The Convertibility Forecast Model of Space Structure in Architecture Programming——Collective Housing in Taiwan for example

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Abstract: House refurbishment related to the convertibility of space organizations is nowadays a common phenomenon in Taiwan, reflecting user demands for the diversity of unit plane and space expansion in quantity, and forming an important research topic over the implementation of sustainable development concept in living environment. In this paper, apartment mansion-type amalgamated dwellings were quantitatively analyzed and investigated, and four models, which were dimension combinations of influence factors, were compared through the field survey and logistic regression model (binary regression method). The results showed that the variables in Model IV consisted of three dimensions—space organization, building entity and spatial planning, with the optimal prediction rate (74.5%), so it was regarded as a convertibility prediction model of space organization; the significance and goodness of fit of each model were analyzed by comparing each variable coefficient with the expected symbol, and next, the concrete meaning of each influence factor belonging to each dimension of each model was indicated by means of coefficient correction, which could further predict the convertibility of space organizations, accurately obtain the factors influencing the convertibility prediction, and improve the prediction accuracy. This research, which conforms to the concept of sustainable environmental development, will contribute to construction project planning and design of residential buildings.

1. Introduction

There is a great demand for the residential house refurbishment in Taiwan. In the planning and design of residential building units in Taiwan, the unicity and stationarity of space organization design and planning are considerably important causes for the frequent refurbishment projects, and the demands for the diversity of unit planes and spatial expansion in quantity, which are reflected by this phenomenon, have formed one of important research topics over the implementation of sustainable development concept in living environment. Guided by the concept of sustainable development, the residential building planning should focus on the convertibility planning of residential space organizations, which becomes especially important due to the upturn living standards in current residential environment, expansion of residential house scale, value change of house planning and design, improvement of flexibility and convertibility design environment, etc. Therefore, the convertibility planning and design of space organizations in this research will be conducive to the realization of sustainable development.

This research, a quantitative research, aims to construct an applicable convertibility prediction model of space organization via logistic regression in the binary regression method. The research scope was Taiwan area, and the objects were apartment mansion-type amalgamated dwellings. The research...
The objectives were as follows: (1) to discuss the dimensions and factors that may influence the convertibility of space organizations, (2) to test the prediction accuracy of different models consisting of different influence dimensions, (3) to screen out the convertibility prediction model of space organizations applicable to apartment mansion-type amalgamated dwellings, and (4) to deduct the meaning and characteristics of model coefficients via the constructed prediction model.

2. Literature Review

2.1. Researches regarding quantitative analysis of residential space organizations

The social sciences researches have developed from psychology, behavioral science to macro-environmental social structure and into all kinds of measurement procedures and visual language, which can facilitate the qualitative discussion. Hiroshi Hara expounded the spatial control plan, categorized residential spatial units through the Graph theory, discussed about the meaning of space organizational syntax through the mathematical properties of spatial structural map, mastered the properties of spatial structures and their meanings, so as to understand the interaction between space organizations and plan appropriate space organizations in advance in the construction projects. [1] Flexibility of residential building unit contains three different meanings: adaptability, convertibility and expansibility, which are explained as follows. [2] (1) Adaptability: The scale and internal layout of the residential building unit are unchanged, and the building unit can be of adaptability completely through special spatial processing; (2) Convertibility: The area of residential building unit remains unchanged, but instead, only the internal layout is properly converted; (3) Expansibility: The scale of residential building unit is appropriately expanded. Based on a quantitative spatial analysis using space syntax, Bill Hillier and Julienne Hanson summarized the spatial traits of different space types in sequential depth and degree of separation by analyzing the space syntax, which could contribute to a clearer understanding of the relationship between human behaviors and built environment. [3] Space organization is explained as below: The combination of field and location is formed based on the hierarchy concept and spatial relationship, so as to reflect the properties of overall spatial structure and the relationship between space units and the whole. [4]

3. Methodology

3.1. Inference theory

3.1.1. Prediction characteristics of logistic regression model

Logistic regression model is an application model used to process categorical variables. When a binary variable in the log-linear model is taken as the dependent variable (the value is either 0 or 1) and a series of independent variables are defined, the logarithm is then applicable to the logistic regression model. [5]

3.1.2. Syntax of prediction model

(1) The occurrence probability of an event is \( P(\text{event}) = \frac{e^{\beta_0 + \sum_{i=1}^{k} \beta_i X_i}}{1 + e^{\beta_0 + \sum_{i=1}^{k} \beta_i X_i}} \) .

(2) The probability for an event not to occur is \( P'(\text{no event}) = \frac{1}{1 + e^{Z}} \).

(3) Odds of experiencing an event

Odds value is certainly positive without upper bound.

\[ \text{Odds Ratio} = \frac{P}{1-P} = e^{Z} \]

(4) Logit value
The logarithm is taken from two sides, followed by logit transformation, and the Z value is namely logit value.

\[ \ln\left(\frac{p}{1-p}\right) = Z = \beta_0 + \beta_1 X_1 + \ldots + \beta_k X_k \]  

(4)

From the above analysis, independent variables from \( X_1 \) to \( X_k \) as well as their convertibility can be obtained through observation, thus judging the prediction accuracy in consideration of influence dimensions. [6]

### 3.2. Scope and statistical significance of survey

(1) Survey scope and sampling level: four major cities—Taipei, Taichung, Tainan, and Kaohsiung—in Taiwan were taken as the parent samples, the licenses issued in recent 10 years (1991-2000) were extracted through the systematic random sampling method according to the proportion of licenses issued in each city, the confidence level was 95% and the sampling error was 0.055%. (2) Respondents: A total of 231 amalgamated dwelling samples with over five floors were selected, with the following characteristics. Each floor consisted of several residential building units, and all floors shared the same vertical generatrix, equipment pipeline, and public space.

### 3.3. Judgement and verification of convertibility of living space organization

The convertibility of each residential building unit was judged according to the questionnaire items in survey data, and scored using the Likert scale (1 score: excellent, 0 score: moderate, -1 score: poor), and the ratio of the total score, which was the product of number of space units and score weight, to the total number of spaces was calculated. If the result was not smaller than 0, this space organization was not of convertibility. [7] The reliability test was tested, the Cronbach \( \alpha \) value was 0.8547, and the closer the reliability coefficient was, the higher the estimation reliability would be. Therefore, the estimation reliability of the convertibility judgment scale used in this paper is considerably high.

\[ \alpha = \frac{m}{m-1} \left(1 - \frac{\sum_{i=1}^{m} \sigma_i^2}{\sigma^2}\right) \]  

(5)

In Equation (5), \( m \) is number of space categories (20 in this research), \( \sigma \) is variance (5.1711), and \( \sigma_i \) is variance of space i.

### 4. Construction and Comparison of Convertibility Prediction Models for Living Space Organizations

Based on the factors influencing the convertibility of space organizations in construction projects, the convertibility could be improved to predict and reduce the occurrence probability of house refurbishment projects. The space syntax of each living space was logicalized into a quantitative value through the combination of space units in the building planning and design in consideration of environmental factors, the related variables influencing the convertibility of living space organization were summarized, a flexible space organization prediction framework consisting of different variable combinations was established, and then a convertibility prediction model was constructed through the binary logistic regression. As for the quantification and flexible processing of space organizations, the influence factors in three dimensions were generalized through the relevant literatures, namely space organization, building entity, and spatial planning.
Table 1  [Space structure aspect] variable value acquisition method and significance description.

| Name          | Code name | Description                                      | Acquisition method          | Numerical significance |
|---------------|-----------|--------------------------------------------------|-----------------------------|------------------------|
| 1  Number of points | $X_v$    | Number of space unit domains                     | Awarded by the diagram      | —                      |
| 2  Number of line     | $X_e$    | Connectivity coefficient between units. If there is a direct connection between spatial units, there is a side | Awarded by the diagram      | —                      |
| 3  Diameter          | $X_d$    | The longest line of all the shortest paths in the organization of housing space | Awarded by the diagram      | —                      |
| 4  Maximum entrance distance | $X_I$   | The depth of spatial organization, the longest line of entry to any unit | Awarded by the diagram      | —                      |
| 5  Homogeneity       | $X_h$    | In the space structure. The uniformity of the unit configuration relationship | $X_h = \frac{C_i(max) - C_i(min)}{C_i(max)}$, $C_i(max)$= Maximum number of total methods from a certain point to each point $C_i(min)$= Minimum number of total methods from a certain point to each point. | The higher the $X_h$ value is, the more uneven the traffic network is, the more uneven the spatial structure configuration relationship is. |
| 6  Connecton strength | $X_\beta$ | The ratio of the number of edges to the number of points in a space | $X_\beta = \frac{X_e}{3(X_v-2)}$, $X_e$: Number of line $X_d$: Diameter | $X_\beta$: The larger the value, the more connections between units, and the higher degree of freedom between spaces. |
| 7  $\pi$ index       | $X_\pi$  | The degree of agglutination between units in a spatial structure | $X_\pi = \frac{X_e}{X_d}$, $X_e$: Number of line $X_d$: Diameter | $X_\pi$: The higher $X_\pi$ value is, the higher the degree of cohesion between units is. |

Data source: Hara Hiroshi. 1981, New Architecture Department 23 Architectural Planning.

Table 2  [Solid building aspect] variable value acquisition method and significance description.

| Name             | Code name | Description                                      | Acquisition method          |
|------------------|-----------|--------------------------------------------------|-----------------------------|
| 1  Number of indoor floors | $X_{dj}$ | The number of floors in a dwelling               | survey data                 |
| 2  Building compartment structure | $X_{pd}$ | Building structure, the structure of the internal compartments of a residence |                           |
| 3  Floor          | $X_{pc}$  | The floor of a building located in a gathering house |                           |
| 4  Residential use | $X_{dd}$  | The purpose of the space organization within the building |                           |
| 5  Located towards the building | $X_{dh}$ | The characteristics of spatial unit organization and environmental factors such as sunshine |                           |
| 6  Residential area | $X_{ta}$ | The size of a residence                           |                           |
Table 3  「Space programming aspect」 variable value acquisition method and significance description.

| Name                          | Code name | Description                                                                 | Acquisition method |
|-------------------------------|-----------|------------------------------------------------------------------------------|--------------------|
| Number of family living spaces | \(X_{ls}\) | Number of space units of living room, god hall, dining room and kitchen.     | survey data        |
| Number of personal living spaces | \(X_{ss}\) | Number of space units of master bedroom, child bedroom, bedroom 1, bedroom 2, study space. |                     |
| Number of sanitary spaces     | \(X_{bs}\) | Number of space units of bathroom 1, Bathroom 2, toilet.                      | survey data        |
| Number of housework           | \(X_{ps}\) | Number of space units of laundry room, storage room, studio.                  |                    |
| Number of flexible spaces     | \(X_{os}\) | Number of space units of aisle, balcony and porch.                           |                    |

4.1. Comparison criteria for the nominal variables in the research model

To establish the logistic regression model, the variables must be processed first. The convertibility can be divided into two levels. One is 1 for convertible space organizations and the other is 0 for unconvertible ones. Numerical value is filled in each continuous variable, nominal variables are dummy variables, and then logistic regression analysis was conducted.

1) Continuous variables: number of points, number of edges, diameter, maximum entrance distance, homogeneity, connection intensity, \(\pi\) index, dwelling area, number of family living spaces, number of physiological hygiene spaces, number of housework service spaces, and number of flexible spaces.

2) Nominal variables: including number of in-house floors, compartment structure, floor level, dwelling purpose, and building orientation, all of which were input in the form of the syntax (1; 0) of dummy variable, and that the variable accounted for the highest proportion in the questionnaire survey was taken as the comparison criterion, but it was not input in the regression process and served as the comparison criterion for other items. For instance, if the quantity of single-floor buildings was the largest, it would not be input, but would be taken as the comparison criterion, and then the variable coefficient of two-floor buildings in the constructed model was namely its difference value from single-floor buildings in the influence on the convertibility (\(Z\)).

In the constructed model, the comparison criteria were as follows: single-floor building (number of in-house floors), reinforced concrete (compartment structure), special purpose for housing (dwelling purpose) and southward (building orientation).

4.2. Variable setting for the convertibility prediction model of living space organizations

In order to improve the convertibility prediction accuracy of space organizations in construction project, the influence variables were combined to form four models. The influence factors in the dimension of space organization were taken as the basic characteristics, building entity and spatial planning were included into the model, and the combinational relationship between prediction model combination and dimension combination of influence variables is shown in Figure 1.
4.3. Characteristic analysis of samples
(1) According to the survey results, the average convertibility value of living room, drawing room, recreation room, dining room, kitchen, master bedroom, children’s bedroom and bedroom 1 was greater than 0, so they could be regarded as spaces with convertibility potentials.

(2) The convertible space unit types in each household were sorted through the selection frequency as follows: drawing room (20.9%), dining room (13.5%), kitchen (10.0%), master bedroom (9.6%), children’s bedroom (8.3%) and bedroom 1 (7.4%), where the spatial compartments of drawing room, dining room and kitchen were unclear. The master bedroom, children’s bedroom and bedroom 1 were all used as bedrooms, so they were usually collectively set in the planning and design, and their functions could be mutually converted, which might be ascribed to the general bedroom use behaviors at present.

5. Analysis of Empirical Results
The model prediction accuracy was verified through the logistic regression coefficient, and the comparative analysis of the model verification is presented in Table 4.

5.1. Correct answer rate and prediction accuracy of convertibility prediction results of models
The prediction rate obtained from the model operation represents the prediction accuracy, and the prediction accuracy of Model I, II, III and IV was 66.2%, 70.1%, 73.2% and 74.5%, respectively, so Model IV had the highest prediction accuracy. Based on the logistic regression of each model, the applicability of each model to prediction was tested via Omnibus verification model, the goodness of fit via Hosmer and Lemeshow verification model, and the adaptability and variable coefficient via likelihood ratio, and the results are listed in Table 4. By combining the previous correct prediction rates, it could be known that Model IV had the optimal prediction performance.

Table 4 Verification analysis comparison table of spatial organization variability prediction model constructed by Logis regression.

| Verification program | Model one | Model Two | Model Three | Model Four |
|----------------------|-----------|-----------|-------------|------------|
| Omnibus test χ²      | 10.243    | 26.063    | 29.468      | 44.46      |
Therefore, Model IV should be an acceptable convertibility prediction model for space organizations in logistic regression model reached the convertibility prediction rate of 74.5%, which was the highest. (1) Model IV included space organization, building edge (number of points), whether the building orientation is eastward, whether the floor level is the first floor, whether the dwelling purpose combines housing and store, whether the building orientation is northeastward, whether the floor level is the second-fourth floor, whether the number of family living spaces is zero, whether the dwelling purpose combines housing with others, whether the building orientation is northwestward, whether the number of in-house floors is two.

| Significant risk | 0.175 | 0.011 (helpful for prediction) | 0.079 (helpful for prediction) | 0.010 (helpful for prediction) |
|------------------|-------|-------------------------------|-------------------------------|-------------------------------|
| Hosmer and Lemeshow test | $\chi^2$ | 12.238 | 8.165 | 7.484 | 6.442 |
| Probability ratio statistic test | Logarithm of likelihood ratio of well | 0.141 | 0.417 | 0.485 | 0.598 |
| -2LL $\chi^2$ value | 283.827 | 268.007 | 264.601 | 249.609 |

Correct prediction rate: 66.6% 70.1% 73.2% 74.5% Highest prediction rate

Cox & Snell $R^2$ 0.043 0.107 0.120 0.175

Negalikerke $R^2$ 0.060 0.148 0.166 0.243

5.2. Variable coefficient analysis of the optimal prediction model

By taking the optimal prediction rate as the selection criterion, Model IV was considered the optimal convertibility prediction model for space organizations, and its meanings were explained as follows: $Z=21.955-2.074X_{p1}+1.728X_{p2}+0.907X_{p3}+0.539X_{p4}+1.971X_{s1}-78.731X_{s2}+2.608X_{s3}+0.829X_{s4}+1.581X_{s5}+0.623X_{s6}+0.34X_{s7}+0.298X_{s8}+0.050X_{s9}+3.147X_{s10}+1.847X_{s12}+0.485X_{s13}+0.484X_{s14}+0.026X_{s15}+0.126X_{s16}+0.496X_{s17}+0.182X_{s18}+1.044X_{s19}+0.206X_{s20}+0.624X_{s21}-2.074X_{s22}+1.728X_{s23}+0.907X_{s24}+0.539X_{s25}+1.971X_{s26}-78.731X_{s27}+2.608X_{s28}+0.829X_{s29}+1.581X_{s30}$

$Z$ : degree of convertibility
$X_{p1}$ : number of points
$X_{p2}$ : whether the compartment is of steel framework structure
$X_{p3}$ : whether the compartment is of steel reinforced concrete structure
$X_{p4}$ : number of edges
$X_{p5}$ : whether the floor level is the first floor
$X_{p6}$ : whether the floor level is the second-fourth floor
$X_{p7}$ : maximum entrance distance
$X_{p8}$ : whether the floor level is the fifth floor
$X_{p9}$ : whether the floor level is the sixth floor
$X_{p10}$ : dwelling area
$X_{p11}$ : number of family living spaces
$X_{p12}$ : number of physiological hygiene spaces
$X_{p13}$ : number of housework service spaces
$X_{p14}$ : number of flexible spaces
$X_{p15}$ : number of non-family living spaces
$X_{p16}$ : number of personal living spaces
$X_{p17}$ : number of personal living spaces
$X_{p18}$ : number of personal living spaces
$X_{p19}$ : number of personal living spaces
$X_{p20}$ : number of personal living spaces
$X_{p21}$ : number of personal living spaces
$X_{p22}$ : number of personal living spaces
$X_{p23}$ : number of personal living spaces
$X_{p24}$ : number of personal living spaces
$X_{p25}$ : number of personal living spaces
$X_{p26}$ : number of personal living spaces
$X_{p27}$ : number of personal living spaces
$X_{p28}$ : number of personal living spaces
$X_{p29}$ : number of personal living spaces
$X_{p30}$ : number of personal living spaces
$X_{s1}$ : number of family living spaces
$X_{s2}$ : number of family living spaces
$X_{s3}$ : number of family living spaces
$X_{s4}$ : number of family living spaces
$X_{s5}$ : number of family living spaces
$X_{s6}$ : number of family living spaces
$X_{s7}$ : number of family living spaces
$X_{s8}$ : number of family living spaces
$X_{s9}$ : number of family living spaces
$X_{s10}$ : number of family living spaces
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$X_{s12}$ : number of family living spaces
$X_{s13}$ : number of family living spaces
$X_{s14}$ : number of family living spaces
$X_{s15}$ : number of family living spaces
$X_{s16}$ : number of family living spaces
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$X_{s26}$ : number of family living spaces
$X_{s27}$ : number of family living spaces
$X_{s28}$ : number of family living spaces
$X_{s29}$ : number of family living spaces
$X_{s30}$ : number of family living spaces

Note: Comparison criteria are “single-floor building (number of in-house floors), reinforced concrete (compartment structure), above the sixth floor (floor level), special purpose for housing (dwelling purpose) and southward (building orientation).”

5.2.1. Analysis of convertibility prediction models for space organizations

The convertibility prediction models were constructed through the logistic regression according to the variable combinations, it was inferred that Model I and III did nothing helpful to convertibility prediction, but Model II and IV were conducive to the convertibility prediction. After the verification of the four models, the constructed convertibility prediction models were of certain goodness of fit. By testing the logarithm of likelihood ratio of goodness-of-fit values of the prediction models, it was obtained that the prediction model coefficients were non-zero, indicating satisfactory adaptability.

5.2.2. Meanings of convertibility prediction models

(1) Model IV included space organization, building entity and spatial planning, and the constructed logistic regression model reached the convertibility prediction rate of 74.5%, which was the highest. Therefore, Model IV should be an acceptable convertibility prediction model for space organizations in...
apartment mansion-type amalgamated dwellings.

(2) The constructed models were negatively affected by number of points, connection intensity, dwelling area, number of personal living spaces, number of physiological hygiene spaces, number of housework service spaces and number of flexible spaces, namely, the convertibility of space organizations was reduced. The positive influence was manifested by the enhanced convertibility of space organizations, and those exerting positive influences included number of edges, diameter, maximum entrance distance, homogeneity, $\pi$ index and number of family living spaces.

(3) The constructed convertibility prediction models showed that “steel framework structure (compartment structure), single-floor building (number of in-house floors), housing and store combination (dwelling purpose), and the fifth floor (floor level)” were the optimal, while building orientation had no significant influence on the convertibility.

5.2.3. Example verification
A standard plan of Siwei Guozhai Community in Kaohsiung was taken for example to verify the convertibility prediction models for space organizations in apartment mansion-type amalgamated dwellings. The 4D plan was converted from simple spatial graph to spatial syntax graph and then space organization chart (Figure 2). The basic data of this building unit was as follows: single-floor building (number of in-house floors), the fifth floor (floor level), westward (building orientation) and 32 m$^2$ (dwelling area). The values calculated according to the graph and formula were: $X_v=11$, $X_e=10$, $X_d=4$ (⑩ to ⑪), $X_f=3$ (① to ⑩, ① to ⑪), $X_h=(4-1)/4=3/4=0.75$, $X_p=10/(3 \times (11-2)) = 10/27=0.37$ and $X_m=10/4=2.5$.

According to the results, Z value (convertibility) was 2.23298, P value was 90.31%, and Odds value was 9.32, and this the convertibility value of the construction project of this amalgamated dwelling was quantitatively predicted.

6. Conclusions
That the “building entity” was selected most frequency was taken as the criterion for comparing the prediction models, it was obtained that Model IV was the optimal prediction model, and based on the continuous variable coefficients influencing the prediction model, the construction project was explained as follows:

(1) Space organization: the model was negatively affected by number of points and connection intensity, namely, the convertibility of space organizations was reduced. Those positively influencing the convertibility (enhanced) included number of edges, diameter, maximum entrance distance, homogeneity and $\pi$ index.

(2) Building entity: the dwelling area exerted a negative influence on the model, resulting in the degradation of convertibility of space organizations.

(3) Spatial planning: the model was negatively affected by number of personal living spaces, number of physiological hygiene spaces, number of housework service spaces and number of flexible spaces,
namely, the convertibility was reduced, and that having a positive influence on the convertibility was number of family living spaces.

For amalgamated dwellings, a high-quality dwelling environment perfectly matching the spatial functions can be constructed only through excellent coordination of space organizations and space scale. If suitable space organizations and building entity conditions can be selected by combining the demand for dwelling characteristics, and the space units can be well combined in the building planning and design, the refurbishment projects aiming to correct the compartment structure after the house purchase will be reduced, and the time wasted due to improper planning and design and misuse can be saved, thus postponing the repair period and contributing the sustainable development of dwelling environment. Moreover, this can also compensate for the gap between house quality and housing needs in the current housing market.

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