Emergence of a Parallel Layout Arising from Users’ Pursuits of Better Living Conditions of Their Dwelling Units in MRHC with MAS

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Abstract

This paper attempted to present a method to solve site-planning problems of the Multistory Row House Cluster (MRHC) with parallel layout by the Multi-Agent System (MAS). The solutions were generated entirely by the interactions of the agents, who represented the users in pursuit of better living conditions for their dwelling units. Thus, they are analogous to the “user-oriented” layout. The standard solution differed from the popular layout in Beijing in that the public Green Land (GL) was separated and located on the southeast and southwest corners of MRHC. Comparing a diversity of layouts, the solution showed the following characteristics: 1) the highest average level of living conditions of dwelling units; 2) the comparatively homogeneous living conditions in dwelling units; and 3) the fewest dwelling units with poorly evaluated living conditions. In addition, this study also examined the relationships between the average living conditions in the solutions and the attributes of the plot, including the plot ratio and aspect ratio.

Keywords: site planning; Multistory Row House Cluster (MRHC); parallel layout; user-oriented; Multi-Agent System (MAS)

1. Introduction
1.1 Background

Parallel layout, together with its variations, is dominant in the Multistory Row House Clusters (MRHC) in north China (Fig.1). It derives from the “Zenlinbau” site-planning principle put forth by the modernists in the 1920’s. The studies and practices on the parallel layout mainly focused on the optimizations of some overall measures, such as the sunlight conditions of the dwelling units. However, from the view of an individual household, such global optimums not always ensure the improvement of the living conditions in its dwelling unit. It is even possible that the interests of few households are sacrificed to achieve an optimum. This drove us to think about the site-planning problems of MRHC from another point of view: what layout may emerge if we directly start by improving the living conditions of each dwelling unit.

Together with the previous study, we attempted to investigate the basic site-planning problem of MRHC in the above way (Fig.2). An ordinal regression model has been established in the previous paper which can efficiently predict people’s evaluation on the living condition of a dwelling unit with its plan locations. This paper concentrates on the simulation. In it, the layout of MRHC is expected to be formed entirely by the users’ selection behaviors for advantageous locations so as to improve their living conditions. The Multi-Agent System (MAS) method is applied in the simulation, for its “multi-subject” and “bottom-up” features. On individual level, the behavior of agents was based on the established regression model to represent the users to pursue better living conditions. The layout of MRHC would emerge on system level as the result of the interactions among the agents. Figuratively, it could be imagined as the site planning was done via an approach that the users strived for advantageous plan locations that might improve their

Fig. 1. Example of MRHC with Parallel Layout, ShijiMingdu Residential Quarter, XingTai City, Hebei Province, China.
The significance of this paper is the presentation of a completely “user-oriented” layout of MRHC for the first time. Although the principle of “user-oriented” has been widely accepted in housing design, it is impossible for the designers to deal with the demand of each user in parallel way. Therefore, our findings might add to the knowledge base of site planning of MRHC.

1.2 Purpose

The primary purpose of this study is the emergence of the layout of MRHC arising from the interaction of the agents, which represent the users’ pursuit of better living conditions for their dwelling units (Fig.3). “Emergence” means that the behavior and interaction of the elements on the micro level generate the order on the macro level, and this order influences the elements in turn. We attempted to estimate this solution from different points of view based on comparisons with other layouts. In addition, because the behaviors and interactions of the agents are influenced by the settings of the environment on the system level, the relationships between the solution qualities and some attributes of the plot were also examined in this paper. The study questions include:

1) What layout may emerge arising from the interactions of the agents? (Their behaviors are designed based on the regression model established in the previous paper.)

2) How to estimate the solution? What estimations will the solution have?

3) What are the relationships between the solution quality and the attributes of the plot, including the plot ratio and aspect ratio?

1.3 Past Studies

The global optimization method is widely applied in the studies on layout-planning problems. Muraoka and Aoki (1998) optimized the layout of multistory houses to maximize the received solar energy with Genetic Algorithms (GA) which had a learning process in the evaluation criterion. Banno et al (2000) dealt with a bi-objective optimization problem of the successive rebuilding planning with GA. The two trade-off objectives were the total area of buildings and the variable view of elevation area.

In contrast to the global optimization method, our simulation had no overall measurements, while the problem was solved by the interaction of the agents in a bottom-up way.

Currently, the studies using MAS are increasing in the Architectural Planning field. Takizawa et al (2000) applied MAS to model an urban system, in which the behaviors of agents were based on economic factors. The emerged city patterns in the simulation were proved to be similar with the land-use pattern of Osaka area. Oda et al (2002) proposed a multi-agent simulator of human behavior in the continuous defined space and applied it for examining the planning of the student hall. Iwata and Munemoto (2003) proposed a layout-planning method of the campus facilities, which is based on the estimation of the mutual relationship among the organizations.

The difference of the present study to the above studies is that the behavior of the agents was designed based on the regression model of people’ evaluation criteria, which was established in the previous study. Compared with the physical indices, people’s evaluations were more comprehensive in evaluating the living conditions of the dwelling units. At the same time, the subjectivism and arbitrariness of the model builder could be prevented by using the data from the investigation.

2. Simulation Model

Our model was a homogeneous non-communicating multi-agent system. Homogeneousness means that all the agents have the identical internal structure, including goals, domain knowledge, possible actions, and decision procedures. The differences are only in their sensory inputs and actual actions, which means that they are situated differently in the environment. Non-communication implies the agents in our simulation do not affect each other directly. However, as a part of environment, the behaviors of an agent will change the sensory inputs of others, and then influence their behaviors. Our simulation was built on the software platform Multi-Agent Simulator.
2.1 2D Space of MAS

A middle-scale MRHC was modeled in the standard model. Table 1 lists the main technical indices. The basic settings were the same as the models used in the investigation in the previous paper.

| Index                                    | Value         |
|------------------------------------------|---------------|
| Plot area of planning land (to the center of the surrounding roads) | 29272.32 m²   |
| Plot Area of residential use (75% of Area of planning land)          | 21954.24 m²   |
| Area of a dwelling unit                                           | 87.12 m²      |
| Total number of dwelling units                                    | 396 sets      |
| Plot Ratio of residential building                                 | 1.57          |
| Population (3.5 people per household)                             | 1386          |
| Story                                                                 | 6             |
| Height of buildings                                                | 19.40 m       |
| Parameter of building interval (interval / height)                 | 1.70          |

The site planning of MRHC was simplified as a 2-Dimensional problem in this study. The reason that the vertical dimension was omitted was that the multi-istory row houses in Beijing are almost all 6-story high, reaching the limitation of walk-up residential buildings for comparable high plot ratio. To support the possibility of the emergence of Green Land (GL) with the least depth, which is about 1.5 times that of normal building interval, we designed a mapping method as shown in Fig. 4. The numbers marked along the axes show the orthogonal coordinate system. Please note that the distance in the north-south direction was rescaled in 2D space, a cell representing a location that the agents could occupy, but not the real distance. For example, continuous two empty cells in the north-south direction means that there are two adjacent possible locations for the agents, which also equals 1.5 times the normal building interval, but not two times that. As for the surroundings, the simulated housing cluster was assumed to abut other housing clusters.

2.2 Definition and Behavior of Agent

An agent did not equal an individual dwelling unit, but a segment in the row house, because it is the minimum unit that could be operated separately. Each agent consisted of a common staircase and 12 dwelling units located on six floors.

The goal of each agent was to improve its Internal State (IS). The light gray part in Fig. 5 illustrates the behavior of an agent (agentk) in a step, which could be thought to be composed of three parts.

First, the agent must understand its IS by feeling its surroundings (Formula 1). Here, the summation of the Comprehensive Evaluations (CE) of all the 12 dwelling units in an agent was represented by that of the two on the third floor, due to the limitation of the investigation. Corresponding to the 5-level measurement of CE, from 1 (poor) to 5 (good), the range of IS was from 2 to 10. In addition, IS=0 was given to the agents against the restraints, which will be introduced below. With the established Ordinal Regression model (Table 2), CE could be calculated by the four nominal variables indicating the plan locations of dwelling units. It should be noted that the agents recognized a group of empty cells to be GL according to the following criteria: 1) its depth was wider than 1.5 times the normal building interval, and 2) its area was no less than 500 m². Specifically, in the 2D space a group of empty cells would be identified as GL, if it was larger than a two by two rectangle.

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IS = \sum CE = CE_e + CE_w = f(P_1, P_2, P_3, P_4)
\]

IS : Internal state of an agent
CE : People’s comprehensive evaluations on the living conditions of dwelling units
CE_e : CE of the dwelling unit in the east half of 3rd floor
CE_w : CE of the dwelling unit in the west half of 3rd floor
P_1 : Predictor indicating unit’s position in a row house
P_2 : Predictor indicating unit’s relation with the green land
P_3 : Predictor indicating unit’s north-south location in MRHC
P_4 : Predictor indicating unit’s east-west location in MRHC

Second, the agents in our simulation took a deliberative strategy in their behaviors, by searching possible destinations, predicting the effects of available actions, and deciding what action to take autonomously. A similar function as in part one was designed for the agents to anticipate the effects of available actions. The difference was that the agent was permitted to ignore some
restraints, as will be introduced below, in a small probability to prevent the system from premature convergence.

Finally, the agents checked to see if they broke the restraints. Those who did would be punished by turning IS to 0. The restraints and the reasons for making them were listed in Table 3.

2.3 Flow of MAS Simulation

The simulation began with the random arrangement of the agents in 2D space. Then, each agent strived for higher IS and interacted with others in each step. When the system met the predetermined terminate condition, the iterations stopped (Fig.5).

3 Emergence of Layout Arising from Users’ Pursuits of Better Living Conditions

The standard simulation model terminated when all the agents stopped moving for more than a predetermined number of steps, which implied the solution was the final result of the agents’ interactions. The solutions of over 20 runs were found approximately identical (Fig.6). The differences were only where the roads were in the areas marked with the bold dash lines. The common parts could be deemed as the order emerged on the system level.

3.1 Layout of Solution

Before presenting the layout of the solution, we would introduce the popular layout pattern in Beijing as the frame of reference (Fig.7). The main characteristic of it is the concentrative GL located in the central area.

The layout of the solution differs from the popular layout in two aspects. One is the location of GL. To arrange GL on the corner is also one of the common design strategies. Although in this way the sense of enclosure in GL was not as strong as surrounded by the buildings, GL can benefit the vista from the road and be shared by the passersby. Another difference is the

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Table 2. Ordinal Regression Model

| Threshold | Estimate | Std.Error | Wald | df | Sig. | 95% Confidence Interval Lower Bound | Upper Bound |
|-----------|----------|-----------|------|----|------|------------------------------------|-------------|
| CE=1      | -4.59    | 0.17      | 757.69 | 1.00 | 0.00 | -4.92 | -4.26 |
| CE=2      | -1.85    | 0.11      | 286.53 | 1.00 | 0.00 | -2.06 | -1.64 |
| CE=3      | 0.55     | 0.10      | 27.62  | 1.00 | 0.00 | 0.34  | 0.75  |
| CE=4      | 3.34     | 0.13      | 684.58 | 1.00 | 0.00 | 3.09  | 3.59  |

* This parameter is set to zero because it is redundant.

Table 3. Restrains and Reasons

| Restrains | Reasons | Predictor | Plan location |
|-----------|---------|-----------|---------------|
| 1. Number of conjoint agents>=3 | Economic reason | CE=1 | West end in a row house |
| 2. Number of conjoint agents<=6 | Fire protection | CE=2 | East end & middle unit in a row house |
| 3. There must be an interval space in the south of the agent | To ensure sunshine for the dwelling units | CE=3 | Directly facing Green Land (GL) |
| 4. There is no other agent on the corner of an agent | To ensure an unobstructed road in MRHC | CE=4 | 1st unit indirectly facing and on the north of GL |

Fig.6. Solution to the Standard Model

Fig.7. Popular Layout in Beijing
decentralization of GL. However, it is due to a desire to facilitate the communication of residents that GL is concentrated. Our result revealed that the users’ pursuits of better living conditions for their dwelling units did not lead to a concentrative GL.

It is reasonable that such a layout emerged from the viewpoint of the mechanism of our MAS model. According to the established regression model, the plan locations on the southeast and southwest corners were evaluated lowest for the deteriorations in "view", "privacy" and "noise". Hence, no agent will stay there if any other optional locations exist. On the other hand, GL are formed passively as the outcome of the competition of agents for advantageous locations. Therefore, GL are left on the unwanted corners by egocentric agents.

3.2 Estimation of Overall Solution Quality

In order to estimate the overall solution quality, it is imperative to prepare indices and a collection of solutions as a reference database. This paper defined four indices from different points of view to describe the overall living conditions in the solutions (Table 4). An extended model was developed with the modified terminate condition as $E_a \geq 6.00$ and no agent against the restraints to generate a diversity of solutions. The threshold 6.00 came from $E_a$ of the popular layout, which implied this model would keep all the solutions with no lower average level of living conditions than the popular layout. Table 5 lists the 17 typical layouts drawn out of 100 runs in the order of the distribution of GL.

### Table 4. Indices for Estimating Overall Solution Qualities

| Index | Definition | Score |
|-------|------------|-------|
| $E_a$ | Denote the average level of IS, viz. living conditions of dwelling units | $E_a = \frac{\sum_{n=1}^{m} IS_n}{n}$ |
| $E_w$ | Denote the degree of homogeneity of living conditions among dwelling units | Number of agents with $IS=m$ |
| $E_{pa}$ | Denote how many agents containing dwelling units with living conditions evaluated above "Neutral" | Number of agents with $IS=7$ and $8$ |
| $E_{pw}$ | Denote how many agents containing dwelling units with living conditions evaluated below "Neutral" | Number of agents with $IS=4$ and $5$ |

### Table 5. Typical Solutions to the Extended Model

| Distribution of GL | Numbered typical layouts |
|--------------------|--------------------------|
| Width (cell) | Depth (cell) | $E_a$ | $E_w$ | $E_{pa}$ | $E_{pw}$ | $E_m$ | Numbered typical layouts |
| 1 | 3 | | | | | | $E_a$ | $E_w$ | $E_{pa}$ | $E_{pw}$ |
| 1 | 4 | 2 | | | | | $E_a$ | $E_w$ | $E_{pa}$ | $E_{pw}$ |
| 1 | 2 | 3 | 2 | 7 | 8 | | | | | |
| 4 | 2 | 2 | 9 | | | | | | | |
| 2 | 3 | 11 | 12 | | | | | | | |
| 2 | 2 | 14 | 15 | | | | | | | |
| 2 | 2 | 17 | | | | | | | |

a: The popular layout.
b: The solution to the standard model
Based on the comparison with the other solutions, the solution to the standard model (No.17) got the highest score in $E_a$, an upper-middle score in $E_m$, a middle score in $E_{an}$, and the lowest score in $E_{bn}$. It revealed that the solution arising from users’ pursuits of better living conditions could be characterized as: 1) the highest average level of living conditions of dwelling units; 2) the comparatively homogeneous living conditions in dwelling units; and 3) the fewest dwelling units suffered with the poorly evaluated living conditions.

From the view of each index, the solutions with the highest score and the lowest score could be found among these layouts (Table 6).

Furthermore, it was found that the average level of living conditions of the solutions was closely associated with the distribution of GL. The tendencies listed below were a reflection of the regression model concerning people’s evaluations of the dwelling units in the layer of housing cluster: 1) for the pairs of the mirror-imaged layouts, the solutions with GL in the east of the plot always exceeded their counterparts in $E_a$; 2) in the north-south direction, $E_a$ of the solutions with GL serving the northernmost row houses are not as high as those without; 3) the solutions with the separated GL had higher $E_a$ than those with a concentrative one.

3.3 Discussion

As a layout entirely decided by the selection behaviors of users does not exist, it is hard to verify this solution by directly comparing it with reality. However, the characteristics of the solution were found coincident with some of the opinions of an expert, although her subject was Residential Quarter, the upper layer of Housing Cluster.

1) She emphasized the importance of homogeneity of the living conditions in dwelling units.

2) She advised that it should be considered primary to improve the living conditions of the dwelling units unwelcome by customers.

3) She opposed the pursuit of an exaggerated appearance when planning public facilities and green land, and suggested to separate the overly large green land and distribute it near dwelling units to maximize the contributions to living conditions.

4. Relationship between Solutions’ Average Level of Living Conditions and Attributes of Plot

Although the interaction of agents generated an order on the system level, they could not change the basic attributes of the 2D space, such as the plot ratio and aspect ratio. These attributes, as part of the system settings, would influence the solution quality naturally.

This part examined the relationships between these attributes and $E_a$ of the solutions arising from users’ pursuits of better living conditions. $E_a$ was chosen for its similarity to commonly used indices. Since the plot division usually preceded the site planning in the plots in the design process, it would be significant to grasp these relationships. In the following text, the relationships between $E_a$ and these two attributes were studied respectively by comparing the solutions to the simulation models which only differed in them.

4.1 Relationship between Solutions’ Average Level of Living Conditions and Plot Ratio

In order to study the relationship between $E_a$ and the plot ratio, the number of the agents was changed in the extended models. The plot ratio varied from 1.33 (with 28 agents) to 1.57 (with 33 agents). The corresponding solutions were shown in Table 7.

As expected, the results proved the well-known principle that the lower the plot ratio was, the higher $E_a$ could be achieved (Fig. 8a). The correlation coefficient was -0.95 (Pearson’s R), with Sig.=0.00. A lower plot ratio implied more empty cells in 2D space, which might group into GL and benefit the agents nearby.

However, $E_a$ was not found to be correlated with the plot ratio linearly. It resulted from the fact that not all the empty cells increasing with low plot ratios could work as part of GL. For instance, in the solution with plot ratio=1.48, an empty cell dissociated from the others

Table 6. Solutions with the Highest and Lowest Score in Each Index

| Score | $E_a$ | $E_m$ | $E_{an}$ | $E_{bn}$ |
|-------|-------|-------|----------|----------|
| Highest | No.17 $^{b}$ | No.8 | No.15, No.16 | No.1 $^{a}$ |
| Lowest | No.1$^{a}$, No.2, No.3, No.5, No.7, No.11 | No.17 $^{b}$ | No.7, No.8 | No.17 $^{b}$ |

a: The popular layout.
b: The solution to the standard model.

Table 7. Solutions to the Models with Different Plot Ratios

| Plot Ratio | $E_a$ | Agent with 1S* | Solution |
|------------|-------|---------------|----------|
| 1.33       | 6.93  | 0 1 10 7 10  | [Solution] |
| 1.38       | 6.86  | 0 1 11 8 9   | [Solution] |
| 1.43       | 6.77  | 0 1 13 8 8   | [Solution] |
| 1.48       | 6.35  | 0 4 18 3 6   | [Solution] |
| 1.52       | 6.31  | 0 5 18 3 6   | [Solution] |
| 1.57*      | 6.24  | 0 5 20 3 5   | [Solution] |

* The standard model
and unable to improve $E_a$ efficiently, which was responsible for little improvement over the solution with plot ratio=1.52. Fig.8b showed that the number of the empty cells worked as GL was more strongly correlated with $E_a$, with Pearson’s R=0.99 (Sig.=0.00). Therefore, whether the empty cells were made full use of determined the efficiency of the improvement in $E_a$.

4.2 Relationship between Solutions’ Average Level of Living Conditions and Aspect Ratio of plot

The aspect ratio was used to describe the shape of a rectangle plot. Its value was calculated with Formula 2. It should be noted that the side lengths used here were the distances before mapping.

$$AR = \frac{L_{ex}}{L_{ns}}$$  

$AR$: Aspect ratio of plot  
$L_{ex}$: The length of the east-west side  
$L_{ns}$: The length of the north-south side

The results are shown in Table 8. A tendency was found to be that the higher the aspect ratio was the higher $E_a$ could be achieved. When the east-west side became wide, the agents tended to conjoin into longer and fewer row houses, because the middle positions and east end positions in a building were preferred to the west end positions according to the preference function. This spared the empty cells that originally worked as the road between the short row houses in the models with low aspect ratios. Two advantages came with this. First, the spared empty cells could form GL to benefit the agents. For instance, the solution with aspect ratio=1.52 have much more GL than the other two. Second, the agents could have more optional locations to occupy other than the disadvantageous locations. Such as in the solution with aspect ratio=0.57, some agents had to stay on the southwest corner with IS=4.

5. Conclusion

The paper proposed that Multi-Agent System (MAS) could contribute to the site planning of a multistory row house cluster with parallel layout from the view of the users’ demands of better living conditions for their dwelling units. In the Standard Model, we designed the behavior of the agents based on the established regression model between people’s evaluations on the living conditions and the plan locations of dwelling units, and a solution emerged arising from the interactions of the agents in the dynamic environment.

Differing from the popular layout type in Beijing, the layout of the solution was characterized as the separated green lands located on the southeast and southwest corners of the housing cluster. As no overall measurement existed in the simulation, we defined four indices to describe the overall quality of the solution concerning the living conditions of dwelling units. Based on the comparison with a diversity of typical layouts generated by an Extended Model, the solution to the Standard Model was estimated as: 1) the highest average level of the living conditions of dwelling units; 2) the comparatively homogeneous living conditions in the dwelling units; and 3) the fewest dwelling units with the poorly evaluated living conditions.

Furthermore, the comparisons also revealed the highest-scored and the lowest-scored solutions among the typical layouts in the four indices, and the tendencies that the solutions’ average level of living conditions varied with the distribution of the green land.

Additionally, the relationships between the attributes of the plot and the average level of living conditions in the solutions were also examined. The findings include: 1) the low plot ratios are advantageous for improving the average level of living conditions, and the efficiency of the improvements depends on if the open spaces are made full use of as the green land; and 2) the high aspect ratios (length of east-west side / length of north-south side) are beneficial to achieve the high score in the average level of living conditions.

It should be noted that only several aspects of living conditions inside the dwelling units worked as the preference function in the simulation. If available, it is also possible to include other criteria in site planning into the system, such as the quality of outdoor space or even the design intentions of architects.

Table 8. Solutions to the Models with Different Aspect Ratios

| Aspect Ratio | $E_a$ | Agent with IS=  | Layout |
|--------------|------|----------------|--------|
|              |      | 4   | 5   | 6   | 7   | 8   |        |
| 0.57         | 6.15 | 2   | 5   | 17  | 4   | 5   |        |
| 0.86*        | 6.24 | 0   | 5   | 20  | 3   | 5   |        |
| 1.52         | 6.55 | 0   | 4   | 15  | 6   | 8   |        |

* The standard model
Notes
1. Lei. Z et al. (2001) Planning for the XingTai Shiji Mingdu, Architectural Journal, Architectural Society of China, No. 395, pp.24-25.
2. German term, means building in a line; usually applied to housing multistory slabs, arranged in parallel rows open at the ends in an east-west orientation. It is commonly associated with functionalist housing projects of the 1920’s beginning in Germany but used in many countries.
3. A software developed by Innovative Information Technology Dept. Kozo Keikaku Engineering Inc.
4. The Ministry of Construction of China (1994) Code for Urban Residential District Planning & Design, Article 7.0.4.1.
5. The detailed introduction about how to use and explain the Ordinal Regression models can be found in the textbooks on the Logistic Regression Models.
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