Optimizing Parallel Layout of MRHC to Improve Quality of Views from Dwelling Units with Genetic Algorithm

Mengzhen Han*, Junzo Munemoto* and Daisuke Matsushita*

1 Doctoral Candidate, Department of Architecture and Architectural Engineering, Graduate School of Engineering, Kyoto University, Japan
2 Professor, Department of Architecture and Architectural Engineering, Graduate School of Engineering, Kyoto University, Japan
3 Instructor, Department of Architecture and Architectural Engineering, Graduate School of Engineering, Kyoto University, Japan

Abstract
This paper attempted the design method for the optimal parallel layout of Multistory Row House Clusters (MRHC) to maximize the overall quality of views from dwelling units with Genetic Algorithm (GA). The evaluation function of GA was designed based on the regression model established in our previous study. Five simulation models were executed respectively, which differed in the combination of Neighbor Blocks (NB) that MRHC faced and abutted. The optimal solutions to all the models can be sorted into similar three types of layouts which have common features such as: 1) improvement in the overall quality of views over the popular layout in the reality; 2) separated green lands inside MRHC; and 3) a not straightly aligned road. Furthermore, the discrepancy of the best solution in the models indicated that MRHC with different external surroundings demanded a different layout. Finally, the influences of the external surroundings on the quality of views in our model of MRHC were compared.

Keywords: optimal parallel layout; view from dwelling unit; Multistory Row House Cluster (MRHC); genetic algorithm

1. Introduction
1.1 Background
In northern China, a prototype of parallel layout prevails in the site planning of Multistory Row House Clusters (MRHC), which can be characterized by a concentrated Green Land (GL) located in the central area of plot (Fig. 1). Despite the advantages such as the convenience for the communication of residents, it has been found not to perform as well as the solutions from our previous simulation in the indices concerning the living conditions of dwelling units (Han et al., 2004b). Therefore, critical studies are significant on the basic site planning of MRHC based on different criteria. The present paper attempts to optimize the parallel layout of MRHC with Genetic Algorithm (GA) in terms of the overall quality of views from dwelling units, which was a criterion concerning the subjective perceptions of people.

Our first study on the living conditions of dwelling units in MRHC revealed that the evaluations on “the view from dwelling unit” made a larger relative contribution in the comprehensive evaluation index than those on “sunlight”, “privacy”, and “noise” (Han et al., 2003). This indicates the importance to concentrate on this issue. The layout optimizations presented in this paper are based on the outcome of our previous paper on the preference of people toward the views from dwelling units (Fig. 2). By using photorealistic computer graphics in the visual test, the previous study has established a regression model, which could predict the degree of preference to a view with the variables describing the relative location of a dwelling unit to the surroundings (Han et al., 2004a). This model worked as the core of the evaluation function of GA, which defined the objective of the optimization. As the result of this paper, besides the optimal solutions to be presented, some valuable

Contact Author: Mengzhen Han, Doctoral Candidate, Munemoto Laboratory, Department of Architecture and Architectural Engineering, Graduate School of Engineering, Kyoto University Yoshidahonmachi, Sakyoku, Kyoto, 606-8501 Japan
Tel: +81-75-753-4899 Fax: +81-75-753-4899
E-mail: ap.hmz@archi.kyoto-u.ac.jp
(Received May 10, 2004; accepted September 13, 2004)
planning principles on how to improve the quality of views from dwelling units in MRHC might be revealed by a comparison with the reality.

Many aspects of living conditions concerning the subjective perceptions of people are studied by means of investigation and data analysis. The findings are often kinds of mathematical models, which describe the quantitative relationship between the studied issues and some physical items. This paper presented an approach to make further use of such outcomes. Specifically, to the basic site-planning problem of MRHC with parallel layout 1, this study tries to seek out the optimal layout with the maximum overall quality of views from dwelling units, and reveal important planning principles from this point of view. The findings might be significant for architects and city planners to understand this issue more profoundly.

1.2 Purpose

The primary purpose of this study is to seek out the optimal layout types in light of the overall quality of views from dwelling units in MRHC with parallel layout, which was measured by the preference of people modeled in our previous study. Furthermore, we attempt five simulation models to examine if the optimal solution would vary with the external surroundings of MRHC.

The study questions include:
1) How can the basic site-planning problem of MRHC with parallel layout be mapped to GA optimization?
2) What is the optimal layout type in each simulation model in terms of the overall quality of views from the dwelling units?
3) Do the optimal solutions vary with the simulation models, which differ in the external surroundings of MRHC?
4) What common features can be extracted from the optimal solutions?

1.3 Past Studies

Due to the complexity of layout optimization problems in the field of Architecture and city planning, researchers usually focused on one, or a few, aspect of performances and simplify them to the sub well-defined problems. GA, one of the modern heuristic search methods, has showed applicability in these cases, with subjects varying from the facilities in a city to the rooms in a building. Aoki (1996) introduced the feasibility of GA in room layout optimization in Japan. A series of studies on room layout optimization in the operation division of hospitals were proposed by Iwata et al (1999). The optimum layouts were achieved to reduce the cost of people’s moving. In the scope of city, Aoki and Muraoka (1996) presented an optimization for facility planning. Another city model was proposed by Takizawa et al (1997) to simulate the formation of land use pattern in a city. It designed two evaluation functions concerning the geographical location conditions and the degrees of mutual combination. The study published by Muraoka and Aoki (1998) dealt with a similar subject as this present paper. It optimized the layout of multistory houses to maximize the absorption of solar energy.

The differences of the present study from the past studies have to do with the following two aspects. The first is to focus on an aspect of living condition concerning the subjective perceptions of people, in contrast to the technological objectives in the past studies. The evaluation function of GA was designed based on the regression model established by a process of investigation and data analysis. The second is the subject of simulation—MRHC, one of the prevailing structures of residential buildings in China. The specific constraints in planning MRHC were handled so as to make the final solutions more feasible to be fed back into real life.

2. Simulation Model

This paper converted the basic site planning of parallel layout of MRHC to a single objective optimization with constraints. MRHC in the same scale as our previous simulation with Multi-Agent System was modeled in the present paper (Han et al., 2004) to keep the results comparable. Table 1 lists the main technical indices.

2.1 Encoding Method

The basic site planning of MRHC was simplified to a 2-dimensional problem in the present paper by omitting the vertical dimension. This is because the multistory row houses in Beijing are almost all 6-story high,
reaching the limitation of walk-up residential buildings for high density. An encoding method was designed to include the constraint concerning the normal building interval for the day lighting of dwelling units (Fig. 3). A segment in the row house was the minimum unit that could be represented in the chromosomes, which consisted of a common staircase and 12 dwelling units located on six floors. Three kinds of genes were used to map the alternative layouts of MRHC to the chromosomes. Gene (1) represented a combination of a segment of row house in the north and its interval space. For the loci in the rows numbered 1 and 2, gene (-1) was used to represent the situation that a segment of row house occupied the middle of the space. This ensured the chromosomes capable to represent the layouts with the least depth green land, which was 1.5 times that of normal building intervals. And, gene (0) represented the empty space without occupancy of row houses. With this mapping method, the constraint of building interval was simplified as: gene (-1) must not neighbor a gene (1) to the south. This encoding method could generate 620 possible layout patterns, including those that might be against the constraints introduced in the following text. It should be mentioned that, according to the regression model established in the previous study, the external surroundings of MRHC might influence the preference degree of views from dwelling units dramatically, which were the Neighbor Blocks (NB) to the south, east, and west of MRHC studied. This study attempted different combinations of NB in five simulation models to examine if they would result in discrepant solutions.

2.2 Handling Constraints

Before being evaluated, a chromosome was checked to see if it was accordant with the specific constraints derived from the site planning of MRHC. Table 2 lists the expressions of these constraints. Repairing strategy was given priority in handling the constraints in pursuit of a more efficient search. Respective repairing procedure was designed to convert the infeasible chromosomes to feasible ones in the constraint 1, 2 and 3. For example, if a chromosome had gene (0) \( m > 7 \), which was against the constraint 1, the system would change \( m = 7 \) gene (0) to gene (1) or gene (-1) randomly.

For the other two constraints, which were difficult to be repaired, the infeasible chromosoms were marked and then penalized with a lowest fitness in the next evaluation process.

2.3 Evaluation Function

The evaluation value (or fitness) of a feasible alternative solution was defined as the summation of the preference degrees of the views from the dwelling units in MRHC (Formula 1). As the preference degree of a view used a 7-scale measurement, from -3 (Extremely disliked) to 3 (Extremely preferred), the range of fitness was between -1188 and 1188. So the objective of optimization was to seek out the individual with the maximum fitness. The preference degree of a view could be calculated with the variables describing dwelling unit’s relative location in the surroundings, according to the regression model established in the previous study (Formula 2).

\[
E = \sum_{i=1}^{n} P_i 
\]

\[
P_i = k_1 \times X_{i_1} + k_2 \times X_{i_2} + k_3 \times X_{i_3} + k_4 \times X_{i_4} + C
\]

Table 2. Constrains and Handling Strategies

| Expression in solution space | Expression in coding space | Handling strategy |
|-----------------------------|---------------------------|-----------------|
| 1. Keep plot ratio=1.57     | Total number of gene(0)=7 | Repairing       |
| 2. Keep building intervals for day lighting | Gene(-1) must not neighbor gene(1) to the south |            |
| 3. Ensure an unobstructed north-south road through MRHC | Gene(1) must not be on southeast or southwest corner of gene(1), and there must be a gene(0) in any rows. | Penalizing (constant penalty) |
| 4. Row houses consist of no less than 3 segments for economic reason | Number of conjoint gene(1)/gene(-1) >=3 |            |
| 5. Row houses consist of no more than 6 segments for fire protection | Number of conjoint gene(1)/gene(-1) <=6 |            |
Table 3. Definition and Value Assignment of Independent Variables of Formula 2

| Definition | Value | Discrimination condition |
|------------|-------|--------------------------|
| $X_1$ Relation with GL of MRHC | 1 | Facing GL, AFOV intersects with GL without obstruction |
| | 0 | Not facing GL, Not meet the above condition |
| $X_2$ Relation with NB faced (to the south of MRHC) | 1 | Facing NB, AFOV intersects with south boundary of MRHC without obstruction, DU is in the nearest 2 rows from south boundary, and the empty space where AFOV passes is wider than 2 loci. |
| | 0 | Not facing NB, Not meet the above condition |
| $X_3$ Relation with NB abutted (to the east/west of MRHC) | 1 | Abutting on NB, SFOV intersects with east/west boundary of MRHC without obstruction, and DU is in the nearest 3 columns from east/west boundary. |
| | 0 | Not abutting on NB, Not meet the above condition |
| $X_4$ Story level | 1 | On 5th or 6th floor, Same as on the left |
| | 0 | On other floors, Same as on the left |

Note: GL-Green land; NB-Neighbor block; AFOV-Axis of Field of view; SFOV-Either side of field of view

Table 4. Value Assignment of Coefficients of Independent Variables in Formula 2

| Coefficient | Value | Alternative situations |
|-------------|-------|------------------------|
| $k_2$ | 3.23 |
| $k_2$ | 0.00 | Facing other MRHC |
| | 0.88 | Facing city buildings |
| | 3.84 | Facing Petty street garden |
| $k_3$ | 0.46 | Abutting on other MRHC/city buildings |
| | 2.03 | Abutting on Petty street garden |
| $k_4$ | 0.31 |

Table 5. External Surroundings of Five Simulation Models

Table 3 lists the definitions and value assignments of the four independent variables. An independent variable would take a value if the corresponding discrimination condition listed in the last column was met. In $X_i$, before checking a dwelling unit’s relation with the Green Land (GL) inside MRHC, it was necessary to identify whether there was a GL or not. The criteria for GL included: 1) its depth was wider than 1.5 times the normal building interval, and 2) its area was no less than 500 m². Table 4 lists the values of the coefficients to the above independent variables. It should be noted that either $k_i$ or $k_j$ had alternative values, which corresponded to the different contents of NB. It was because our previous study had investigated the views from dwelling units with different surroundings, including the different combination of NB outside MRHC. Therefore, it was available for the present paper to present and compare the optimal solutions to the simulation models with different external surroundings.

2.4 Settings of Genetic Algorithm

The definition and implementation of the operators of GA were based on GENESIS 5.0. Due to the cross-effects of the constraints, it was easy to converge to some local optimal solution prematurely. To prevent this, the rank-based selection operator was employed to choose the individuals for the next generation. Accordingly, a comparable slow evolution process had to be taken. After trial and error, the appropriate values for the main parameters of GA were as the followings: Total generations=40000 (as the terminate condition); Population size=4000; Crossover rate=0.6; Mutation rate=0.05; and Generation gap=1.

3. Result of Layout Optimization

3.1 Three Types of Optimal Solutions

Five simulation models were performed respectively, which covered the common situations of the combination of NB that MRHC faced and abutted (Table 5). That is to say the evaluation functions in five models took different values in $k_2$ and $k_3$. In each model, GA converged to a certain optimal solution. We will only present the performance of GA in model 1 as the instance, because the situations in these five models are similar. Fig. 4 shows the variances of the fitness of the best solution and the average fitness of current best 10 solutions with generations in simulation model 1. At the beginning, even the current best solution was evaluated as -1188, which implied that no feasible

![Fig.4. Performance of GA in Simulation Model 1](image-url)
solutions were generated by the random initiation under the cross effects of the constraints. In the following generations, the fitness of solutions increased abruptly, owing to the repairing processes in three of the constraint, which reduced the infeasible individuals efficiently. Then, the increasing fitness of both the best solution and the average implied that the individuals evolved better each time. After 14199 generations, the final optimal solution emerged, with a fitness of -597.12. When reaching the preset terminate condition (generation>40000), the optimization stopped and made reports. As the results of GA might vary with the parameters, we tried times of running with different settings. The solution evaluated -597.12 was the best one we could ever get for simulation model 1, which was probably the global optimal.

The 10 best solutions were acquired after the layout optimization. Some of them were very similar, with slight differences such as the location of road between two buildings in a row. From the viewpoint of site planning, they were essentially the same type. Therefore, we classified the similar solutions into a prototype to make the results more clear. We found that three types of layouts always performed best in all five simulation models, although the rank varied (Table 6). Layout type 1 was characterized with two least depth Green Lands (GL) aligned along the east or west side of MRHC. Layout type 2 had three least width GL staggered in the middle area. These three GL could also be deemed as a single one, because they were connected with each other at the ends. And layout type 3 had two GL differing both in width and depth. A common characteristic was that GL of MRHC were made full use of by separating into small ones. As its corollary, the north-south road inside MRHC was no longer straightly aligned in all of them.

The optimal solutions were found to vary with simulation models, which indicated that the different external surroundings of MRHC demanded different layout types (Table 7). Layout type 1 performed best in four simulation models, from Model 1 to 4. These four models were coherent in that MRHC did not face Petty Street Garden (PSG) as the south NB. Therefore, GL inside MRHC played the most positive role in improving the views from dwelling units, according to the coefficients in the evaluation function. A dwelling unit directly facing GL would exceed those not by 3.23 in the preference degree, if other conditions were the same. The most efficient utilization of GL might be the reason that

| Prototype | Optimal solutions | Popular layout |
|-----------|------------------|----------------|
| Sketch | Type 1 | Type 2 | Type 3 |
| Fitness in simulation models | Model 1 | -597.12* | -635.88 | -674.64 | -752.16 |
| Model 2 | -540.60* | -579.36 | -618.12 | -695.64 |
| Model 3 | -502.08* | -530.28 | -569.04 | -657.12 |
| Model 4 | -445.56* | -473.76 | -512.52 | -600.60 |
| Model 5 | -182.40 | -175.08* | -213.80 | -337.44 |
| DU facing GL | 84 | 72 | 60 | 36 |
| DU facing NB | 108 | 120 | 120 | 108 |
| DU abutting on east NB | 36 | 36 | 36 | 36 |
| DU abutting on west NB | 36 | 36 | 36 | 36 |

Note:*-the best solution in the model; DU-Dwelling unit; GL-Green land; NB-Neighbor block

Table 7. Optimal Solution Obtained in Each Simulation Model
type 1 performed best. From the comparison of “dwelling units facing GL” listed in Table 6, this advantage of type 1 could be found. However, layout type 2 surpassed type 1 in the simulation model 5 in the overall quality of views from dwelling units. Although type 2 had less dwelling units that benefited from GL than type 1, it had more that benefited form PSG to the south of MRHC, which had even larger relative contributions in the preference degree of views than GL. This might answer for the advantage of type 2 in Model 5.

3.2 Relationship between External Surroundings and View Quality

This paper proceeds to examine the relationship between the combination of NB and the overall quality of views that might be achieved by comparing the fitness of the optimal solutions to the five simulation models. Fig. 5 illustrates the average preference degrees of the views from dwelling units in the five optimal solutions. The average preference degree equaled the fitness of a solution divided by 396 (total number of dwelling units). It was for the convenience to refer to the 7-scale measurement of the preference used in the previous study that the fitness of solutions was converted to this index.

Negative values were found in the average preference degree of views in all the five optimal solutions, varying between “Disliked” to “Neutral”. This indicated that, on average, people might not be satisfied with the views from dwelling units in MRHC, which implied an importance to make studies on how to improve the view quality in this prevailing structure of residential buildings. Relatively, in the order of the average preference degree achieved, from high to low, the simulation models could be ranked as Model 5, Model 4, Model 3, Model 2, and Model 1. Among them, Model 5 had an obvious advantage over the other four models. This revealed that the most advantageous external environment was PSG to the south of MRHC in terms of the view quality of dwelling units, and the worst situation was to be surrounded by other MRHC. Besides the principles that could be easily derived from the established regression model, it was found that, for our model of MRHC, the south NB played a more important role than NB to the east or west in the influence to the quality of views from dwelling units. Take the larger advantage of Model 3 over Model 1 than that of Model 2 as the example. Although according to Formula 2, the increase of coefficient $k_2$ (1.57) caused by replacing “Abutting on other MRHC or city buildings” with “Abutting on PSG” (Model 2 over Model 1) was larger than that in $k_3$ (0.88) caused by replacing “Facing other MRHC” with “Facing city buildings” (Model 3 over Model 1), the dwelling units abutting on east or west NB were fewer than those facing NB to the south. This accounted for the more significant effects by the south NB in our model of MRHC.

It was coincidental that these three types of solutions all had the equivalent number of dwelling units abutting on the east and west NB, which determined the same fitness of the mirror-imaged layouts. However, it should be noted that some pairs of mirror-imaged layouts did have a discrepancy in the simulation model 2 or 4, which had asymmetrical NB to the east and west of MRHC.

4. Verification of Solutions

In order to verify the solutions of optimization, we compared them with the popular layout of MRHC in the housing market. The prototype of the popular layout was illustrated in the last column of Table 6. Corresponding to the settings of external surroundings in five simulation models, the summations of the preference degrees of views were calculated as the fitness of the popular layout. In each model, the fitness of the optimal solution was found to be much higher than that of the popular layout, 28.1% on average. This showed the usefulness of the present layout optimization method in improving the overall quality of views from dwelling units in MRHC, based on the findings of the previous study.

5. Conclusion

For Multistory Row House Clusters (MRHC) with parallel layout, which originated from the idea to lay out optimally for better living conditions, this study presented a design method to solve its basic site-planning problem according to the preference of people toward the views from dwelling units, in contrast to the currently used engineering indices, such as insolation hours. The findings provided a greater insight into the site planning of MRHC with parallel layout, which might help the designers to see the principle points in light of this creation, and then allow for them.

Three types of layouts performed outstandingly in all five simulation models with different external surroundings of MRHC. Compared with the prototype of the popular layout in the housing market, they show the following common features: 1) improvement in the overall quality of views from dwelling units; 2) separated green lands inside MRHC; and 3) a not straightly aligned road through MRHC.

Furthermore, the different ranks of these three types of solutions in the simulation models proved that no universal best layout existed for MRHC from the viewpoint of the overall quality of views. For the simulation models that MRHC did not face a petty street garden to the south, layout type 1 performed best, which
had the most dwelling units served by two least depth green lands located along a side of plot. While MRHC faced a petty street garden, layout type 2 became the optimal solution, which had the most dwelling units benefiting from the petty street garden outside MRHC and the second most ones served by the green lands inside. The characteristic of type 2 is that three connected least width green lands zigzag in the middle of MRHC.

In addition, the comparison of the solutions to different models revealed the influence of the external surroundings to the overall quality of views from dwelling units. Facing a petty street garden was the most advantageous for MRHC in terms of a high overall quality of views, while surrounded by other MRHC was the most disadvantageous. To the model of MRHC in this paper, it was also found that the neighbor block to the south played a more influential role than those to the east or west in the overall quality of views.

Together with our previous study, this paper showed the advantage of the combination of the investigations on subjective evaluations and the generative approach of computer application in seeking out the solutions that could highly reflect the criteria of people. It is promising to develop some intelligent system that can model the criteria of customers and provide alternative layouts according to them in an interactive way. It is a direction of our future study on design methods.

Note
1. The phrase “basic site-planning problem of MRHC with parallel layout” was used to indicate what was dealt with in the simulation was the prototype of parallel layout, which held the basic information of the spatial relationships of the multistory row houses, green land, and road in MRHC. The variations of the typical parallel layout, such as those with slightly staggered row houses or diversity of orientations, were excluded, because they were adopted mainly for the generation of contrast of the monotonic exterior spaces in parallel layout, which was not the objective of this study.
2. The Ministry of Construction of China, (1994) Code for Urban Residential District Planning & Design, Article 7.0.4.1
3. Mitsuo GEN, and Runwei CHENG, (1997) Genetic algorithm and engineering design, John Wiley & Sons, pp.50
4. The details and sketches of discrimination conditions can be found in reference Han (2004)
5. An implement for function optimization based on genetic search techniques, provided by John J. Grefenstette, October 1990.

Reference
1) AOKI Yoshitsugu, (1996) Analogy between Plan Generation and Genetic Evolution—Genetic Algorithm for Optimization of Room Allocation, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.481, pp.151-158.
2) AOKI Yoshitsugu, and MURAOKA Naoto, (1996) A Method of the Facility Location by Genetic Algorithm, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.484, pp.129-135.
3) HAN Mengzhen, MUNEMOTO Junzo, and MATSUSHITA Daisuke, (2003) Relation between People’s Evaluations on Living Conditions and Plan Locations of Dwelling Units in MRHC with Parallel Layout in Beijing, Journal of Asian Architecture and Building Engineering, AIJ, Vol.2, No.2, pp.95-102.
4) HAN Mengzhen, MUNEMOTO Junzo, and MATSUSHITA Daisuke, (2004) A Study on Preference of View from Dwelling Units in MRHC with Composition Division of CG Images, Journal of Architecture Planning and Environmental Engineering, AIJ, Submitted.
5) HAN Mengzhen, MUNEMOTO Junzo, and MATSUSHITA Daisuke, (2004) Emergence of a Parallel Layout Arising from User’s Pursuits of Better Living Conditions of Their Dwelling Units in MRHC with MAS, Journal of Asian Architecture and Building Engineering, AIJ, Vol.3, No.1, pp.149-156.
6) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999a) Application of Genetic Algorithms to Room Layout and Corridors Pattern Evaluating by Cost of Moving — Case Study on the Optimum Layout in Operation Division in Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.518, pp.329-333.
7) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
8) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
9) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
10) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
11) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
12) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
13) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
14) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
15) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
16) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
17) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
18) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
19) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
20) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
21) IWATA Shinichiro, MUNEMOTO Junzo, YOSHIDA Tetsu, and BANNO Akifumi, (1999b) Application of Genetic Algorithms to Room Layout Evaluating by Cost of Moving and Creativity Support— Case Study on the Optimum Layout in Operation Division of Hospital in ‘an Approach to the Optimum Layout of Single-Storey Buildings’, Journal of Architecture, Planning, and Environment Engineering, AIJ, No.519, pp.341-347.
