OPTIMAL ORGANIZATION OF ARCHITECTURAL SPACES BASED ON GENETIC ALGORITHMS

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Abstract. Genetic algorithms categorized as global search heuristics are search technique of seeking approximate or exact solutions for optimizing problems. Our generative tool named notchSpace starts from a population of randomly generated individuals which rationally subdivide architectural spaces with a low “fitness”. During generations’ evolution, the population is recombined, modified and mutated at a low rate to form new modes of building spatial subdivision; a new population is used in the next iteration. NotchSpace works up a research platform to evolve architectural spaces, and it explores the thinking of translation from computer algorithms to the field of architecture.

Keywords. Genetic algorithms; evolutions; fitness; crossover.

1. Background

Originated from creativity, incarnated in ambiguity, genetic algorithms model applied in architecture need architects to survey the relative elements in design, which manifest architectural design system as the complex adaptive system that mutually cooperate with each other, thus translate the modeling process form the architects-oriented angle to the architecture-oriented angle. On one hand, in the process of architectural design, the architecture configuration is clearly demarcated and vividly portrayed after the maturation of design solution. But on the other hand, generative design focuses on the customary formula, such as algorithms and restrictions, yet the resultants in accordance with the rules are beyond anticipation. Look through the basic strategy of cellular automata, genetic algorithms and multi-agent, they all reveal the unique and
unrepeated nature of generative production, thus provides many evidences that generative approach in computer is a scientific design measure, and it witnesses the reformation of architecture design, which enables human creation to simulate the nature.

Taking one branch from the methodology of complex systems as an example, our generative tool employing genetic algorithms is implemented as a computer simulation to optimize subdividing spaces from defined primary shapes. Genetic algorithms (GAs) applying processes and concepts, such as chromosomes, crossover, mutation and selection originated from evolutionary biology, is a search technique for optimizing or solving research subjects in different fields. The evolution starts from completely random or rational but non-optimized individuals which are stochastically selected based on their fitness during each generation. Meanwhile, methods of crossover and mutation are applied to form a new population trend with higher fitness, which becomes current generation for the next iteration. The extended context of GAs can be found from Holland (1992).

2. Prototype

Building orientation, which is a basic requirement for building interior space involved the absorbing of sunlight, landscape, etc., must be considered during processes of architectural design. Thinking methods of architectural spatial subdivision differ greatly from different architects, but undeniably there are many thinking tendencies for each architect. While employed genetic algorithms and computer coding aimed to solve the pre-defined problem, the generative tool addresses its goal for evolving the format of building spatial subdivision for optimizing building orientation incorporating a global consideration whose solution is not known in advance.

Figure 1. Spaces to be subdivided.
NotchSpace defines initial interior spaces as square figures where vertical traffic space located in centre of a small cube and the other eight cubes are spaces to be subdivided (Figure 1-1). Moreover, notchSpace extends its subdivision of spaces to upper floor so that 16 lattices to consider (centre cube is vertical traffic space too), see Figure 1-2.

1, 2, 3 or 4 neighboring cubes (upper or down floor included) can combine as one Architectural Functional Unit (AFU) are defined, and as a result, there are 144 possible modes of interior space combination. Figure 2 presents 8 different interior spatial subdivision modes.

According to requirement of building orientation, notchSpace sets eight orientations of south, east, north, west, southeast, northeast, northwest and southwest for choosing as evolving goal during its running time and the demands of the generative tool are summarized and presented as follows:

1) Based on chosen orientation, the interface of notchSpace provides three-dimensional and dynamic display, such as current generation, current fitness, orientations for evolving, etc.

2) The AFU can be composed of 1 to 4 cubes, simultaneously, considering forming rich and colorful interior spaces which avoid tedious space within only one floor; the generator can make one AFU within two floors.

3) Architects can choose 1 or 2 orientations for notchSpace to evolve, and each AFU must have at least one cube towards defined orientation(s). The achievements may not implement all the defined conditions, but must get a global best “fitness”.

4) Genetic algorithms are the cores of the tool, but interface of notchSpace doesn’t provide input for GAs parameters, such as size of initial population, mutation rate. The users set orientations from view angle of architectural goal; they needn’t know any principles of GAs, and all
the parameters of GA are changed automatically according to the running requirements, for example, the initial population size changes according to numbers of building floors.

3. Methodology

Each AFU is consisted of 1 to 4 small cubes whose ways of spatial combination extend to 144 modes represents as chromosomes, and the whole building is assembled by some of 144 modes. Based on the 144 modes, there are many complex combination modes for assembling one building. GAs evolving over time through multiple attempts and offering a bottom-up approach have the ability to address the problem of a multiple possibilities. Creating the building space structure to satisfy defined orientation requirements is the main agenda for notchSpace. The methods involved are related to construction of chromosomes, fitness setting, initialization, selection, crossover, mutation, etc.

3.1. CHROMOSOME STRUCTURE

Initially, many individual solutions are randomly generated to form population which divides a primary shape into rational but non-optimized spaces according to any rules of subdivision. Normally, the initial population contains 800 to 1500 basic individuals which are generated randomly but doesn’t cover the entire range of possible solutions (the search spaces).

In hundreds of initial population, each cube of a building (as a individual) codes a uniform identity number, and the first index of “0” starts from the southwest cube of the ground floor in anti-clockwise order; in every number multiple of 8, one more upper floor is emerged. For example, an 8-floor building needs 64 cubes coded from “0” to “63” (see Figure 3), and each number maps to the location and orientation of identity cube. For instance, “63” maps to the west cube of 8th floor; and “12” maps to northeast cube of 2nd floor and so on. In addition, the one to one correlation of the identity number and its mapping cube can be figured out by means of mathematical operations.

Figure 3. Mapping number to cubes’ location.
Employing a random function, several sets of numbers which their summation is “8” for one floor are generated, and each of the random number is restricted within 1 to 4. One possibility of initial chromosomes of 8-floor building as follow:

\[ 64 = (2+3+3)+(1+4+2+1)+(3+2+1+2)+(2+2+3+1)+(2+1+2+1+2) + (4+1+3) + (4+1+2+1) + (2+1+2+2+1+2) \]

The above digit string represents AFU of every floor. Take the first floor as an example: “2+3+3” means there are three AFU in the first floor, and the first AFU is combined by 2 cubes; the second and the third are those of 3 cubes. The above 8 groups’ relationship of cubes is showed in Figure 4-1 (vertical traffic space locates in center). The chromosome which only makes spatial subdivision within same floor is the first step of one initial individual. Furthermore, each AFU detects whether it can be combined with upper or lower floor of adjacent AFUs, yet maintains 4 cubes at most, whose result is presented in Figure 4-2. By means of the process, one AFU may occupy across two floors of building.

### Figure 4. Initialization of chromosomes.

#### 3.2 FITNESS AND SELECTION

Fitness function is defined over both genetic selection and measures the quality of all solutions. For example, orientations of every subdivided spaces of a building are set ideal orientations of south to get sunlight; hence the defined orientation is an important goal for evolving. The process will be evaluated as an index of fitness. The simple formula is:

\[
\text{fitness} = \frac{\text{sum of AFS meeting the defined requirements}}{\text{sum of the whole divided AFS}}
\]

Therefore, the fitness parameter is in the interval of [0, 1].

A proportion of the existing population is selected through a fitness-based process for breeding a new generation, and the fitter solutions of individuals measured by a fitness function are more likely to be selected (roulette wheel selection is employed), but on the other hand, a small proportion of less fitness solutions are selected as well. Selection is implementing during each successive generation.
3.3 CROSSOVER AND MUTATION

The steps of crossover and mutation are to generate a second-generation population of solutions. Applying methods of TSP (Travelling Salesman Problem) for reference (Grefenstette and Gopal, 1985), notchSpace set its crossover methods as OX (Ordered Crossover), and mutate in a low rate occurs synchronously during process of crossover.

It is well known that one of a necessary condition for crossover is the two individuals must have the same length of chromosomes. The experiment of TSP offers many effective methods for process of crossover and mutation. Take the two individuals (Figure 5) as an example: the common parameter of the two individuals is “64” (they have 64 cubes), hence the same size becomes a basic condition for the process. The point of crossover can generated from a random number among 0 and 64. Taking the number “28” (crossover point) as an example for the process as follows:

**Point for crossover:** as above mentioned, we get number “28” as the crossover point, and the number of “28” maps the northeast cube of the fourth floor (see Figure 5-1: the yellow one). The cube divides the whole cubes into two parts: one upper part is from identity number of 28 to 63, and the other lower part is from 0 to 27.

**Searching for AFU involved:** As presented in “Chromosomes Structure”, considering there are AFUs occupying two floors, and when AFU are searched both from 28 to 63 and 0 to 27, the AFUs divided or involved by the crossover point (AFUs in Figure 5-2: red color) are recorded. These AFUs will be recombined by other AFUs in next steps.

**Chromosomes exchanged:** The chromosomes of two individuals are separated into two parts, and a part of their chromosomes is exchanged. The upper AFUs which are involved by crossover point are marked in blue color and those AFUs of lower ones marked in green color (see Figure 5-3). Since both individuals exchange their chromosomes at the same point of “28”, after the process of crossover, they will maintain the same chromosomes size of “64”. But the AFUs around crossover point may remain an “insection”, which will make these AFUs become smaller and smaller, they must be recombined by other AFUs in the next step.

**Detecting and recombing sub-chromosomes:** The AFUs involved by crossover point belonged to two different individuals, they detect whether they can combine with upper floor, lower floor or with the AFUs at the same floor, the positive condition is the number of cubes constructed the AFU must be four at most. The processes avoid quick convergence yet illness achievements generated.
Figure 5. Process of crossover
Apart from these steps presented above, another two important elements considered are methods of mutation and its probability. Mutation process can simply exchange locations of two cubes of one individual, but test results show that it wasn’t an efficient method, because a sort of mutation has occurred during process of crossover: After the step of searching for AFUs involved, any AFUs change their spatial structures, and recombine with other AFUs. However, considering the whole processes of genetic algorithms required, notchSpace also set a low mutation probability of 0.001.

According to the requirement of different orientations defined, the tool can generate many achievements rapidly, which display the power of the generative method. Take a 12-floor building as an example (Figure 6, same color as one AFU), and southwest was set as a desired orientation, the achievement was obtained within 20 seconds (fitness equals 1.0). The building provides 30 AFUs, and small sorts of 144 ASF employed in this case. The achievement of 3D spatial subdivisions will help architects a lot for their early stage of architectural design.

![figure 6](image)

*Figure 6. One achievement and interface of notchSpace*

**4. Critiques and Conclusions**

Genetic algorithms are powerful for solving fuzzy optimization problems, which is the main reason that they are widely applied in architecture (Narahara and Terzidis, 2006). Based on the model of genetic algorithms and computer coding practice, notchSpace explores the characters of thinking in the process of translation from computer algorithms to architecture. Furthermore, the methodology will be extended in other architectural aspects.

For all that, there are vast spaces for its development: The 9 cubes initialized isn’t flexible for the demand of actual engineering applications, and the data structure must be recomposed to meet real applications. More flexible methods for locating cubes to form complex architectural spatial structures should be studied. Moreover, the crossover method of the tool which sometimes makes a
bradytelic evolution and a quick convergence needs to be improved.

Architecture design is generally reckoned as a sort of operation of “black box” that is closely bound up with creativity and innovation. Besides its production, the methods are going through a transformation as well. Those who arrogate to themselves with new techniques tend to be fond of and aware of the new strategies to meliorate their artifice convention. Generative architecture design deduces the sensitive design fruit through rational design fundamentals, and leading Architecture to combination of science and Arts.

References
