel fitting function, the effect of the floor f on the view x_1 is simulated as:

$$X_2 = 3.925x^6 - 66.521x^5 + 112.12x^4 - 29.842x^3 - 30.505x^2 + 11.04x + 7.1675 \quad (X=f/\max)$$

2.3.3 The modeling of the influence factor x_3 -daylight. According to the requirement of constructing a residential building, assuming that two adjacent buildings are equal in height and the minimum of the distance between the buildings is required to make the first floor get daylight, which is to satisfy the following relationship: $\tan 26.5^\circ = \frac{H}{d}$

$$\text{so, } d = \frac{H}{\tan 26.5^\circ} \approx 2H$$

Let's say t is the first time the sun shines on a certain floor on the winter solstice, and T is the time of the floor with daylight during the whole day, so it is: $T = (12-t) \times 2$. The $(H-h)/d$ is the sine value of the height of the sun at the time t , and h is the height of the floor above the ground.

$$\text{so: } t = \frac{\arctan(\frac{H-h}{d})}{V} = \frac{\arctan(\frac{H-h}{d}) \times 12}{26.5^\circ} \quad (3)$$

$$\text{then: } x_3 = 10 \times \frac{T}{24} = 10 \times \left(1 - \frac{\arctan(\frac{H-h}{2H})}{26.5^\circ}\right) = 10 \times \left(1 - \frac{\arctan(\frac{\max-f}{2\max})}{26.5^\circ}\right); \quad (4)$$

2.3.4 The modeling of the influence factor x_4 -ventilation. In the modeling of the ventilation evaluation criteria, it is in consideration that the ventilation quality is not only related to the height of the building, but also related to the ratio (r) of the natural ventilation open area to floor area. The national regulations stipulate that this ratio mentioned above should not be less than 5%, and the room ventilation area of a 20-square-meter house should be between one and two square meters. Therefore, we find that the ratio is 5% to 10%. It is widely believed that housing type has a greater effect on ventilation, and the survey results show that the value is about $2/3$ and $1/3$. The Evaluation score is:

$$= 10 \times \left(\frac{1}{3} \times \text{height} + \frac{2}{3} \times \text{room type}\right)$$

$$\text{Of: } V = h^{0.2375} + V_0 \quad (V_0 \text{ is wind speed on the ground})$$

$$R_1 = \frac{V_h}{V_{\max}} = \frac{h^{0.2375} + V_0}{H^{0.2375} + V_0}$$

$$\text{So the final score is: } X_4 = 10 \times \left(\frac{1}{3} \times \frac{h^{0.2375} + V_0}{H^{0.2375} + V_0} + \frac{2}{3} R_2\right) = 10 \times \left(\frac{1}{3} \times \frac{(f * p)^{0.2375} + V_0}{(\max * p)^{0.2375} + V_0} + \frac{2}{3} R_2\right)$$

(The constant p is the height of each floor)

2.3.5 The modeling of the influence factor x_5 -noise. The function of the linear sound source

attenuation is: $\Delta L = 10 \lg \frac{1}{2\pi r}$

Of which r is the line distance from the linear source; l is the length of the line source. In particular, when $r/l < 0.1$ (such as highways, etc.), it can be regarded as an infinite long line source. At this point,

the attenuation value of the sound source at r_1 to r_2 is: $\Delta L = 10 \lg \frac{r_1}{r_2}$

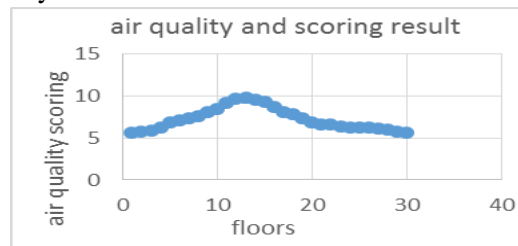
Corresponding to the current modeling situation, $r_1 = \sqrt{d^2 + h^2}$, of which the constant d is the horizontal distance between the highway and the residential building; h for one certain floor height in the residential building. Because the sound source strength is obtained directly from the calculation, thereby $r_2 = 1$, the final attenuation relation is obtained from the above analysis: $L = \lambda - 10 \lg \sqrt{d^2 + h^2}$

$$(\lambda = 70 \text{ dB}) \text{ then: } L = \frac{\int_{(f-1)p}^{fp} 70 - 10 \lg \sqrt{d^2 + h^2} dh}{p}$$

With constant p for the height of each floor, and constant d for the horizontal distance of highway to the residential building, according to the calculated noise degree, the habitable evaluation score x_5 with noise factor in the corresponding floor can be obtained in the corresponding score table.

$$X_5 = -0.00002L_3 - 0.0004L_2 + 0.0216L + 9.8611$$

2.3.6 The modeling of the influence factor x_6 -air quality. Normally, regardless of the pollution, with the increase of floor height, air quality is gradually getting better, but according to the survey result, air quality above 40 meters high may decline:



The polynomial fitting is: $X_6 = -0.00007f^6 + 0.00006f^5 - 0.0015f^4 + 0.0122f^3 + 0.0057f^2 - 0.0002f + 5.5627$

On this basis, we have a function of the livable fraction of the house:

$$S = 0.0920X_1 + 0.0340X_2 + 0.3450X_3 + 0.3450X_4 + 0.0920X_5 + 0.0920X_6$$

3. Computer simulation of the scoring rules

Computer program is taken to test the correctness of the model and to find the fitting degree between the satisfaction of the buyer and the result of the rating. The purpose of the program is to simulate a process of apartment selection. Assuming a residential building has 50 floors; each floor consists of 4 apartments of ABCD, of which the R^2 value of AB is 0.4, that of CD is 0.8; the daylight condition of the 4 apartments on the same level are the same (nothing to do with the apartment type); each floor is 3 meters in height, the annual average wind speed is 2 m/s on the ground, and the distance between the building and the nearest highway is 30 meters. Now assume that there are 200 buyers entering to choose apartments in order, and each buyer will choose an apartment. So in all customers' minds, the corresponding weight distribution to the six factors is the normal distribution with the above obtained standard as the average value.

The input of the program is 200 six-tuples, corresponding to the weight in each buyer's mind. The 200 six-tuples are randomly generated by the MATLAB (200 samples to a single element are normal distribution with the average given weight). The output is the results of the 200 buyers choosing flats (200 triples (floor f , room type K ($K \in \{A, B, C, D\}$), unsatisfying indicators (integer, the bigger the unsatisfying))).

We analyze the similarity of the 200 people's process of choosing apartments and the actual apartments purchase in the reality list. The assumptions list of the program simulation is the following:

| | | |
|----------------|---|------------------------|
| max | Total floors | 50 th floor |
| P | Height of each floor | 3m |
| R ₂ | Ventilation | 0.4/0.8(AB/CD) |
| V ₀ | Average wind speed | 2m/s |
| D | Distance of buildings and the nearest freeway | 30m |

First, according to the assumption, put the corresponding data into object function S to get new S, a normal distribution of 200 six-tuples is given by Matlab. Based on each six-tuple, with Mathematica, we calculated each buyer's evaluation on each apartment. There is a total of 40000 grades. The unsatisfactory indicator is the ranking of the flat ratings. And the simulation itself used the C language program to simulate the choice of flats for 200 people, and the core code is as follows:

```
for(i=0;i<200;i++){//housing choosing one by one
  for(j=0;j<200;j++){//choosing one by one from the most favored one
    for(k=0;k<i;k++){//compared to the chosen one
      if(in[i][j].floor==out[k].floor&&in[i][j].type==out[k].type){//chosen
        out[i].sadrate++; //unsatisfying indicator +1
        break;//considering minor favored house
      }
      else{//not chosen
      }
    }
    if(k==i){
      out[i].floor=in[i][j].floor;//add to chosen
      out[i].type=in[i][j].type;
    }
  }
}
```

The run program gets 200 three-tuples that reflect the process of the flat buyers' choices and the distribution of dissatisfaction. The analysis concludes:

(1) The objective function s of evaluating livability of is credible, because the simulation is the same as the actual scene of buying an apartment in reality. The buyers can avoid the tallest flat and prefer to buy a higher the middle one. The flats with better ventilation are more popular (C and D).

(2) According to the analysis of dissatisfaction, the later the buyers enter the scenery, the less likely they are to buy a satisfying flat.

4. Conclusion

Decision making of choosing a flat is crucial for every buyer. There are various factors that influence the decision making of the selected flat. This article enumerates the six factors that are selected by the questionnaire to analyze the decision-making process. An apartment scoring system was developed based on the Analytic Hierarchy Process (AHP), and described the composition of the score function and its concrete relationship with the six factors. The score method fully reflects the importance of each influence factor, which could give the buyers intuitive and referable grades, reducing the degree of difficulty in the decision-making. This paper also uses a computer program to simulate the apartment purchase process, to simulate a normal distribution of 200 apartment buyers, and compares with the process of choosing apartments in the early surveyed scene to testify the reasonability of the scoring system. The goal of the future research is to put forward a new evaluation system in combination with the location factor of the building, further reducing the buyers' difficulty of selecting houses.

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