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Pedestrian circulation simulation based on Ant Colony System in site analysis

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ABSTRACT

Site analysis is among the first steps in the architectural design process. Diverse ways of the aforementioned step can cause dramatic changes in solutions and final designs. Considering different parameters that impact current pedestrian circulation system design, the process of site analysis has become more complicated and additional critical items can interfere with this process. Therefore, it would be worthwhile to quantify the qualities in order to evaluate site analysis. As the nature of Ant Colony System algorithm is compatible with the nature of site analysis, it has been used to simulate pedestrian circulation inside a proposed site. Based on the simulated diagrams of people movement with the assumption that the building is constructed, the designer or planner would be able to place entrances and different occupancies in appropriate locations, find the noisy zones, and have a reasonable understanding of the pedestrian circulation in the proposed site.

1. Introduction

Site analysis is an essential part of architectural design. This leads the output of a design to be in congruence with outer and inner requirements. Site analysis reveals different potentials of sites, and therefore directs the design process in a more compatible approach with its environment. The aim of the whole process is to satisfy the design requirements to the highest possible degrees [1].

There are plenty of interrelated arguments in architectural design process. Recently emerged circumstances have made it more complicated. Increasing population, global effects of industrialism and crucial needs for sustainability can be mentioned as some of the issues that need further investigations. Therefore, since 1960s computer technologies with different problem solving methods have assisted architects in design process [2]. These methods facilitate design process in analyzing, space layout planning, thermal simulation, objective modeling and etc.

There have been different inspirations from natural mechanisms implemented in architecture. The mentioned ideas vary from simple concepts, like the idea of bridging by observing a fallen log [3] to different algorithms derived from nature [4–6]. On this paradigm, Ant Colony Optimization (ACO) algorithms introduce a probabilistic technique for solving computational problems which can be deduced as finding best routes through graphs [7,8]. The ACO metaheuristic algorithms were inspired by the foraging behavior of real ants and is characterized as a distributed, stochastic search method based on the indirect communication of a colony of ('artificial') ants [9,10]. This method has been implemented in some recent research on simulation of crowd movements in a research on human pedestrian movements, which focuses on the movements of pedestrian especially when the crowd is panicked [9]. A research has studied optimization of a site layout affected by the mutual interaction of facilities. The aims of this paper are minimizing travel distance, decreasing materials handling, and avoiding the obstruction of materials and plant movements. Lam et al. [11] revealed 20–60% reduction in the cost of materials handling by the adoption of an appropriate facility layout Lee [12] has worded on the reduction of the total walking distance of passengers to and from various facilities. The author has proposed an integrated model that estimates the total walking time of a passenger by simulation and searches for a near-optimal layout by ACO. Lee [12] indicates that the results showed that it would save passengers time and would improve the service efficiency of the station. An ACO algorithm has been proposed for defining the signal settings of each intersection of an urban network which would effect on costs and on user route choices. The artificial ants has two kinds of behavior in that research; first, that is based on the response to pheromones and second, the innovative one that is based on the pressure of an ant stream [13].

This research seeks to propose a method to simulate pedestrian circulation. Previous studies have applied different methods for

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simulating pedestrian travels and human behavior in route finding. These studies range from probabilistic methods to metaheuristic algorithms varying from travel distance analysis in health care facilities to transportation analysis [14–17]. This paper utilizes ACO algorithm to simulate pedestrian movement in a park as the case study.

2. Materials and methods

As part of the site analysis process, the pattern of circulations around the proposed location has an essential effect on topological arrangements. Indeed, it helps to choose proper locations for entrances, clarifies noisy and silent zones, and altogether gives a comprehensive understanding of movements around the special site.

Human movement in a site determines some of the most important characteristics of the space. For instance the entrances are the openings of a building that should have some special characteristics such as being easily found as its simplest essential parameter. This means the mentioned component should be implemented in a place that allows people to have the optical connection with the least obstacle. Beside visual concerns, ease of access is another criterion that illustrates the relation of crowded zones and entrances.

As an architect or a group of designers, that is supposed to design a building in the supposed site, one of the important sets of data that should be considered from the very first stages of design is the considerations of sound zones. The aforementioned parameter would be more imperative in some special cases or maybe more important in some special zones compared with others. As a considerable portion of the noise resources are generated by human, such as the noise of vehicles, scrutinizing people movement would considerably show the mentioned zones. It reveals the routes that are used more frequently. It also helps to have a realistic imagination of the densities of people in different zones.

ACO algorithms help to simulate pedestrian circulation and are efficient ways for route finding. It simulates pedestrian circulation based on dimensions, predefined attractive points, and some statistic data. This paper seeks to simulate pedestrian circulation with the help of ACO algorithms and utilizing Matlab R2012a software. Different steps of the process are described below:

1. Identifying the number of entrances and the proportion of people who have entered through each entrance to the total number of entered people through all entries.
2. Proposing a graph from feasible routes in the park.
3. Assigning the attractiveness to each node based on statistics and expert decisions.
4. Calculating the possibility of all routes for each entry.
5. Selecting the direction for entrance based on previous step.
   a. Running the model for each entry.
   b. Multiplying the greatest possibilities of each entry to the related number of entered people.

Honarmandan Park, located in Tehran, Iran, is chosen as the case study of this research (Fig. 1). This selection was due to the grid of the pedestrians, buildings, and green spaces around the construction site, which create a big challenge for the site analysis. Furthermore, this park has historical background and has been used for different artistic exhibitions such as national biannual sculpture exhibition. Therefore, there are different nodes with different degrees of attractiveness that should be considered in site analysis. Due to the function of different constructions inside the park (Fig. 2) and the development guide, it has been supposed to design a library at the selected zone, which is showed with character 'D' in Fig. 3.

2.1. Entrances

As illustrated in Fig. 2, the park has 6 different entrances. Inquiries show that each of these entrances have their own potential and play different role in attracting people to come through. Of course this depends on diverse parameters like the direction of one way road around the site, the building functions outside the park, and many other factors. Table 1 shows the number of people who has entered the park through each one of them. This data shows the average number of entered to the park based on the

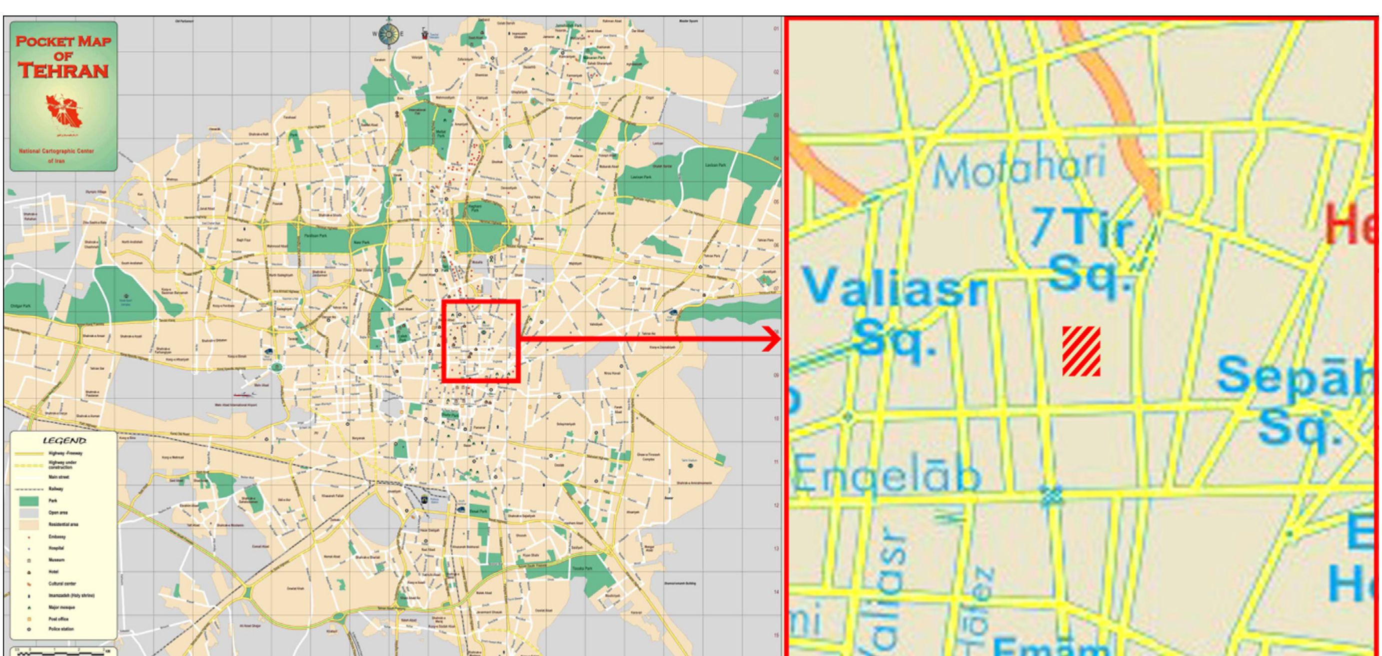

Fig. 1. Left: Map of Tehran (Iran) [18]; Right: Location of the site [19]. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

Fig. 2. Site plan of the Honarmandan Park in Tehran [20].

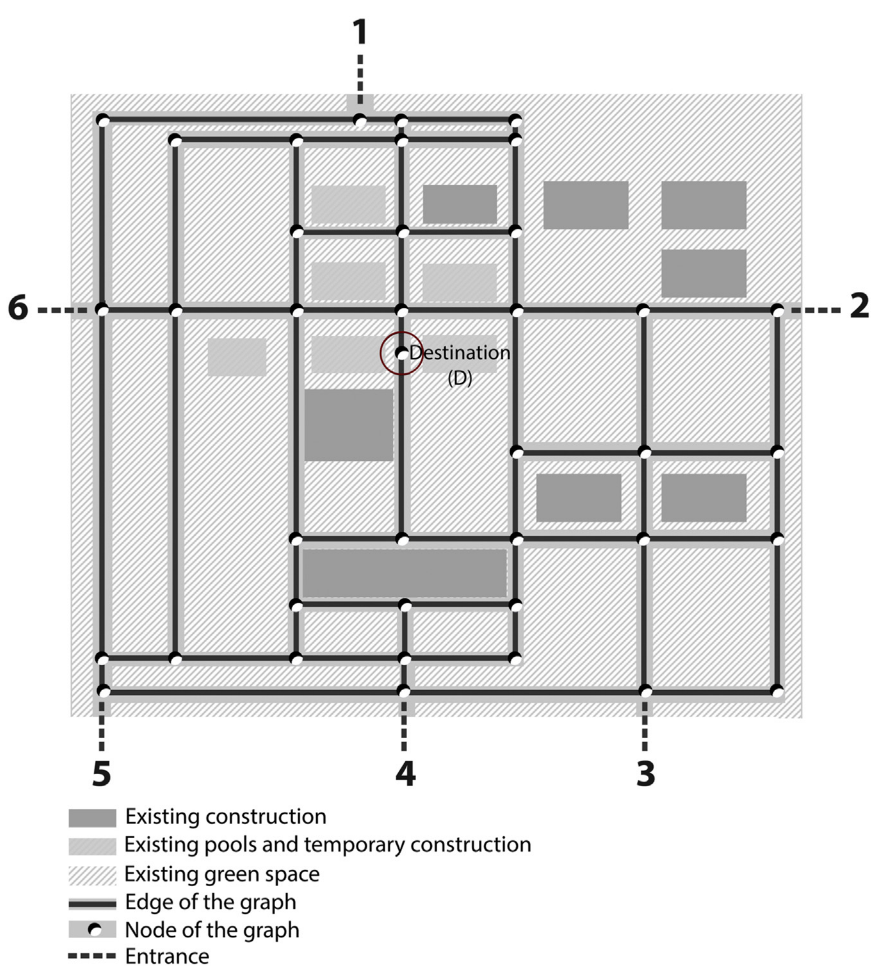

Fig. 3. Graph of routes and nodes of the site.

Table 1
Number of people comes through the park from each of the entrances.

	Ent. 1	Ent. 2	Ent. 3	Ent. 4	Ent. 5	Ent. 6
Number of people	78	17	28	108	62	36

inquiries on 5 h observation in 5 different days.

2.2. Proposing graph

A graph has been made with different nodes in the park (Fig. 3). The lines of the graph represents all routes excluding those in the construction site, dotted lines extended to the outside and their assigned numbers, stand for the entrances of the park, and the area depicted with '*D*', shows the location of the construction site.

2.3. Attractiveness

The attractiveness showed by η_{xy}^{b}, is the priori desirability of the move from node *x*, as the start point, to node *y*, as the destination point [21]. This parameter is defined as the inverse value of the distance (Eq. (5)) and is controlled by a constant (b) assigned for each route. This helps the process of route finding to be qualified by experimental knowledge of the experts. On the other hand, it accounts for both quantitative and qualitative aspects in the process of solution finding. Therefore, the desirability and attractiveness of each route is controlled by both quantitative (inverse value of distance) and qualitative values, as controlled by b value. The attractiveness assigned to nodes and segments can be based on the surveys and observations of current situation of the park.

In this case, the attractiveness assigned to each node is based on the function of that node and its current situation. This has been achieved by local observations. The functions of the constructions in the park is illustrated in Fig. 2. The important hint here is that the assigned attractiveness should be based on the previously mentioned parameters plus the effects of the in hand design. It means if this number is assigned without considering the effects of the proposed design on pedestrian circulation around the site, it will not represent real situations after the construction. Therefore experts can predict the attractiveness of each node after the construction is completed and assign the predicted attractiveness to the nodes.

2.4. Pheromone

Once all of the 'artificial' ants have completed their routes, they have deposited pheromone along the segments of the chosen roads. Based on the evaporation of pheromones, the trails are updated as showed in Eqs. (1) and (2). τ_{xy} represents the pheromone in the route *x* to *y* for ant *k* in iteration *t*. This update will be accomplished depending on the distance of the nodes (*d*) (Eq. (5)), pheromone evaporation coefficient (ρ), which is between 0 and 1, the user defined constant (Q), (m) represented for the number of ants, and (L_k) as the distance between x and y. (Eq. (3)).

$$\tau_{xy}(t)=\rho\tau_{xy}(t-1)+\Delta\tau_{xy} \quad (1)$$

$$\Delta\tau_{xy}=\sum_{k=1}^{m}\Delta\tau_{xy}^{k} \quad (2)$$

$$\Delta\tau_{xy}=\begin{cases}\dfrac{Q}{L_k} & \text{if } k \text{ uses arc (xy) in its tour}\\ 0 & \text{otherwise}\end{cases} \quad (3)$$

2.5. Possibility

The aim of the possibility in ACO is firstly to maximize the possibility of choosing the routes with less lengths and more attractiveness (Eq. (4)). This will reduce the chance of choosing unsuitable routes. Therefore ACO algorithm seeks the best route for specified entrance and destination. Destination is specified by a node called *D* (Fig. 3), representing the center of the proposed site for building.

$$P_{xy}^{k}=\begin{cases}\dfrac{\tau_{xy}^{a}+\eta_{xy}^{b}}{\sum_{xy\notin tabu\,k}\left(\tau_{xy}^{a}+\eta_{xy}^{b}\right)} & if\ xy\ \notin\ tabu\ k\\ 0 & otherwisw\end{cases} \quad (4)$$

$$\eta_{xy}^{b}=1/\mathrm{d}_{xy} \quad (5)$$

2.6. Selecting the direction of the entrance

Ant Colony algorithm has been run for each of the 6 entries as the entrance and the node *D* as the destination. A route with highest probability for each entrance is the answer of ACO algorithm (Eq. (4)). If each answer is multiplied by its correspondent quantity extracted from Table 2, the best route between all possible routes from each of the 6 different entrances to the destination node will be revealed. This can assist the architect to locate the main entrance of the building. Furthermore, the map, which can be created by putting these results on each other like translucent layers, will show the total results for all routes. In Eq. (4), *a* and *b* are user defined factors for controlling the attractiveness and the pheromone of related path *xy*. *Tabu* represents any route (edges of the graph) which is not acceptable.

3. Results

All of the results are caught from Matlab R2012a. The linear graph (Fig. 3), has been analyzed based on the nodes and routs of the site with ACO Algorithm. Then, the data caught from ACO algorithm have been manipulated as it is shown in Table 2. This reveals the most appropriate direction of the building in which the entrance should be accommodated.

Total value of all routes for North direction is 73+16+19+32, which equals 209. This value for South direction is 66. Based on the comparison of these two values, it can be inferred that the entrance should be in north side of the entrance. The result of running the ACO algorithm for entrances has been depicted in Figs. 4–9. The red circle in the middle of the graph shows the center of the site where the proposed library would be designed, the destination of 'artificial' ants, and the other red circle illustrated in six different nodes of the outline of the graph in each figure depicts the entrances, the start point of 'artificial' ants. These figures illustrate a gradient map that shows the probability

Table 2
Possibilities of ant colony algorithm for all entrances.

	Number of people	The largest possibility	Total value of the route	Direction chosen by the route
Ent. 1	78	0.93	73	N
Ent. 2	17	0.95	16	N
Ent. 3	28	0.69	19	N
Ent. 4	108	0.64	69	N
Ent. 5	89	0.74	66	S
Ent. 6	36	0.89	32	N

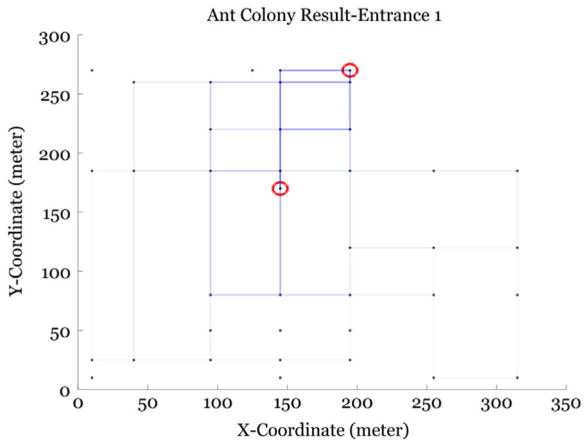

Fig. 4. Result of route finding for entrance 1 based on ant colony algorithms.

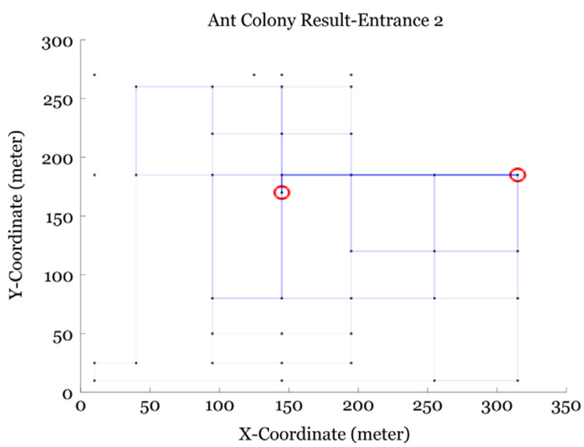

Fig. 5. Result of route finding for entrance 2 based on ant colony algorithms.

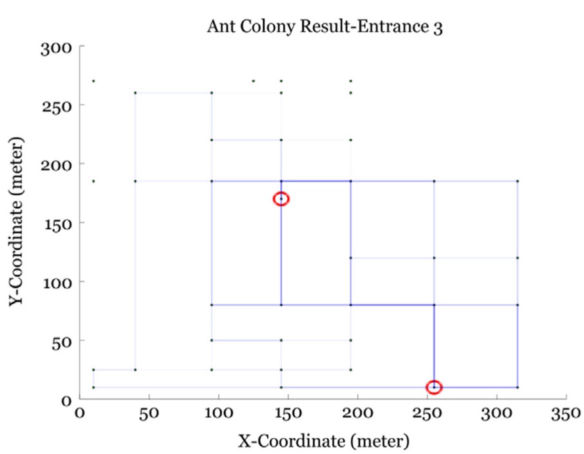

Fig. 6. Result of route finding for entrance 3 based on ant colony algorithms.

of choosing different routes by transparent lines.

It should be mentioned that the reverse movement of the 'artificial' ants is defined as 'Tabu', which means is not acceptable. Therefore, an agent will not be trapped between two nodes because of the higher attractiveness or lower distance. In reality this is not true as a person might circulate on his/her recently passed edge. Also the opacity of the lines show the probability of choosing that route. The higher intensity the color of the edge shows the higher probability of choosing it. In this study, traffic of pedestrians is not considered and the diversion level will not effect 'artificial' ants choices.

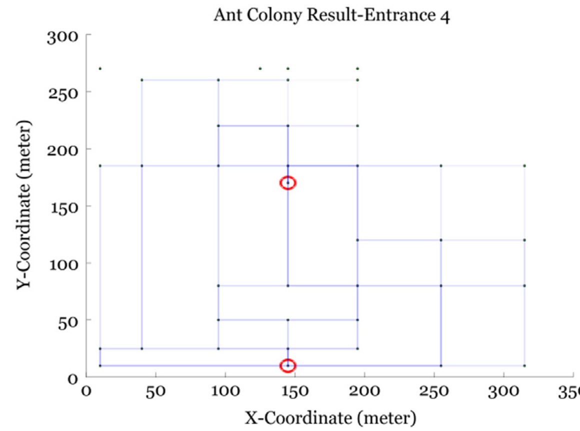

Fig. 7. Result of route finding for entrance 4 based on ant colony algorithms.

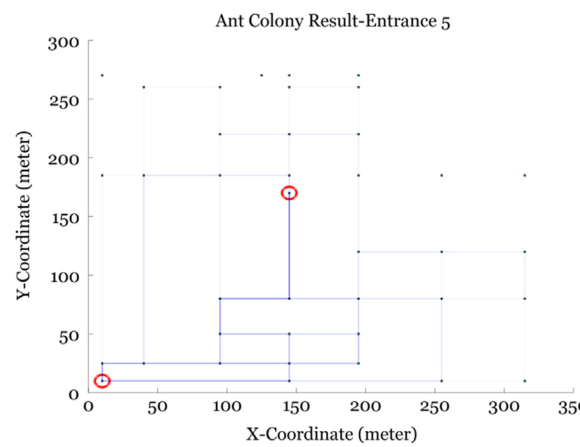

Fig. 8. Result of route finding for entrance 5 based on ant colony algorithms.

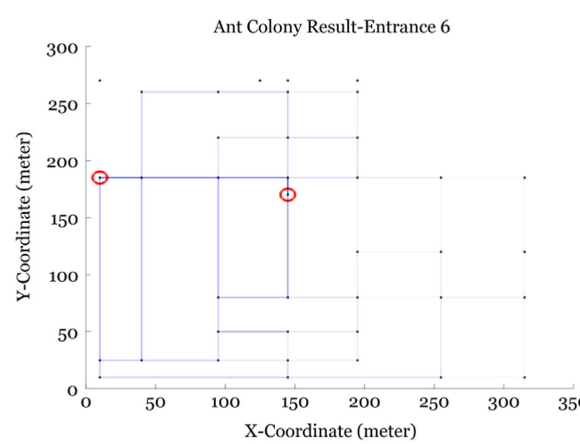

Fig. 9. Result of route finding for entrance 6 based on ant colony algorithms.

4. Discussion

Using Ant Colony is a good method to simulate the movement of people in a specific site. The advantages of this technique are obvious when the case has complicated situations and different solutions differ greatly in costs and qualities.

The results in this research, gives the highest probability of choosing the route. More importantly, it shows the hierarchy of these routes with their opacity in a way that more transparency means that special segment has been lighter traffic and vice versa. The aforementioned feature would help not only the silent and noisy zones, but also would illustrate appropriate zones for diverse applications. For instance, the west south corner of the destination point has the lowest traffic compared with other zones. Therefore, in this project, the reading room can be accommodated in this zone. With the same way of analysis, the north side of the site has the heaviest traffic of people, so it can be deduced that zones with more interaction with people that do not need to be in a silent zone can be located in this direction; in this case, as an example, it can be a bookstore. Of course these should be considered in accordance with other considerations and analysis like lighting, circulation of the inside of the project and etc. Then, each of these can get its own weigh and be analyzed with a multi agent system.

4.1. Verification and validation

One method to verify the model is to determine the degree of accordance between the simulation model and its associated data and developer's conceptual description and specifications [22]. As illustrated in Figs. 4–9, the lines with highest transparency, which means the most probable lines that pedestrians might choose, have a reasonably low travel distance from each entrance to the destination. It means there is no unexpected redundancy in route finding of the algorithm and hence, ACO has proposed a reasonably accurate routes.

Besides travel distance, attractiveness assigned to each node should also impact solutions. Although the strongest lines are mostly the shortest paths, but in some cases some diversions can be seen which is derived by the attractiveness points. For instance in Fig. 4, the restaurant (depicted in Fig. 2) has affected the way finding of the 'artificial' ants. These facts verify that the model is behaving in the way it is supposed to work.

Validation reveals how accurate the simulation model represent real world [23]. There are different methods that can be used to validate a simulated model. On way is face validity [24], which requires asking knowledgeable individuals to find the logical behavior of the model. This can be inferred from Figs. 4–9. The other method is sensitivity analysis [25], which determines the effect of changing one parameter and fixing others (also called scientific method) on the results. In this study, in order to analyze the sensitivity of the ACO model to its parameters, the attractiveness value assigned to the nodes close to restaurant and retail is reduced by half while keeping other parameters constant. Results show that it impacts the 'artificial' ants circulation in the expected way. As illustrated in Fig. 10, the routes in the left side of the destination, where retail and restaurant is located (refer to Fig. 2), are stronger when a higher attractiveness value is assigned to them (Fig. 10: Left) than lower values (Fig. 10: Right).

4.2. Comparison with other methods

There are different methods other than ACO that can be used to simulate pedestrian circulation. Space Syntax is one of the methods that can be utilized in wayfinding with different approaches such as line map and Visibility Graphic Analysis (VGA). These methods are fairly efficient in finding paths with lowest length. Although VGA has enhanced in predicting movement pattern and has higher resolution analysis compared to line map analysis, still congestion level and attractiveness should be implemented into these methods to simulate human behavior in wayfinding more realistically [24,25].

Veeraswamy [26] studied Dijkstra, Yen's algorithms and modified existing spatial representation technique in building EXODUS to best suit the requirements of the wayfinding models. This model accounts for some of the characteristics that make the model close to human real behavior in wayfinding compared to other evacuation/circulation models. Although major criteria such as time and number of turns are accounted in the model, there are other parameters that need to be implemented or focused more in it such as attractiveness to simulate agents more realistically.

Goel and Tiwari [27] have used multinomial logistic regression for the details of access-egress and other travel characteristics of metro users in Delhi, and its surrounding cities. Although multinomial logistic regression also suits well for simulating people circulation as well as access-egress, one of the issues of this method, which includes linear predictor function, is the assumption that each independent variable has a single value for each case. However, in AC algorithms the controlling value (b) can be updated in different iteration, although this is not the case in this study. Also, as in this case, the issue of defining the infinite ways that people can choose to reach the destination after entering through one of the entrances and passing through different nodes should be considered while using multinomial logistic regression.

Predicting the diversion probability in route finding of people should be considered when simulating people movement. This makes the model more accurate as it accounts for changes in people route choice behavior and consequently, it behaves closer to real people. Yun and Tang [28] utilized disaggregate choice analysis method to analyze diversions in drivers' route choice behavior. The outcome reveals that congestion level and age are two of the main factors in diversions of the drivers' route choice behavior.

Although trails in AC algorithm (Eq. (2)), which represents pheromone deposit and evaporation, relates to congestion level, it is part of the solution finding method of the algorithm for the shortest distance and does not account diversions in route choice because of the crowd as a stimulus. Also, if the attractiveness is

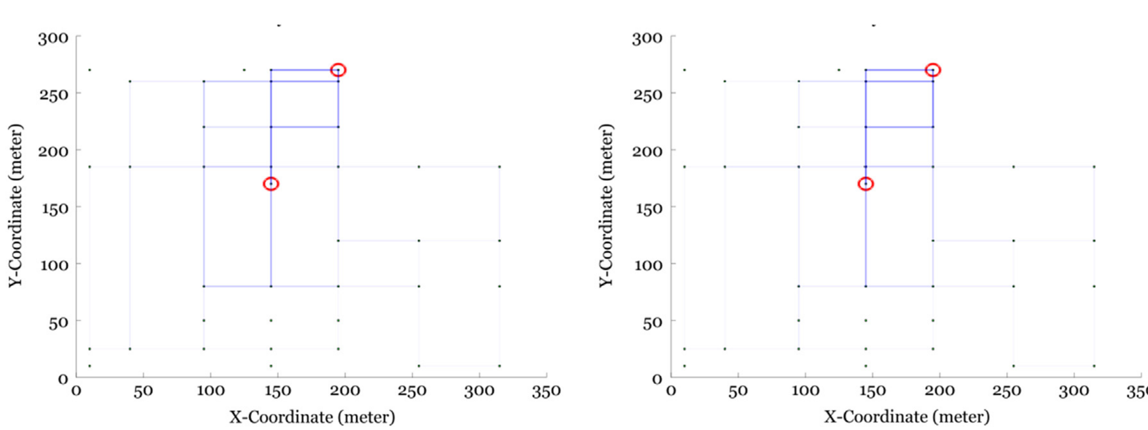

Fig. 10. Result of route finding for entrance 1 with different attractiveness values assigned to retail and restaurant nodes; Left: base case; Right: lower values.

Table 3
Comparison of some of the methods in circulation simulation and wayfinding.

Method	**Function**	**Travel length**	**Diversion Probability**			**Dynamic values**	**Advantages**	**Issues**	**Refs.**
			Attractiveness	***Congestion level***	***Age***				
Space Syntax	Nodes and links in line map analysis	✓		*			Efficient method for finding efficient ways with least lengths (and highest visibility in VGA)	The assumptions that people movement is purposive and their good knowledge of environment should be considered.	[24]
	Visibility Graph Analysis (VGA)	✓		*			Enhancement in predicting movement pattern and higher resolution analysis compared to line map analysis	Like line map analysis method, congestion level and attractiveness are two of the main characteristics that impact human circulation and needs to be implemented in space syntax	[24,25]
Multi criteria decision analysis	Dijkstra, Yen's, etc. algorithms	✓		✓		✓	Accounts for some of the characteristics that make the model close to human real behavior in wayfinding compared to other graph-based evacuation/circulation models.	Although major criteria such as time and number of turns are accounted in the model, there are other parameters that need to be implemented or focused more in it such as attractiveness.	[26]
Multinomial Logistic Regression	linear predictor function	✓		✓			Linear predicator function can account for diverse parameters to predict the probability. As the depended variables are nominal, Multinomial Logistic Regression can be utilized effectively.	The assumption that each independent variable has a single value for each case. the issue of defining the infinite ways that people can choose to reach the destination after entering through one of the entrances and passing through different nodes should be considered	[27]
Ant Colony Optimization	Ant Colony Algorithm	✓	✓	+	+	✓	The controlling value can be updated in different iteration. User-defined values (such as attractiveness of the nodes) simulate agents while accounting for main human behavioral parameters in wayfinding	At this stage, the interoperability of this method with widely used modeling software in architecture and urban planning domains has not been addressed.	[8,10]

*Although space syntax reveals congestion level, it does not take congestion level into account for agents in wayfinding.
+ Although this study has not addressed congestion level and age parameters in ACO, as discussed in Section '4.2.' of this paper, a few modifications can add these parameters in the model.

used as a constant, it cannot respond to the congestion level dynamically. In order to take diversions of people route choice into account, current AC algorithms used in this paper needs a few modifications. These modifications can store the number of artificial ants and calculate their density in each edge and node. Then based on surveys and behavioral studies, the attractiveness of that point can be changed dynamically. Consequently, by changing the attractiveness of the route, the model would account for congestion level.

In order to take the parameter of age into consideration, the AC model used in paper should be modified. Different attractiveness controller values for different congestion level and distances might affect the route choice of a person in different age. One approach to implement that in AC model can be running the model multiple times for different ranges of ages with different attractiveness controller values. Then the results of the models for different ages would be added up. A brief comparison of some of the methods in circulation simulation and wayfinding is shown in Table 3.

5. Conclusion

It has been seen that ACO is an efficient tool for analyzing circulation. It also illustrates high perceivable figures which help to have a realistic insight about the matter. These diagrams and numerical probabilities led to some general specifications of the design, such as defining the suitable direction for main entrance, noisy zones, having a comprehensive knowledge about the site circulation and people movement, lowering the cost of construction and transportation and etc.

6. Limitations and future works

Although ACO results revealed reasonable predictions in pedestrian circulation in the case study site, there are some issues that should be considered in this method. In reality, a wide range of parameters might impact pedestrian route choice. As discussed before in this paper, age and diversion level can be implemented in the model directly or indirectly, but there are other factors that are hard to be implemented in the model. Social and behavioral concerns, safety issues, changes in weather, daily and annual position of the sun, construction zones around the site, and the fact that each individual might have his/her own criteria for route finding are some of the issues that need further investigation. Moreover, there are some issues with model that needs further investigations. As discussed in prior sections in this paper, the inverse movement in this model is not allowed. Therefore, 'artificial' ants can not go back on the edge that they have just moved on. Also, for having a better prediction on route choice of the people, we need to analyze their views from their own point of view.

Also, the result of each entrance is isolated from the effects of circulations of people who have come through other entrances of the park. This means there would most probably be the same segments of graph in different chosen routes from diverse entrances;, but the pheromone of these segments does not effect on the same segment in other entrances simulations.

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