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COMPLEX ADAPTIVE RESIDENTIAL QUARTER PLANNING USING MULTI-OBJECTIVE OPTIMIZATION

An agent-based modeling approach

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Abstract. This paper presents a complex adaptive residential quarter planning software. It is developed using Java object oriented programming language and targeting at configuring the tower-type apartment in a dense area during early design stage. Rules are analyzed and formulated based on building code and zone ordinance. Moreover we develop an agent-based modeling with multi-objective optimization algorithm. In this modeling, each agent acts independently according to the rules that are designed to solve the complex geometric problems that are related to physical constraints. At the end, we present a simulation outcome of a case study.

Keywords. MOOP; Urban design; residential quarter planning; agent system

1. Introduction

1.1 DESIGN PROCESS

Residential quarter planning in itself is a multi-objective problem similar to many other real-world problems. Design decision-making process involves varied tradeoffs among multiple objectives, which should be optimized simultaneously. Depending on the information size of the target problem, the amount of both incoming information and outgoing information that is processed with by a designer is enormous. During early design stage that is specially admitted to be one of the most important steps, it is requested to acquire many tangible design solution candidates (Zeisel, 1984; Simon, 1996; Lawson, 1997).

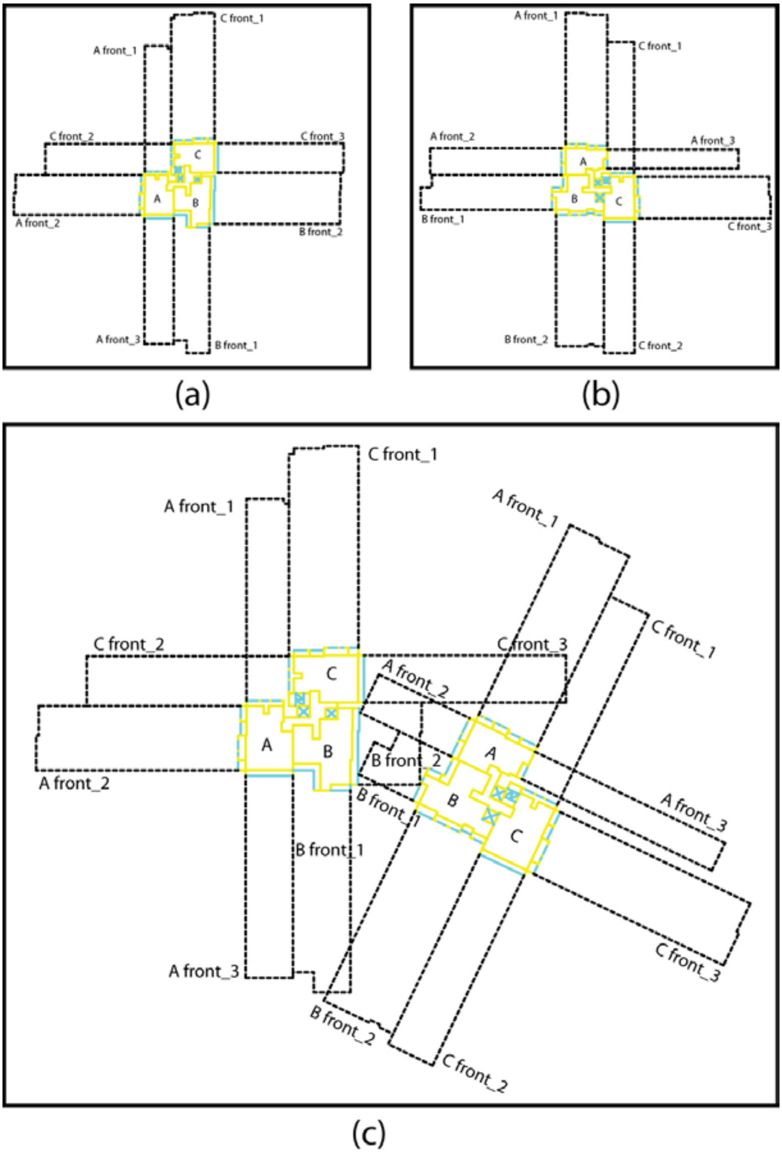

Figure 1. Tower-type apartment cases and distance constraints (a) Tower A, (b) Tower B, and (c) frontline casting from units

The reasons for that are to minimize the risk to select wrong idea and to obtain more feasibly creative design. However it is not easy to acquire satisfactory design spaces within given duration when human's cognitive ability becomes the major resource to navigate many intermediate design alternatives. Solution evaluation that is designer-led with very little computational support can be largely subjective as well. Multiple design objectives to satisfy and various constraints to comply with are insufficient and are violated respectively in some circumstances. Those reasons lead to the limitation of conceptual design decisions. In this research, we develop a residential quarter planning software based on multi-objective optimization procedure.

1.2 RESIDENTIAL QUARTER PLANNING IN SOUTH KOREA

In residential quarter planning with high-rise apartments in South Korea, the distance between facades of units of respective apartments is the key constraint to decide the maximum height of an apartment. When the average maximum storey is calculated with 'the building-to-land ratio' and 'floor area ratio', a designer arranges the preferable tower-type apartments to figure out the possible building configuration. At this time, distance between apartments is generally considered as objective index to consider the openness (view), daylight, and privacy. Figure 1(a) and 1(b) are typical tower-type apartments in Korea, which are arbitrarily named as Tower A (587m^2) and Tower B (660m^2) respectively. Tower A is composed of vertical stacks of three units: Unit A (186m^2), Unit B (186m^2), and Unit C (213m^2). Tower B is another type composed of vertical stacks of three units: Unit A (150m^2), Unit B (186 m^2), and Unit C (188 m^2). In case of Tower B, three units (Unit A, Unit B, and Unit C) commonly share the core at the lower level. But there are instances where only two units are at the higher level without one unit. If a façade of a unit in an apartment has opening over 50cm wide, the frontline of the façade with a predefined maximum length is extended horizontally to the façade of neighbouring apartments. When the extended frontline from one apartment meets the facade of other neighbouring apartments, the distance in-between is calculated. This process is repeated until all distances are calculated. Finally the shortest distance among distance values of a unit can guide the maximum height of the stack. If we assume that two apartment are arranged as shown in Figure 1 (c), 'B front 2' of unit B of Tower A is shorter than 'B front_1' of unit B of Tower A in relation to the neighbouring Tower B. Therefore 'B front 2' decides the maximum height of the stack of unit B of Tower A. The maximum height of the respective units of the apartment can be calculated in this way and the maximum height of the apartment is acquired from the maximum height of the respective units.

2. Agent based modelling

In this research, agent-based modelling (hereafter ABM) is utilized not to provide a description of a specific system but to solve the residential quarter planning by adapting the ABM theory. ABM is composed of autonomous decision-making entities called agents (Bonabeau, 2002; Macal and North, 2007). Each agent acts independently according to the rules and execute its pre-programmed behaviours. Repetitive competitive pro-actions and re-actions between agents are important features of the proposed ABM similar to other general ABMs.

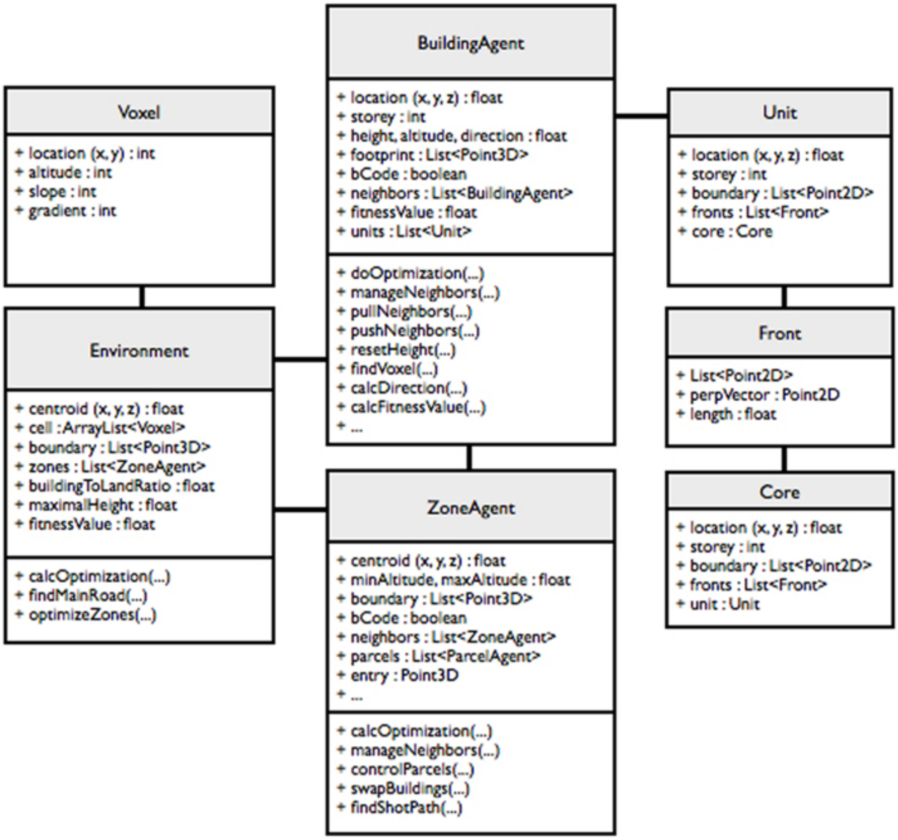

Figure 2. Agent-based modeling for residential quarter

In this proposed system, two kinds of agent are modelled; one is building agent and the other are zone agent as shown in Figure 2. Environment of the ABM is modelled based on GIS information of the target site. However instead of precisely designing learning system that is found of importance in general ABM, specially designed rules are utilized to help each agent find a suitable behaviour and to assist a program operator to obtain meaningful planning. Emergent phenomena that are captured at the local area between neighbouring building agents can explain the clear relationship between agents. Global phenomenon can be thought as design proposals that we wish to obtain at the end. Whether the outcomes are feasible or not can be decided by optimization technique as following next.

3. Optimization

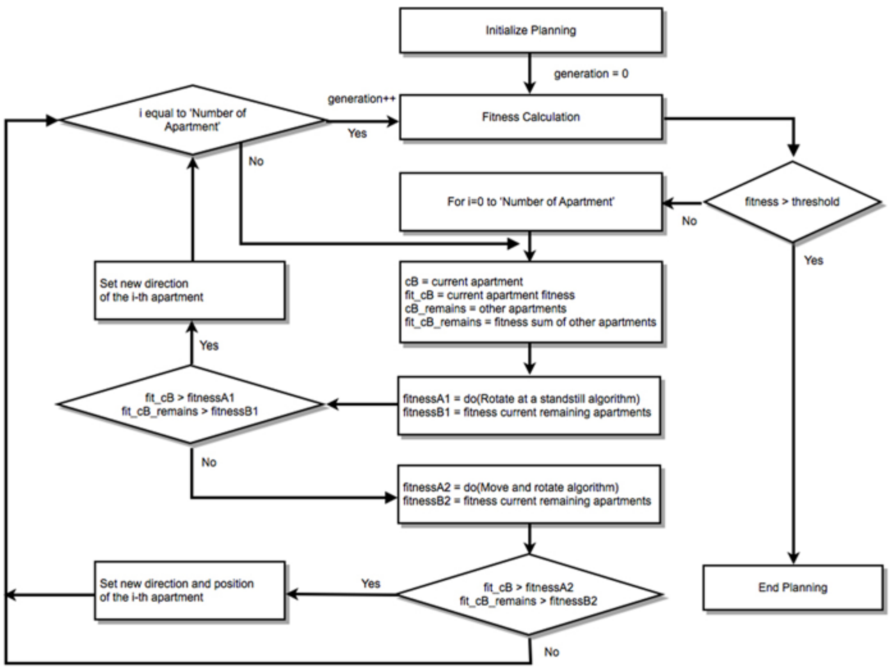

Figure 3. Apartment optimization algorithm

The word of "optimization" refers to the process of searching for the best of all possible candidates to the problem of interest based on certain performance criteria (Papalambros and Wilde, 1991). A general formulation of optimization finds the best solution by finding either the maximum or the minimum value of objective function by varying design variables under the given design constraints (Haftka and Gürdal, 1992). Deb (2002) states the general formulation of multi-objective optimization problem (MOOP) as follows:

Minimise	$f_m(x)$,	$m = 1, 2, . . . , M$;	Objective functions
Subject to	$g_j(x) \geq 0$,	$j = 1, 2, . . . , J$;	Inequality constraints
	$h_k(x) = 0$,	$k = 1, 2, . . . , K$;	Equality constraints
	$x_i(L) \leq x_i \leq x_i(U)$	$i = 1, 2, . . . , n$.	Variable bounds

Where $x = x_1, x_2, \ldots, x_n$ is design variables; M is number of objective functions; J and K are number of equality and inequality constraints, respectively; n is number of design variables; and, $x_i^{(L)}$ and $x_i^{(U)}$ are lower and upper bounds on a design variable, x_i. In this study, four objective functions considered to be important for the residential quarter planning; view (f_1), economy (f_2), density (f_3), and direction (f_4). View means relative visual area that can be seen from an apartment. View is calculated by considering both sum of areas that are extended from each front line and possible maximal area. If a 'Tower A' is the ten-storeyed apartment and there are three units sharing a core at from 1st floor to 6th floor, two units at 7th floor and 8th floor, and one unit at 9th floor and 10th floor respectively, the core that is shared by units is not operated economically. Economy is calculated by considering the number of units sharing the core at each floor and the maximum storey of the apartment. In order to reflect the 'the building-to-land ratio', it is important for an apartment to reach maximum 'total floor area'. Density is calculated by a ratio of the acquired 'total floor area' to reach maximum 'total floor area'. And the direction function reflects the building's direction and the land aspect. One unified fitness function of an apartment can be calculated by introducing weighted sum fitness function (Coello, 2001) as follows:

$$F_i = w_1 \text{ x } f_1 + w_2 \text{ x } f_2 + w_3 \text{ x } f_3 + w_4 \text{ x } f_4, \quad i = 1, 2, 3, \ldots, n$$

$$F_{\text{generation at g}} = (F_{(1, g)} + F_{(2, g)} + \ldots + F_{(n, g)}) / n$$

Where F_i means a weighted sum fitness of an apartment and $F_{\text{generation at g}}$ means a weighted sum fitness of a residential quarter at generation g. n means the number of apartments in a residential quarter.

4. Algorithms

This section presents the three algorithms of the computer program: (1) apartment allocation, (2) apartment optimization, and (3) branch road generation. The main structure of the programs is shown in Figure 4.

4.1 APARTMENT ALLOCATION

Apartment allocation technique is used for an initial spatial design. An apartment model is positioned on level x with initial random location. Direction and height of the apartment are computed with the given site information. When a number of apartments are positioned at the beginning in order, already-positioned ones are used as references for the will-be-positioned. Subsequently, the next apartment is positioned, such that the input constraints are satisfied. This process is continued until all apartments are positioned while 'the building-to-land ratio' is not violated. When the initial setting ends, multi-objective optimization is processed until all apartments reach a user given fitness considering threshold.

4.2 APARTMENT OPTIMIZATION

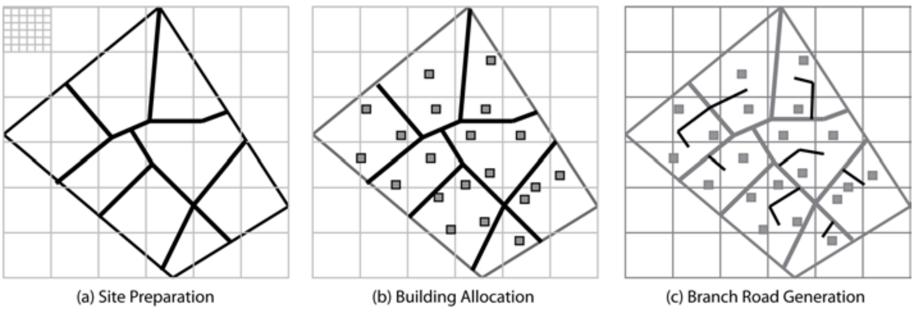

Figure 4. Algorithm steps

The algorithm to improve both each apartment and the residential quarter is created. At the beginning, fitness of each building is calculated without changing geometric information. Then 'Rotate at a standstill algorithm' or 'Move and rotate algorithm' is performed procedurally as shown in Figure 3. For example, 'Rotate at a standstill algorithm' only change the direction of the current optimizing apartment. To change the direction, both fitness value of the current apartment and fitness value of the remaining apartments except current apartment are less than that of the proposed apartment and that of the remaining apartments except the proposed apartment.

4.3 BRANCH ROAD GENERATION

When the optimization process is terminated, planning branch roads can be generated. With the centre points of the apartments and residential quarter boundary, Voronoi diagram (Berg et al, 2008) can be obtained and each cell boundary segment is reconstructed as an acyclic graph for path finding algorithm. The acquired convex polygons are reshaped to rectilinear shapes by intersection condition. Generally three points meet at an intersection point and one of the smallest angles can be modified to the right angle. Which results in a relatively straight line and it can contribute to the economic planning of the branch road system. The process of building road systems among zones is dependent on both the distance from each zone to access points of the residential quarter and the gradient angles of graph edges constructed from zone boundaries. A connecting path from a zone to one nearest access points can be efficiently computed by Breadth-First Search (BFS) algorithm (Goodrich and Tamassia, 2010). If necessary, closed loop road can be made by linking two neighbouring graph vertices. The end product of this algorithm is a series of road segments applied with breadth. Occasionally by linking buildings of a zone to one of road vertex nearby, a cul-de-sac road can be generated. Too much road area certainly occupies free space; branch road algorithm is designed to minimize the road area within a zone. Additionally there is freedom for a designer to add road segment in order to make through road, loop road, and ring type road. When this algorithm is complete, all building secure accessibility to one or more entries.

5. Implementation

Planning residential quarter can be shaped to three steps: Preparatory stage, intermediate stage, and determining stage.

Preparatory stage has site analysis, site data, and design knowledge acquisition, which is a prior process before running the software. Site analysis is the work of exploring the site to decide which items need to be admitted. Site data is composed of several elements such as topographic information and transportation. A site can be imagined represented by voxels uniformly spread on the site. Agents use the information of a voxel (a vector or a cell in a grid system) by comparing two locations. A voxel is used as a reference in order to assist agents to decide their behaviours as well. Aspect, slope, and altitude are chosen as important elements when it comes to housing complex planning and design in a hilly site. Data of those is precisely gathered by processing digitized elevation model (DEM) with ArcGIS package.

- Aspect is classified to ten discrete directions including north, northeast, east… northwest, and none.
- Slope is calculated by degree ranging from zero to 56˚.
- A voxel on the site has an aspect value, a slope value, and an altitude value.

Additionally very important factors such as building to land ratio, density, and zoning are gathered, which are used as parameters later on. Intermediate stage is a process about manipulating the tool. A main task is to calibrate parameters, which is necessary because if the predefined parameter values are not appropriate, it is impossible to get good solution candidates. Therefore it is indispensible to adjust the initial parameters. Determining stage is the process of solution space selection. Rather than sorting solution space in a descending manner, this stage tries to get feasible solution set, solutions of which will be reflected one by one by human evaluators. So the only one solution that is evaluated as best both quantitatively and qualitatively will be selected as most possible candidate that will proceed to the next design stage. The town design tool is programmed using Java programming language. As mentioned above, the system admits basic information of the site. Basic information is encoded as CSV, XML, and BMP file type based on the information characteristics and process function. To achieve an effective calculation, a set of rules that is used to evaluate the temporary design alternatives is heuristically calibrated. Using a set of rule, it generates design alternatives together with analysis data. 3D geometry data encoded with XML is especially preferable for the interoperability with BIM.

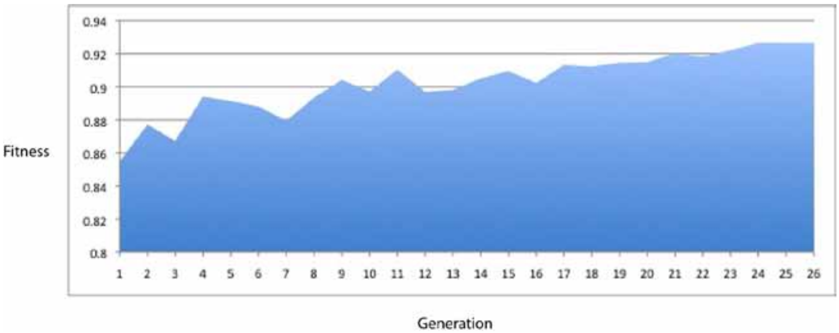

Figure 5. A record of fitness value of the target site at each generation

The target site is located in the centre of Seoul and the new town project is ongoing right now for the purpose of revitalization of the old town by highly dense apartment complex. Figure 5 represent fitness values at each generation. At the initializing stage, the software finds suitable location for each new apartment that the fitness value is relatively high. Which increases the possibility to reach the optimal fitness value that is greater than threshold. This process ends when fitness value (0.926556502) is over threshold value (0.925). Figure 6 shows the interface of the residential quarter planning software. Because of complex geometric calculation, only one area was simulated and all buildings have relatively good fitness value.

6. Conclusion

Rules are analysed and formulated based on the currently shared planning constraints in Korea. This paper associates multi-objective optimization principle to agent based modelling to deal with residential quarter planning in Korea. Even though the tool is designed for residential quarter planning specially targeting at high dense area in Korea, its application to other similar contexts is possible. We assume that this tool can generate feasible residential planning solutions during the conceptual design stage in practices if rigorous methods to deal with more constraints can be found.

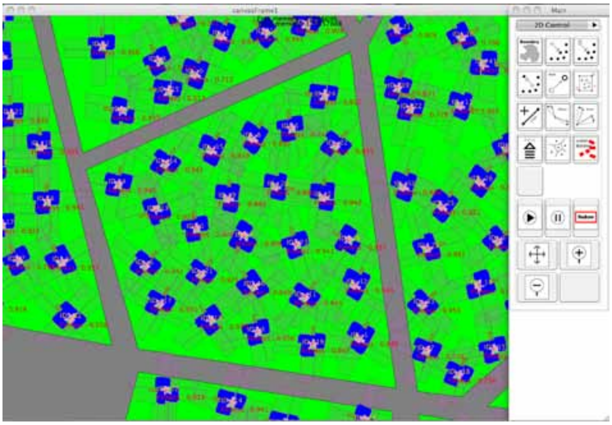

Figure 6. Software interface

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