Application of ant colony Algorithm and particle swarm optimization in architectural design

To cite this article: Ziyi Song et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 113 012172

View the article online for updates and enhancements.
Application of ant colony Algorithm and particle swarm optimization in architectural design

Ziyi Song¹, Yunfa Wu¹, Jianhua Song²

¹College of Architecture and Urban Planning, Anhui Jianzhu University, 856 Jinzhai Road, Hefei 230000, China.
²Anhui Wanwei Group Co., Ltd, 56 Chaowei Road, Chaohu 238000, China.

Abstract. By studying the development of ant colony algorithm and particle swarm algorithm, this paper expounds the core idea of the algorithm, explores the combination of algorithm and architectural design, sums up the application rules of intelligent algorithm in architectural design, and combines the characteristics of the two algorithms, obtains the research route and realization way of intelligent algorithm in architecture design. To establish algorithm rules to assist architectural design. Taking intelligent algorithm as the beginning of architectural design research, the authors provide the theory foundation of ant colony Algorithm and particle swarm algorithm in architectural design, popularize the application range of intelligent algorithm in architectural design, and provide a new idea for the architects.

1. Introduction
For architectural design units, the design staff, usually based on personal experience, rely on professional software to work. How to design the ideal innovative design based on the previous experience has always been a concern of people. Ant colony algorithm and particle swarm algorithm is a good way to solve this problem. Ant colony algorithm and particle swarm optimization are both self-organizing and adaptive artificial intelligence techniques that simulate the evolutionary processes and mechanisms in nature. Both of these intelligent algorithms provide a common framework for solving complex system optimization problems. They do not depend on the specific area of the problem and are robust to the type of problem. They have successfully solved many problems. These two kinds of intelligent algorithms can bring a brand-new field in architectural design too. How to use intelligent algorithm to break the human brain thinking limitations?

2. Ant colony Algorithm and particle swarm algorithm (PSO algorithm)

2.1. Ant Colony Algorithm
Ant colony algorithm first appeared in 20 World 90's, by Dorigo, Maniezzo in Italy. After a great deal of research on ants' foraging process, they found that the whole ant colony has the ability to realize some intelligent behavior, but the behavior of ant individual is short. For example, the ant colony can find the shortest path to food source in different environment. This is because ants within the ant colony can carry out information transmission through some kind of information mechanism. After further study, the ant will release a substance that can be called "pheromone" in its path, ants in ants have a sense of "pheromone", they will walk along the "pheromone" concentration higher path, and each passing ant will leave "pheromone" on the road, This creates a mechanism similar to positive
feedback, so that after a period of time, the entire ant colony will reach the food source along the shortest path.\textsuperscript{1}

2.2. Particle swarm algorithm
PSO, also known as particle swarm optimization algorithm or bird swarm foraging algorithm, abbreviated to PSO, was proposed by Kennedy and Eberhart in 1995. The PSO algorithm belongs to the evolutionary algorithm, starting from the stochastic solution, searching for the optimal solution by iterative method, the quality of the solution is evaluated by the adaptability, the PSO algorithm is simpler than the genetic algorithm rule, it does not have the "crossover" and "mutation" operation of the genetic algorithm, it can find the global optimum by following the current search. This algorithm has attracted much attention in the academic circles because of its easy realization, high precision and fast convergence, and has shown its superiority in solving practical problems.

Each solution to the problem is imagined as a bird, called a "particle." All particles are searched in a D-dimensional space line. All particles are determined by a function to determine the current position. Each particle must be given a memory function, remembering the best location to be searched. Each particle also has a speed to determine the distance and direction of the flight. This speed is adjusted dynamically according to its own flight experience and the companion's flight experience.

3. Algorithm Basic Process

3.1. Basic process of ant colony algorithm
We assume that the ants' food points have \( n \), and the distance between each food point is known to require a shortest path that passes through each food point once and only once.

The M ant is randomly placed in \( n \) food points, each ant's taboo table is the current food point of the ant, and each side information is initialized to \( C \). The taboo table embodies the memory of ants, so that the ants will not go repeat the road, improve efficiency. The first \( k \) ants at food point I select the next food point J the probability is:

\[
P^k(i, j) = \begin{cases} 
\sum_{s \in \text{tabu}_k}^{[\tau(i, j)]^\alpha \cdot [\eta(i, j)]^\beta,} & \text{if } j \notin \text{tabu}_k \\
0, & \text{otherwise}
\end{cases}
\]

Of which, \( \tau(i, j) \) indicates the pheromone concentration on the Edge \((i, j)\) is expressed; \( \eta(i, j) = 1/d(i, j) \) is the heuristic information, \( d \) is the distance between the food point I and J; \( \alpha \) and \( \beta \) reflect the relative importance of pheromone and heuristic information; A list of food points that Ant K has visited.

When all the ants have completed the tour, the pheromone is updated according to the following formula. In which, \( \rho \) is a constant of less than 1, indicating the persistence of information. \( Q \) is a constant; \( L_k \) indicates the path of the ant of \( k \) in this iteration.

\[
\begin{align*}
\tau_{ij}(t+n) &= \rho \cdot \tau_{ij}(t) + \Delta \tau_{ij} \\
\Delta \tau_{ij} &= \sum_{k=1}^{m} \Delta \tau_{ij}^k \quad (2) \\
\Delta \tau_{ij}^k &= \begin{cases} 
\frac{Q}{L_k} & ij \in l_k \\
0 & \text{otherwise}
\end{cases} \quad (3)
\end{align*}
\]

We assume that the number of food points \( m \) for \( 31, \alpha \) and \( \beta \) is 1 and 0.5 respectively. The results of the calculation are shown in Figure 1 below:

With the continuous research and exploration of ant colony algorithm, the application of the algorithm is more and more extensive, which can solve many practical problems, such as business trip problem, restricted routing problem, traffic route determination and so on.
3.2. Basic process of particle swarm optimization

In the D-dimensional space, there are N particles, the particle I position: \(x_i=(x_{i1}, x_{i2}, ..., x_{iD})\), the \(x_i\) into the adaptive function \(f(x_i)\) to find the adaptive value; particle i speed: \(v_i=(v_{i1}, v_{i2}, ..., v_{id})\); The best position the individual has ever experienced: \(pbest_i=(p_{i1}, p_{i2}, ..., p_{id})\); The best position the population has ever experienced: \(gbest=(G_1, G_2, ..., G_D)\). Typically, the range of change in the position of the D \((1 \leq d \leq D)\) dimension is limited \([X_{\text{min},d}, X_{\text{max},d}]\) in , and the range of velocity is limited within \([-V_{\text{max},d}, V_{\text{max},d}]\) (that is, if the boundary value is exceeded in the iteration \(v_{id}, x_{id}\), the speed or position of the dimension is limited to the maximum speed or boundary position of the dimension).

The first d-dimensional velocity update formula for particle I:
\[
v_{id}^k = w v_{id}^{k-1} + c_1 r_1 (pbest_{id} - x_{id}^{k-1}) + c_2 r_2 (gbest_d - x_{id}^{k-1})
\]  
(4)

The d-dimensional position of the particle I updates the formula:
\[
x_{id}^k = x_{id}^{k-1} + v_{id}^{k-1}
\]  
(5)

Of which, \(v_{id}^k\) represents the Part d component of the K-sub-iterative particle i flight velocity vector; \(x_{id}^k\) represents the D-dimensional \(v_{id}^k\) component of the K-th iterative particle i position vector; The \(c_1, c_2\) represents the acceleration constant, adjusts the learning maximum step size, \(R_1, R_2\) represents two random functions, takes the value range \([0, 1]\), to increase the search randomness; \(W\) stands for inertia weights, Non-negative, adjust the search scope of the solution space. The approximate process is:

- Initialize particle population (group size \(n\)), including random position and velocity.
- The fitness of each particle is evaluated according to the fitness function.
- For each particle, compare the adaptive value of its current fitness to its individual history best position, and if the current adaptive value is high, the historical best position will be updated with the current position.
- For each particle, compare the adaptive value of its current fit to the global best position, and if the current adaptive value is high, the global best position is updated with the position of the current particle.
- Update the velocity and position of each particle according to the formula. If the end condition is not met, then step 2 is returned. The algorithm stops when the algorithm achieves the maximum number of \(G_{\text{max}}\) iterations or the increment of the best fitness value is less than a given threshold value.

4. Application of ant colony algorithm and particle swarm algorithm in architectural design

4.1. Ant colony Algorithm for optimal spatial streamline

![Figure 1.](image-url)
I define all the functional spaces of a public building as $m$, and the functional partition label as $i$, $n$ identifies the number of subspace of each functional fraction, and $P$ represents the basic unit space of space $m$ (which can be understood as a column net space), $\alpha_p$ of which indicates the ideal use rate of $P$.

Assuming that there are functional partitions of A, B, C three, through the comparison of the number of $P$, the construction of the Chinese Communist Party has a space of a number of 3,b for the C 1, then the user in the building to complete the flow of a week of the channel space of 6. Using the definition of the search space in the following figure, the column represents 6 sorting stages, and the rows represent 3 kinds of space to choose from. Ant colony algorithm is to constantly change the size of the circle, and finally find a satisfactory solution. After several iterations, the search space changes, the most likely possible solution is B-A-C-A-B-A, as shown in figure 2.

![Figure 2.](image)

With greedy strategy, each step is selected from the current selectable policy. The strategy of minimizing the value of the target function, that is, when the user is in random position $J$, if there are multiple functional partition space available to choose from, then select a space $I$, the most evenly used rate of the $J$ position entering $I$. The following formula shows:

$$\eta_{ij} = \frac{Q}{\sum_{p=1}^{m} (j\alpha_p - b_p - \beta_{k-1,p})^2}$$

(6)

The state transition probability formula is as follows:

$$p_{ij}^k(t) = \begin{cases} 
\alpha \tau_{ij} + (1-\alpha)\eta_{ij}, & \text{if } i \notin \text{tabu}_k \\
0, & \text{otherwise}
\end{cases}$$

(7)

The pheromone update rule formula is as follows:

$$\Delta \tau_{ij}^k = \begin{cases} 
\tau_0(1 - \frac{Z_{cut} - LB}{Z - LB}), & \text{if space } i \text{ is relative to } j \text{ position} \\
0, & \text{otherwise}
\end{cases}$$

(8)

$LB$ represents the lower bound value of the target function, $Z$ represents the average of the current target function, and $Z_{cut}$ represents the current target function value. This dynamic labeling method can increase the difference of pheromone between feasible solutions in the search process and avoid the precocious algorithm.

$$\Delta \tau_{ij} = \sum_{k=1}^{n_{ant}} \Delta \tau_{ij}^k$$

$$\tau_{ij}(t+n) = (1 - \rho) \cdot \tau_{ij}(t) + \Delta \tau_{ij}$$

(9)

Ant number $n_{ant} = 5$, maximum cycle $N_{max} = 400$; $\alpha = 0.2$; $Q = 20000$; $\rho = 0.9$; $LB = 0.0$; Ant colony System $q^0 = 0.5$; Both the global update rule $\alpha$ and the local update rule $\rho$ take 0.1. $f(s_{best})$ select the global optimal solution.
The results of the calculation are shown in Table 1.

Table 1. A slightly more complex table with a narrow caption.

| Times | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Ant System | 3852 | 3650 | 3945 | 3841 | 3305 | 3679 | 3855 | 3752 | 3508 | 3438 |
| Ant colony | 2860 | 2862 | 2938 | 2985 | 2862 | 2938 | 2860 | 2865 | 2972 | 2862 |

It can be learned that the optimal solution for the last ant colony System is 2860, this is for us in this building to find an optimal organization streamline, can meet the requirements of the use of the premise, let people pass quickly, this is for railway stations, subway stations, cinemas and other personnel intensive public buildings have a special significance.

In China, the application examples of ant colony algorithm can be seen in the teaching of Nonlinear Architectural design studio in Tsinghua University in the past two years. For example Design works: The information products Display Center at five crossing subway station, as shown in Figure 3, they use the ant colony algorithm to study ant colony, use computer program to calculate and simulate the activity state of ants and the formation process of ant nest, and produce a special building streamline and space form, Its formation is based on the cognition and utilization of space by ants. Then, based on the applicability of building function, the simplification and function filling of space and streamline, created an organic architectural form, which has the remarkable characteristics of continuous internal space and structural epidermis integration.

4.2. Particle swarm optimization for fire evacuation

In order to be able to achieve efficient and rapid evacuation of personnel clusters, it should be ensured that large public buildings in the shortest possible time when the fire can be evacuated to the safety of all personnel out of the safe exit, based on this idea to build the corresponding optimization model, with the shortest evacuation time as the optimization goal, Considering the fire condition of the space node of large public buildings (including its dynamic and static information) and the number of evacuees, the following models are constructed:

\[
\min T
\]  

(11)
\[
\sum_{j} \int_{0}^{t_{ij}} h_{ij}(t)dt = L_{ij}
\]

(12)

\[
h_{ij}(t) = h_{ij} \alpha_{ij} e^{-\eta_{ij}t}
\]

(13)

\[
\sum_{k} \sum_{l} x_{kp} = x
\]

(14)

\[
\sum_{t=0}^{T} \sum_{i \in s} x_{ij}(t) = \sum_{t=0}^{T} \sum_{j \in D} x_{ij}(t) = x
\]

(15)

\[
p_{ij} \geq 0, e_{ij} \geq 0, s_{i} \geq 0
\]

(16)

The formula is the target function, \( T \) indicating the time for all evacuees to exit safely, \( h_{ij}(t) \) indicates the \( p_{ij} \) evacuation speed of the evacuation personnel on the path, \( \alpha_{ij} \), \( \eta_{ij} \) indicates the hazard degree of the fire, \( x_{kp} \) indicates the number of people \( k \) evacuated by the path in the \( p_{ij} \) safe exit, and \( x \) indicates the total number of evacuees; \( S \) indicates the disaster point collection.

Through the establishment of mathematical models, then the model parameters are entered into the formula of particle swarm algorithm, and after several iterations, the algorithm can find the shortest evacuation route by determining the shortest evacuation time, which is of great significance to the fire evacuation design, which means that we can calculate the shortest path by the algorithm in the design, and optimized in the design, can greatly reduce the evacuation time.

5. Conclusions

Through the study of the algorithm, the interdisciplinary technology into the field of architectural design, the formation of new architectural design technology, is relative to the exhaustion of existing modeling software modeling capabilities, writing software program command another kind of innovative way to show infinite vitality. We take space users as ant individuals in ant colony algorithm, and use ant colony algorithm to improve the streamline organization of building space, which has important significance for design, analysis and evaluation of efficiency architecture. Ant colony algorithm is also one of the underlying rules of cluster theory, and building epidermis and urban structure using cluster theory is the new theory of thought which is universally recognized in the 21st century. The PSO algorithm is simpler, more direct and more efficient than the ant colony algorithm, and has a significant effect on evacuation design and evacuation port design.

Regardless of the ant colony algorithm, or particle swarm algorithm, is one of the intelligent algorithm, are the underlying rules of architecture design, this limitation determines that the intelligent algorithm can only be used as an auxiliary means of architectural design, but not to be the core of the guidance, but the intelligent algorithm for architectural design provides a new way of thinking. It has played an active role in the development and implementation of architectural design.

References

[1] Kang Yuyun. Matrix Innovation Design Method of electromechanical products driven by meta-function chain. Shandong Publishing House, 2015.11

[2] Jiang Zigang, Liu Xiaodong, Hofer boat, Song Wei. Simulation of evacuation of mall personnel based on Pathfinder. Fire Science, 2014 (03): 175-181.

[3] Gao Yuhuan. Research on the application of Ant colony algorithm in architectural design. The National Professional Steering committee of architectural discipline in colleges and universities. Simulation, coding and synergy-the 2012 symposium on digital Technology Teaching of Architecture in National Architecture Department. National College of Architecture Discipline Professional Steering Committee: National University Architecture Discipline Professional Guidance Committee of Construction Digital Technology teaching Work Committee, 2012(5).
[4] Junyan Dong, Wen Cheng. Research on Optimized Construction of Sustainable Human Living Environment in Regions where People of a Certain Ethnic Group Live in Compact Communities in China. Renewable Energy and Environmental Sustainability, 2016(1):1-7

[5] Ma Zhiliang. Parametric Design and Its Fabrication for Nonlinear Architecture. Tsinghua University, 2014:23